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SPECIAL SECTION

Digital maturity in tram systems: Model design and practical application

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Abstract. The ongoing digital transformation generates demand among companies for tools that will allow them to assess their current stage of advancement in the digital transformation process and support them in developing a further development plan. Digital maturity assessment models meet these needs. The article presents the framework of a new digital maturity assessment model dedicated to tram systems – DMM-TRAM. The model comprises five assessment dimensions covering personnel, information, passenger flow, infrastructure, and operational risk management. These areas are divided into 15 sub-areas, and the system maturity is assessed on a four-point scale, with level 1 representing the basic level and level 4 (leader) representing the excellent level. The developed model was verified on a selected tram system in a selected city in Poland. This allowed us to prove the validity of the defined assessment dimensions and the empirical nature of the requirements formulated for individual assessment levels in each sub-area. The assessment of the selected system indicated diversification of maturity levels in individual areas, as the lowest score obtained was DMAI = 1.67 (Personnel management), and the highest was DMAI = 2.75 (Information management).

Keywords: smart city; digital transformation; digital dimensions; transport system.

1. INTRODUCTION

Digital transformation, as described in the literature, refers to socio-technical phenomena and processes of adaptation of digital technology in the context of its individual, organizational, and social applications [1]. The understanding that digitalization processes are not limited to applying information and communications technology (ICT) for process improvement is critical to their implementation. Indeed, digital transformation refers to fundamental changes in business strategy and processes, organizational culture and knowledge, and the functioning of the entire socio-technical system [2]. Therefore, the processes of digitization and digitalization must be accompanied by changes in the approach to resource management, the improvement of employee competencies, and the creation of knowledge bases and information management between all stakeholders.

Digital transformation is described in the literature as a process consisting of several phases leading the organization to reach a benchmark state concerning the digital world's requirements [3]. A tool to help identify the scope and level of digital transformation in organizations is the digital maturity model (DMM). Their development aims to provide tools to assess the current maturity of a given organization or system to implement Industry 4.0 solutions and to develop specific metrics to support the organization's development related to further digital transformation [4]. DMM models thus make it possible to enhance an organization's readiness for advanced digital technologies at all levels and areas of business considered [5].

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The tram system is a specific urban public transport system considered one of the most efficient and low-carbon transport solutions [6]. Due to these two characteristics, it is a recommended system for implementation. However, simultaneously, its implementation in the urban connectivity network is extremely capital-intensive due to the required transport infrastructure. A critical issue in managing this system is to optimize the costs associated with the maintenance of the infrastructure, to ensure the required level of reliability of the transport process, and, consequently, to increase the resilience of the entire system to disruptions. For this reason, stakeholders responsible for its operation are showing particular interest in new digital solutions that can support the required processes of system monitoring, data analysis, and interpretation for decision-making.

This paper aims to present the framework of a new digital maturity assessment model dedicated to urban tram systems and its verification on the example of a selected urban system in Poland. The main contributions include:

- Development of a framework for a new digital maturity assessment model dedicated to tram systems.
- Definition of measures for assessing the digital maturity of the system based on a four-point rating scale.
- Assessing the level of maturity of a selected tramway system in the accommodation using the proposed digital maturity assessment model.

The article is structured in six sections. The introduction defines the purpose of the article and the main contribution. Section 2 presents the digital transformation trends related to urban transport systems and the assumptions for developing digital maturity models. The developed model for digital maturity assessment is presented in Section 3. The results of verifying the model on the example of the maturity assessment of a real transport system are presented in the "Results" section. Section 5 discusses the results obtained, in which references are made to research by other authors, and the advantages and limitations of the developed assessment tool are indicated. The entire article is summarized in Section 6, which indicates further research directions and possibilities for the use of the results by representatives of science and industry.

2. THEORETICAL BACKGROUND

2.1. Solutions for transport in Smart City

The literature review presented in [7] demonstrates that technological development is the second most critical area of focus of research on Smart Cities. Many researchers emphasize its importance through the definitions of Smart City that are created, which are based on a variety of technologies related to water recycling, advanced energy networks, and mobile communications, whose applications enable the reduction of environmental impact and the improvement of the life of the inhabitants [8]. This importance is also highlighted in many review articles on Smart City [9, 10]. Noteworthy is the definition formulated in [11], whose authors emphasize using "... digital technologies, communication technologies, and data analytics, to create an efficient and effective service environment that improves urban quality of life and promotes sustainability". The concept of Smart City is also often combined with the concept of Digital City. Digital City aims to create an environment for information sharing, collaboration, and interoperability, and it offers innovative services to meet the needs of governments, businesses, employees, and residents anywhere in the city [12]. At the same time, the Smart City Council emphasizes that cities are considered intelligent and implement digital technologies in all city functions [7].

Mobile applications play a significant role in the digital transformation of cities, aimed at improving communication and managing urban infrastructure. These applications are based on developing innovative technologies using the Internet of Things, artificial intelligence, and big data. They are often implemented in healthcare, energy, security, and education domains. According to the research presented in [11], the largest share of applications dedicated to cities includes transport-dedicated tools.

Literature research indicates that leading digital technologies being implemented to improve transport systems in cities include:

- The Internet of Things can be used in urban traffic control, monitoring parking spaces and air quality, improving road safety, and the efficiency of urban fleet management [13, 14].
- Artificial intelligence, which is used to solve congestion problems, improve the reliability of passenger service (travel) times, improve the efficiency and productivity of the use of resources involved in transport processes, support environmental decisions, and improve urban safety [15, 16].
- Big Data, which is primarily used in decision-support analysis and monitoring of transport infrastructure, creates data superstructures for urban transport management and allows the collection of data on transport participants, vehicle fleets, and transport infrastructure [17, 18].
- 5G technology, which provides the necessary communication infrastructure required by various urban transport applications, can be used for communication between vehicles and transport infrastructure in Intelligent Transport Systems. Not only does it provide real-time route information, but it also gives the possibility to control vehicles in emergencies remotely [19, 20].

The technologies highlighted above are not the only solutions implemented in contemporary urban transport systems to support their digital development. However, our literature review indicates that the main focus of researchers is, in many cases, on these selected systems, and also, in the digital maturity model presented in this article, these solutions are included.

2.2. Digital maturity model

Maturity models are a set of tools and good practices that enable the assessment of an organization's management competencies and, at the same time, the identification of objectives and related changes aimed at its development [21]. Maturity models can be used for different analytical purposes, and the organization can interpret the results they provide differently. Angreani *et al.* [22] in their research distinguished four primary areas of their application: (1) assessing the level of fulfilment of specific standards by the organization; (2) measuring selected areas for monitoring the current state and benchmarking with other organizations; (3) defining development directions for the organization based on requirements formulated for successive maturity levels; (4) identifying the organization's strengths and weaknesses. Several maturity models are currently being developed, dedicated to different areas of business activity and considering different concepts and development trends observed in the industry and the environment. However, all these models are built considering specific rules and frameworks that are standards for their creation. Thus, when designing a maturity model, it is necessary to define [3]:

- The object of assessment, i.e., the object to be assessed for maturity, e.g., technology, people, or management concept.
- Assessment dimensions, i.e., areas of organizational capability that relate to the different aspects of maturity specific to the phenomenon being assessed.
- Assessment levels, which in most models are built and defined on a five- or four-point scale.
- Maturity assessment principles, which can be based on (a) a continuous model, in which the total level of the assessed object is measured by the average level of maturity achieved in each dimension, or (b) a staged model, in which the value of the lowest level of fulfilment in the selected dimension determines the level of maturity.

Digital maturity models (DMMs) occupy an important position among the developed maturity models. This is influenced primarily by the continuous development of new technologies driven by the concept of Industry 4.0 and by the COVID-19 pandemic, which has significantly accelerated digital transformation processes in the industry [23]. Decision-makers are also increasingly interested in answering the question of at what level and to what extent organizations are exploiting the potential of digital tools in the market. Indeed, many studies show that organizations with high levels of digital maturity are more resilient to crisis [24].

Digital maturity assessment models are primarily used to benchmark and position a company in the market against competing entities and to guide digital transformation processes to achieve successive maturity levels [25, 26]. Most of them are holistic assessments [27], but DMMs dedicated to a specific sector or area of the company's activity are also increasingly described in the literature, e.g., DMMs for logistics 4.0 [28] or for the energy sector [29]. Review studies presented in [30] demonstrate that the assessment of digital maturity can apply to many areas of a company's business and different levels of management. Due to the complexity of the dimensions to be assessed, in many models, they are further detailed at the sub-area level. At the same time, analyses of existing digital maturity models published in review articles such as [22, 31] identify recurring dimensions of digital maturity assessment. These include technology, strategy, employees, products and services, customer service, corporate culture, corporate environment, and operations (processes). However, it should be noted that the models analyzed by these authors referred primarily to industrial organisations. The literature research also points to some limitations in the current digital maturity models, which should be addressed when developing new assessment tools. The most important of these include [3, 32]: (1) the lack of methodological rigour in the design of the model framework; (2) the limited empirical research associated with model validation; (3) the lack of consideration of specific sector or organizational characteristics in the requirements created for each maturity level.

3. METHODOLOGY

According to the requirements defined in the literature and based on studies of real transport systems, a digital maturity assessment model for the tramway system (DMM-TRAM) was developed. The test procedure is shown on Fig. 1.

The developed DMM-TRAM is dedicated to the tram system, and the assessment subject is the current level of digital transformation for the period of model preparation. The assessment dimensions were identified based on a literature review of digital maturity models, asset management concepts, and available digital solutions described in academic research and the trade press. The expert experience of the authors, who have worked

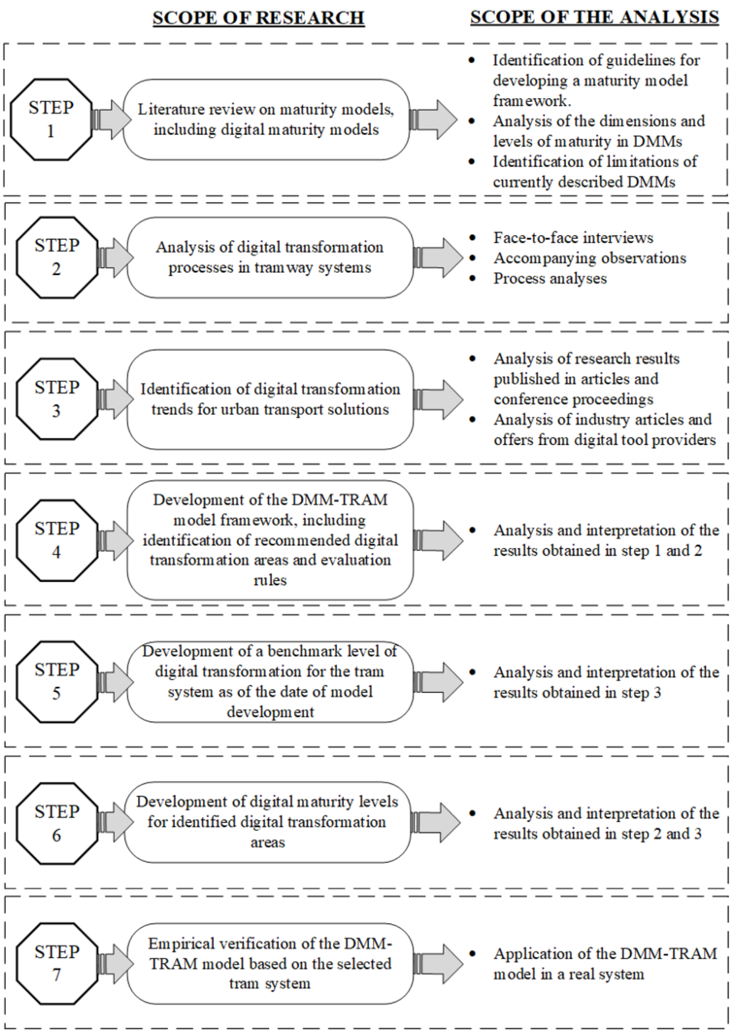

Fig. 1. Research procedure

for many years in organizations involved in the planning and implementation of tram services in the city, was used to define the guidelines for meeting the requirements for each of the assessed maturity levels.

The DMM-TRAM framework consists of five assessment dimensions divided into 15 sub-areas. Maturity is assessed at four levels:

- Level 1 – basic. Characterized by a lack of integration of data and transport service processes, and a low level of digitization.
- Level 2 – developmental. Characterized by the standardization and integration of selected components of the tram system and the digitization of the fundamental processes involved in its operation.
- Level 3 – advanced. Predictive systems are introduced, access to large data sets in digital form, and support of their management processes using digital tools.
- Level 4 – leader. Full digital maturity of the tramway system. Realizing the full potential of technological development by integrating individual system components and implementing digital good practices in all stages and levels of management.

The DMM-TRAM framework is described in Table 1. A continuous assessment model was used to determine the global level of digital maturity, i.e., the system assessment is the average maturity score obtained in all assessed sub-areas, according to (1)

$$\mathrm{DMAI} = \frac{\sum_{i=0}^{n} \mathrm{LDMD}_i}{n}, \tag{1}$$

where DMAI – an indicator to assess the digital maturity of the entire system, n – number of sub-areas assessed, LDMD – the level of digital maturity for each i-th sub-area.

The model is a dedicated tool for (1) assessing the current state of the system – identifying the current level of digital maturity of the system and (2) setting directions for further development of the system based on the defined requirements for subsequent maturity levels.

4. RESULTS

The developed framework of the DMM-TRAM model and, above all, the adopted requirements for meeting the individual maturity levels were verified using the example of a selected tramway system in one Polish city. The following research methods were used in the verification process: (1) face-to-face interviews with managers and operational staff, (2) accompanying observations, (3) process analysis, (4) examination of procedures in place, (5) functionality analysis of digital systems in use, and (6) asset inventory. A critical element of the verification was the evaluation of the DMM-TRAM model by experts who represented the various stakeholders in the system under study. They assessed the validity of the defined assessment dimensions and the formulated requirements for the individual maturity levels. The remaining data acquired during the study were used to conduct a maturity level assessment of the selected tram system.

The tram system under study comprises 24 tram lines running throughout the week and one additional tram line that runs only at weekends. The services are operated by a single municipal operator, which is a municipal company. The operator owns the vehicle fleet and is responsible for its proper operation and maintenance. The operator has also been responsible for managing the track infrastructure, including its maintenance, for several years. The transport organizer is the Transport Department, a Wrocław City Hall unit responsible for commissioning transport services to the company. Bus stop infrastructure is managed by a separate municipal company, whose task is to maintain the plat-

Table 1
Framework of DMM-TRAM

	Sub-areas	Level 1	Level 2	Level 3	Level 4
Personnel management	Improving skills	Theoretical training is delivered via traditional lecture, and materials are provided on paper. The practical part is delivered in a limited manner in real vehicles.	Theoretical training is delivered via a lecture based on a multimedia presentation and demonstration films. The practical part is delivered in a limited way in real vehicles.	Theoretical training is delivered in mixed forms – e-learning and computer simulations. Practical training is conducted partly in VR technology (goggle-based tools) and partly in real conditions.	Theoretical training is delivered in mixed forms – e-learning, computer simulations, and VR training scenarios. Practical training is conducted partly in advanced immersive technology solutions (VR, AR, simulators) and partly in real conditions.
	Operational preparation for transport tasks	The itinerary presented in the form of a list of stops on the line.	The route presented in the form of static routes on a map on paper or electronically.	The route presented in the form of instructional videos showing critical parts of the route.	The route presented in the form of dynamic scenarios (video), with the option of selecting lines, critical junctions, and the location of stops in the area of interchanges.
	Operational preparation for city traffic	Urban driving training as a passenger.	Driving in the city with a person supporting the process of correctly responding to hazards.	Training in the form of standardized scenarios using simulators or VR in a computer environment.	Training in the form of scenarios adapted to the city training using simulators or VR.

Table 1 [cont.]

	Sub-areas	Level 1	Level 2	Level 3	Level 4
Information management	Providing passenger information	Timetables and information about changes published only in a paper version to be displayed at stop points.	Timetables and information about changes published on the carrier's website.	Timetables and information about changes are available in the form of mobile applications.	Timetables and dynamic information about the current location of individual vehicles are available in real-time in the form of mobile applications.
	Providing information on interchange points	Interchange points indicated on paper route plans.	Information on transfer possibilities for the selected lines combined with on-train passenger information.	Information about the possibility of interchange for selected lines combined with passenger information provided during the trip, including departure time of the proposed lines with their direction.	Information on connecting lines combined with on-train passenger information, including departure times of proposed lines, their direction, the level of filling, and estimated time of arrival at selected points.
	Exchange of information with other operators	No ongoing exchange of information with other entities. Telephone contact as needed.	Information exchanged by e-mail, regularly (periodic reporting), and as needed.	Reporting of data to shared knowledge bases periodically using a standardized form. Current communication provided using mobile tools or email inboxes.	A common communication system for sharing current information (especially of a critical nature), a common platform available in cloud computing used for periodic data reporting; a common knowledge base updated regularly by all stakeholders.
	Locating vehicles	No vehicle location information. The position estimated from the timetables.	Information collected from the driver using radio or mobile systems.	Position transmitted by location-reporting transmitters at designated critical points (loops, stops).	RTLS (Realtime Locating System) systems transmit the position of the vehicle at one-second intervals (each vehicle equipped with a radio transmission device, transmitting a unique vehicle identifier with the location).
Passenger flow management	Timetable management (route planning)	Timetable design without support from computer systems.	Timetable design on generic, non-dedicated specialized software.	Designing timetables on software dedicated to their creation, without the possibility of verifying automatic problems arising from the overlapping of lines on the routes, and capacity analysis of interchanges and loops.	Designing timetables with the support of software dedicated to their creation, with the possibility of modeling and verifying the solutions developed. Software with possibilities for optimizing the use of rolling stock, preventing overlapping, etc.
	Monitoring of vehicle fill levels	Recording passenger numbers by controllers based on simple counting systems (manual counters) or determination of vehicle fill levels. Measurements in selected vehicles taken with a low frequency of updates.	Monitoring of vehicle occupancy levels based on an estimated number of passengers recorded by the vehicle monitoring system (cameras). Measurements in selected vehicles taken periodically.	Monitoring based on, for example, sensors installed in the vehicle doors, recording the exchange of passengers. Possibility of continuous measurement. Measurements in vehicles equipped with sensors. Filling information with hardened monitoring of the current status. Analysis of the data is in historical data mode.	Monitoring based on sensors, e.g., mounted in the vehicle door, recording passenger exchanges. Possibility of continuous measurement. Measurements in all vehicles taken with the possibility of ongoing monitoring of the filling level of each vehicle. Possibility to provide real-time filling information directly to passengers (via app and/or passenger information at stops).

Table 1 [cont.]

	Sub-areas	Level 1	Level 2	Level 3	Level 4
Infrastructure management	Maintenance of tram stop infrastructure	Repairs made based on passenger calls or based on traditional periodic field audits.	Repairs made based on passenger reports via e-mail or app and based on regular form-based field audits (standardization).	Repairs made based on passenger requests via a dedicated information channel and based on a structured way of inspecting tram stops using a standardized survey form.	Repairs made based on the collection of information from passengers in the form of personalized questions on the state of the tram stop infrastructure during the journey, and a standardized system of tram stop data processing based on video footage, with an automated system for verifying the state and quality of tram stop equipment.
	Vehicle maintenance	Repairs are conducted when damage occurs. Basic data entered manually into the service logbook; a lack of data recording standards introduces different labels for the same operations.	Replacement of fluids and components according to internal company standards. Defined vehicle operation data recorded on paper or using simple IT tools according to a developed recording standard. Scheduled inspections and maintenance work. Monitoring of operational parameters as part of daily control.	Predictive maintenance strategy for the fleet. Trams equipped with sensors to monitor selected operating parameters in real-time. Predictive diagnostics to prevent failure. Sensor data integrated with operational and maintenance data in a single IT system.	Proactive strategy, using real-time continuous monitoring data to predict the occurrence of damage. Digital solutions used to simulate potential damage (e.g., through a digital twin). Data collected in an integrated system, artificial intelligence, or machine learning algorithms are used to analyze the data and determine predictions.
	Overhead line and rectifier station maintenance	Repairs based on telephone calls from passengers or traditional periodic field inspections, with no remote monitoring.	Repairs performed using basic applications and partial (selective) non-integrated remote monitoring.	Repairs undertaken using dedicated repair and maintenance applications and partially integrated remote monitoring.	Repairs undertaken using fully integrated (regardless of component manufacturer variation) remote monitoring.
	Track maintenance	Repairs based on telephone calls from passengers or on traditionally periodic field inspections, with no remote monitoring.	Repairs performed using basic applications and partial (selective) non-integrated remote monitoring.	Repairs undertaken using dedicated repair and maintenance applications and partially integrated remote monitoring.	Repairs undertaken using fully integrated (regardless of component manufacturer variation) remote monitoring.
Operational risk management	Measurement of performance indicators	Collection of selected performance data and its processing without the support of IT solutions.	Measurement of defined performance indicators and their analysis against target values supported by non-integrated IT systems.	Built-in system of performance indicators, data collection, and analysis based on integrated IT systems.	Data collection based on automatic measurement and analysis using artificial intelligence.
	Reporting of emergencies	Crises reported verbally or as a daily paper note. Basic information about the incident provided. No guidelines on the extent of data.	Crises recorded on dedicated electronic forms as soon as reported. No standard for recording incident data.	Crises, once reported, recorded in a shared storage space, creating a knowledge base for crisis management. Standardized structure of the data recorded.	Crises recorded in a central knowledge base and trigger emergency procedures, e.g., vehicle damage, reported to the central database. Temporary vehicle shutdown automatically considered when planning vehicle movements on the following days.

forms. At selected stops, bus shelters are managed by an external private entity, which maintains the bus shelters in agreement with the manager.

The survey of the selected tram system allowed the current state of digital transformation to be assessed. The results obtained and the detailed characteristics of the sub-areas studied

Table 2
Maturity assessment of the selected tram system

	Sub-areas	Description	Level
Personnel management	Improving skills (SA1)	Training divided into theoretical and practical parts and conducted in a traditional form using multimedia presentations. Training materials in printed form. Occasional use of the Lander training simulator. Lack of use of applications/programs supporting learning/training.	2
	Operational preparation for transport tasks (SA2)	Preparation takes place at the theoretical training stage. Trainees are tested on their knowledge of routes. Routes are provided as a traditional schedule, which must be memorized. Changed (temporary) routes are issued in the form of additional schedules. The tram driver is prepared for alternative routes in case of a breakdown and the need to establish a detour on his own. Lack of applications/programs supporting current work/solving problems in the field.	1
	Operational preparation for city traffic (SA3)	Observation rides (as a passenger) and rides as a tram driver with a support person (trainer). Lack of applications/programs supporting current work/solving problems in the field.	2
Information management	Providing passenger information (SA4)	Timetables and dynamic information about the current location of individual vehicles are available in real-time in the form of mobile applications.	4
	Providing information on interchange points (SA5)	Interchange points indicated on the paper route maps.	1
	Exchange of information with other operators (SA6)	Due to the current division in force in the city (e.g., roads and platforms managed by ZDIUM), there is a regular exchange of information by e-mail and telephone if such a need arises, e.g., to coordinate renovations. Renovations covering the tram infrastructure are conducted at the request of the Municipality of Wrocław; the company regularly reports the progress of works to the Wrocław City Office by e-mail.	2
	Locating vehicles (SA7)	Publicly available application for monitoring vehicle location. Vehicles located via GPS.	4
Passenger flow management	Timetable management (route planning) (SA8)	Routes and frequency of services are established by the ordering entity, i.e., the Wrocław City Office. The company uses dedicated AGC BusMan software to synchronize communication routes.	3
	Monitoring of vehicle fill levels (SA9)	No monitoring or observations collected by drivers/tram drivers. Only a tiny part of the fleet collects data on vehicle filling, but it is periodic.	2
Infrastructure management	Maintenance of tram stop infrastructure (SA10)	Lack of a standardized form of management of bus stop infrastructure, and corrective actions taken based on individual decisions of managers.	1
	Vehicle maintenance (SA11)	Vehicles are under daily inspections, and registration is in the form of handwritten sheets. In vehicle sensors, e.g., brake pad wear, sand use, door damage, etc. Prediction to a limited extent, e.g., the need to buy new trolley rims (known approximate period of use).	2
	Overhead line and rectifier station maintenance (SA12)	24/7 service of remote control and supervision system devices for rectifier stations and network infrastructure in the Central Power Dispatch Office (CDM). Remote control is performed using event registration software, database management software, system administration software, and data transmission system communication software between CDM and distributed facilities. All faults, damages, and failures are immediately removed. The activities should commence within 30 minutes of being notified by the manager or the Contractor noticing them.	4
	Track maintenance (SA13)	No switch monitoring system includes a preview of the entire track system. The manager has access to selected turnouts. The preview for each turnout consists of launching an individual page and entering login data. Drives from various companies are installed in Wrocław. The manager does not have an integrated system not only for the entire track system but also for a given manufacturer. There is no dedicated telephone number or application for reporting. External reports (general telephone number and e-mail address) and internally diagnosed faults are assigned for ongoing implementation to the Contractor with the internal use of the WhatsApp application, which is assessed as impractical.	2
Operational risk management	Measurement of performance indicators (SA14)	Checking the punctuality of journeys based on clocks (electronic monitoring) in vehicles. Significant delays must be justified, e.g., road conditions/signals.	2
	Reporting of emergencies (SA15)	Constant communication via radiotelephone with the Traffic Control Centre, events are recorded in the internal system.	2

are presented in Table 2. In addition, the assessments obtained are presented graphically in Fig. 2.

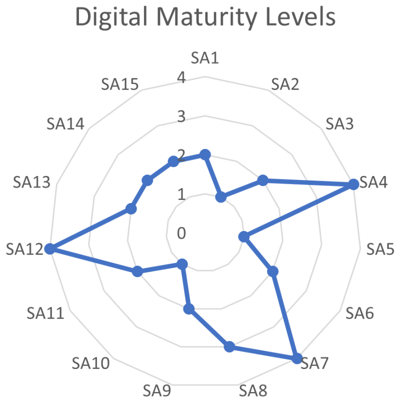

Fig. 2. Maturity levels of the analyzed tramway system in the assessed sub-areas

The DMM-TRAM model adopted rules for assessing digital maturity using a continuous model. This means that the digital maturity level of the system is assessed according to equation (1). Therefore, the entire system under study amounts to DMAI = 2.27. However, it is worth noting, at this point, that if the decision-makers had considered it reasonable to adopt a phased model, the level of digital maturity of the system under study would have to be assessed at level 1 (basic). This fact should also be emphasized, as this phenomenon may determine the need to change the rules of maturity assessment, especially when using the model for benchmarking analyses.

The highest level of digital maturity concerns the 'Information Management' dimension, which reached DMAI = 2.75. In this dimension, as many as two sub-areas reach the highest level of maturity. It is worth noting, however, that the sub-area 'Sharing information about interchange points' only reached the basic level in this dimension. The lowest level of digital maturity in the studied system is characterized by the dimension 'Personnel management', which has a DMAI = 1.67. Especially in the sub-area concerning operational preparation for the implementation of tasks, the carrier does not use the current digital solutions.

Based on the assessment of the current state, guidelines were formulated for the technological and organizational changes required to be implemented as part of the further digital transformation of the system.

5. DISCUSSION

The maturity model developed responds to the requirements defined for DMMs in the literature [3, 32]. It is a model that considers the specific nature of the transport system to be evaluated. The model developed is adapted to the specifics of the tram system because it is the second most popular public transport system in large cities (potential for wide practical application). At the same time, tram systems are more complex as compared to bus transport and therefore report an increased need for digital transformation in operating processes. The developed structure of assessment areas and distinguished sub-areas constitutes a novel approach, previously not described in the literature.

The defined assessment dimensions correspond to the transport-service processes and consider the resources used throughout the tram system. The guidelines formulated for achieving the requirements of the individual maturity levels consider the decision-making and operational processes occurring in real tram systems. In this way, the DMM-TRAM meets the information needs of decision-makers representing the various stakeholders in the urban transport system. At the same time, the results of literature studies on the development of urban tram systems and the development of digital maturity models were used in its preparation. Consequently, the model framework was based on academic research and good practices, which facilitated meeting the required methodological rigor. Its implementation in assessing the selected real system empirically verifies this rigor. It confirmed the accuracy of the selected assessment dimensions and the formulated characteristics for the different maturity levels. Therefore, it can be concluded that the developed model addresses all the gaps identified in previously published digital maturity models indicated by [3, 32].

A specific feature of the tramway system is the strong dependence of transport quality parameters on the decisions and actions of the various system stakeholders. Thus, to ensure comprehensive results, the DMM-TRAM model considers the operator's digital maturity and the level of digital transformation throughout the system. Therefore, the dimensions assessed include: (1) aspects related to the maintenance of the transport infrastructure, which in many cities are the responsibility of other organizational units; (2) aspects related to the organization of passenger flows, which remain the decision-making responsibility of the city's passenger transport organizer. The validity of this approach is also confirmed by the fact that some digital solutions need to be integrated at a whole-system level to fully achieve the expected benefits.

The model was verified using the example of a selected real system. The verification confirmed that the DMM-TRAM can be used to assess the current state of the tram system under study to determine the current level of digital transformation (diagnostic function of the model). Another important function of this tool is to support managers' decision-making processes in investments and changes related to digital transformation. Based on the guidelines formulated for each dimension about the subsequent maturity levels, a digitization strategy for the studied system can be developed, and the directions for further development and the technological and organizational changes that need to be made can be determined (planning function of the model). The model can also be used to evaluate several tramway systems. Then, based on the results obtained, it is possible to conduct a comparative analysis for a set of evaluated systems, e.g., for tramway systems in the country (benchmarking function of the model). This facilitates determining the level of digital transformation in the region for this urban transport branch and identifying leading development trends. The comparison results can also form the basis for a benchmarking analysis, as they make it possible to identify a leader among the evaluated systems. Thanks to the characteristics prepared for the evaluated dimensions, decision-makers can develop exemplary development trends and recommended technological solutions to implement in their systems.

The three functions performed by the model indicated above should be considered its strengths. Its sectoral nature, which considers the system's specific features under evaluation, is also an important benefit of its application. The DMM-TRAM framework developed is generic, allowing it to be adapted to other urban transport modes as well. However, the defined requirements for achieving successive levels of digital maturity primarily include the specific characteristics of the tram system.

The need for periodic updating of the DMM-TRAM should be considered a critical limitation of the DMM-TRAM. Digital transformation processes and the new tools constantly being developed to support the operation of urban transport systems are developing very rapidly. This makes it necessary for level 4 (leader) to consider the rapidly changing market, which necessitates periodic revision and supplementation of the requirements for level 4.

6. CONCLUSIONS

The article presented a new digital maturity assessment model (DMM-TRAM) for tram systems. For this reason, by specifying the assessment dimensions in the form of sub-areas, various stakeholders involved in the tram transport process were considered, without solely focusing on the carrier. When defining the assessment dimensions, knowledge about urban transport systems, requirements for the design of maturity models, and the concept of resource management were used. Consequently, the model framework covers the tram system comprehensively and follows methodological rigor. When defining the requirements for individual maturity levels, knowledge about digital solutions currently available on the market and the results of previous studies of various tram systems in Poland and Europe were used.

As demonstrated in Section 5, Discussion, DMM-TRAM is a multifunctional tool that can be used in (1) diagnosis of the current state, (2) planning further digital transformation, and (3) benchmarking analysis. For this reason, the presented model framework and its implementation should be interesting material for industry representatives, both carriers and organizers of public transport in the city. Based on the results, they can implement the proposed model in their system to assess the level of digital transformation achieved. The presented model solution can also inspire other researchers who can adequately extend or modify the proposed framework for DMM-TRAM to the research conducted.

The DMM-TRAM model presented in the article is an extension of earlier research by one of the authors, which was described in [33], among others. The presented model also has excellent potential for further development. For this reason, further research will focus on assessing other tram systems, comparing the results, and adapting them to other urban transport systems.

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