Statistical analysis of Hungarian cities' autonomous vehicle preparedness: correlations, ranking and neural network

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In China, the United States and Western Europe, autonomous vehicles (AVs) have become more prevalent in urban areas than before. In certain big cities, these vehicles are not only present for testing purposes but also available as robotaxi services for extensive growth. Accordingly, experts have become more concerned with the future challenges and benefits of a possible mass adoption of AVs in cities. Therefore, the number of people aiming to ascertain and quantify the preparedness of cities for AVs has been increasing. As for the cities in developed countries, there has been an increase in available information that is relevant to AVs. Nonetheless, there remains little information regarding the preparedness of cities in post-socialist countries for AVs.

This study aims to identify the preparedness of Hungarian cities for AVs by gathering the responses, via a questionnaire, of decision-makers and professionals in cities having a population of more than 20,000 and public transport systems. Out of the 61 cities meeting the above-stated conditions, 55 have responded to the questionnaire (90% response rate). We investigated the relationship between the official statistical data of the cities and the responses to the questionnaire and found that the larger the internal area of the settlement in question, the shorter the time period will be until the expected arrival of AVs for testing purposes and the authorisation of permanent road tests. The ranking of Hungarian cities based on AV preparedness is also specified in this study. Based on this database, we established a neural network in which the number of trucks per 1,000 inhabitants, the current situation, the existence of plans and the number of registered businesses per 1,000 inhabitants in the commercial and vehicle repairs sector are the most likely factors to predict expectations.

Keywords:
autonomous vehicle,
urban development,
neural network,
one-dimensional scaling

Introduction

Today, the question is no longer whether autonomous vehicle (AV)-driven urban mobility will become a reality or not but, instead, when it will happen (Threlfall 2018). There are various estimates of this effect, but the technological developments related to autonomous road vehicles have certainly been accelerated (Grindsted et al. 2022). The number of cities that are involved and companies with road test licences is increasing: in August 2023 in the state of California, 10 companies already had licences to road tests without safety drivers, four had deployment licences and a further 40 were permitted to test the vehicles with safety drivers.[1] One of these companies has already completed more than 20 million kilometres with more than 600 accident-free vehicles throughout the United States, of which 1.6 million kilometres have been completed with no human driver.[2] In developed countries, there has been a substantial expansion of urban robotaxi services operated without safety drivers: both the number of licences issued and that of the areas covered by the service are dynamically expanding (Zhou–Xu 2023, Tavor–Raviv 2023).

Although progress towards the use of AVs has been accelerated, the success of the transition depends largely on the preparedness of the host environment. It significantly goes beyond the question of adopting the technology researched in international literature: we must also see how well people would accept the changed urban space caused by AVs (transport system, cityscape, land use, economy, environment etc.) and how ready the cities are to establish the urban infrastructural, technological, regulatory etc. conditions needed for achieving the benefits and addressing the challenges that occur.

There are scenarios based on scientific modelling according to which a mass transition from the use of cars by the owners to the use of self-driving fleets would offer a realistic possibility to solve the current urban mobility problems (congestion,

[1] Updated at https://www.dmv.ca.gov/.
[2] www.waymo.com

noise, air pollution, mobility stress etc.) considering that the number of vehicles that participate in urban traffic would be significantly reduced via a new mobility system (Fagnant–Kockelman 2016, Alazzawi et al. 2018, Martinez−Viegas 2017, Overtoom et al. 2020, Liljamo et al. 2021, Kesselring et al. 2020, Spurling–McMeekin 2014). Other authors argue that some of the benefits may be economic and societal (Threlfall 2018, Lipson–Kurman 2016, Litman 2017, Bezai et al. 2021): the hours spent driving can instead be turned into productive time, the number of road accidents caused by human error can be minimised, safety and comfort can increase, pollution and fuel consumption can be reduced and the movement of the disabled and the elderly can be made more effortless (Litman 2017, Bezai et al. 2021).

Simultaneously, contrary to expectations, AVs can become counterproductive because they can even slow down urban mobility (Overtoom et al. 2020, Alam–Habib 2018, Zhao–Kockelman 2018). Moreover, an ineffective regulatory framework may increase rather than decrease safety risks, the distance travelled, emissions, congestion and social inequalities (WEF 2020). AVs can also increase car dependency, encourage more car use and longer commutes leading to higher total vehicle kilometres travelled, which in turn can result in more pollution and higher carbon dioxide emissions (Auld et al. 2017, Kim et al. 2015), and the expansion of cities into suburban areas (Guan et al. 2021, Thakur et al. 2016). Greater car dependency can also contribute to physical inactivity, resulting in a wide range of related diseases, such as cardiovascular diseases, dementia, diabetes and cancer, which worsens public health (Rojas-Rueda et al. 2020, Sohrabi et al. 2020). Additionally, countless city-related challenges can be linked to autonomous technologies (Threlfall 2018, Bezai et al. 2021), such as making the transport system more vulnerable (Alfonso et al. 2018, Atzori et al. 2018), traffic management issues (Straub−Schaefer 2019) and city budget issues (Smahó 2021). Narayanan et al. (2020), DuPuis et al. (2015), Chapin et al. (2016) and Fraedrich et al. (2019) established that the use of urban areas is one of the most significant factors that would crucially change because of both the autonomous technologies and lifestyle trends.

Consequently, the significance of AV readiness is increasing, which further highlights that the success of the spread of AVs depends not only on technological development but also on the characteristics of the host environment (Khan et al. 2019). Owing to previous research, there has been an increase in information on the AV readiness of countries (KPMG 2018), as well as information regarding the conclusions that can be drawn at city levels (Fraedrich et al. 2019, Freemark et al. 2020, Jiang et al. 2022, Khan et al. 2019). It is striking, nonetheless, that the studies that quantify the AV readiness of cities have been largely based on cities in developed countries. Concerning developing countries, we are aware of an analysis of Iran (Zali et al. 2022), but we have little information on the AV readiness of cities in the post-socialist region.

AVs require special urban development interventions for the safe operation of this technology. AV-specific urban development is key to obtaining the benefits expected from AVs and avoiding all possible disadvantages. Otherwise, AVs may even add to the mobility problems that road authorities currently face (Duarte–Ratti 2018).

In line with the above, our research aims to determine the AV preparedness of Hungarian cities. The decision-makers, urban development and transport development experts of 61 Hungarian cities having a population of more than 20,000 and a public transport system received questionnaires that contain our research questions. 55 cities completed the questionnaire; hence, the response rate is 90%. The methodology of our analysis comprised the use of correlation and rank correlation to describe the relationships between variables, the use of a neural network to predict and estimate expectations and the use of multi-dimensional scaling to establish the ranking system of settlements. The greatest novelty of our study is that, to the best of our knowledge, this study is the first to examine the AV readiness of the cities in post-socialist countries.

Literature review

To determine AV preparedness, we should highlight KPMG's widely cited AV Readiness Index, which defines AV readiness with the use of four pillars (technology, regulatory environment, infrastructure and social acceptance) (Threlfall 2018). Since the most complicated question that requires the utmost planning and preparation is the critical mass and the spatial concentration of AVs, and considering that this problem will arise in cities, our study focuses on determining AV readiness at the urban level.

Studies on urban AV readiness generally tend, in many cases, to focus on a few selected topics (such as regulation, infrastructure, land use, governance and social aspects); researchers, however, have undertaken a complex, holistic approach as well (Table 1). The latter include Fraedrich et al. (2019), the most significant result of their empirical survey is that the measures that are related to being prepared for the adoption of AVs have been implemented in only one-third of the cities examined, and in this respect, no difference can be observed between medium-sized (with 50,000–500,000 inhabitants) and large-sized (with more than 500,000 inhabitants) cities. Zomarev–Rozhenko (2020) treated the appearance of AVs as a complex phenomenon, and they regarded cities as a set of environmental, transport-related, technological, economic, social, political and regulatory indicators.

Table 1

Overview of studies on AV readiness

Author name	Focal point	Attributes
Aoyama and Leon (2021)	governance	They conceptualise the various types of engagements by cities through four different roles: city as regulator, mediator, data catalyst and promoter. They present two illustrative examples: Pittsburgh, Pennsylvania and Boston, Massachusetts.
Brovarone et al. (2021)	regulation	Making various policy interventions from 10-, 20- and 30-year perspectives Backcasting procedure Involvement of all the significant stakeholders, questionnaire survey
Campisi et al. (2021)	smart cities	They provide an overview of the development of smart cities by defining a methodology that allows for the identification of criteria to identify the optimisation of urban mobility with a particular interest in the development of future autonomous mobility.
Chajka-Cadin et al. (2020)	infrastructure	Autonomous vehicles (AVs) and connected AVs Based on their work on the experience and opinion of city officials and specialists Conducting questionnaire survey
Dale-Johnson (2019)	regulation	Asking well-informed professionals Comprehensively discusses the pillars of readiness Conducting questionnaire survey
Fagan et al. (2021)	urban planning	Document for policymakers, urban decision-makers and urban planners with clear action plans and an emphasis on the importance of proactivity
Fraedrich et al. (2019)	complex	Holistic approach Evaluation of different uses and possible outcomes Conducting questionnaire survey
Freemark et al. (2020)	regulation	Involvement of relevant stakeholders Questionnaire and focus group based on specific proposals for intervention
Grindsted et al. (2022)	governance	The range of documents included in the research is not limited to transport strategies The impact of privately owned AVs in addition to the impact of shared AVs Plans are compared with the UN objectives regarding sustainable cities as well
Jiang et al. (2022)	infrastructure	A multi-stakeholder and multi-criteria analysis through an analytic hierarchy process Online survey with participants representing three professional and three general public stakeholder groups
Lau–van Ameijde (2021)	urban planning	Wide range of possibilities for the application of AVs Breaks away from the practice of automobile-centred design

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Author name	Focal point	Attributes
Manivasakan et al (2021)	infrastructure	Makes readiness quantifiable Readiness is generally considered as covering the entire AV phenomenon
Milakis–Müller (2021)	society	Covers a wide spectrum of the pillars of preparation for AVs Backcasting approach
Riggs et al. (2019)	infrastructure	Ensuring a level of awareness through education Involving various stakeholders
Seuwou et al. (2020)	smart cities	AVs are viewed as necessary tools for achieving the goals of cities Describes hindering factors and formulates proposals
Zhou et al. (2021)	governance	Also examines short-, medium- and long-term impacts Differentiation between socio-economic groups
Zomarev–Rozhenko (2020)	complex	Measures specified are differentiated according to four potential future scenarios Comprehensive overview of the emergence of AVs

Several studies highlight the prominent role of infrastructure when examining the factors of AV readiness in cities. Using a focus group of automobile manufactures, engineers, design and policy experts, Riggs et al. (2019) examined how AVs could appear on city streets in a way that would enhance the city's liveability. They pointed out that making public road infrastructure AV-friendly is a priority, but this transformation would be a long and gradual process. Manivasakan et al. also focused on the development, evaluation and testing of urban infrastructure that supports AVs. They defined three factors to evaluate the readiness of cities for AV-compatible infrastructure: safety, efficiency and accessibility. Based on the results of Chajka-Cadin et al. (2020), the first step towards the spread of connected AVs technology is the improvement of the physical and telecommunications infrastructure. Jiang et al. (2022) also emphasised the central role of infrastructure but, at the same time, highlighted the importance of regulation as well.

Freemark et al. (2020) approached the cities' AV readiness from a regulatory perspective. They found that the representatives of cities with larger populations, higher per capita spending power and faster population growth are more likely to support the introduction of AV-related regulation. Moreover, wealthier cities are more likely to be the first to initiate the creation of a regulatory environment, whereas smaller cities with fewer resources are expected to follow in the footsteps of larger cities. Brovarone et al. (2021) also presented a regulatory-minded approach by realising that in the case of an unregulated diffusion of AV technology, the associated negative effects can easily outweigh the positive ones. Dale-Johnson (2019) examined the issue of urban AV readiness with a primary focus on regulation and the real estate market, in relation to which the following factors were identified: the safety of AVs, their integrability into the transportation ecosystem, land use, infrastructure and municipal revenues.

Lau–van Ameijde (2021) regarded the question of AV readiness as an urban planning issue. They ran several simulations using animation software to explore how the use of AVs could result in the creation of more open urban spaces, dynamically changing flexible zones, and progressive social processes. Fagan and co-authors (2021) had a similar view and identified the five most important urban planning policy actions: i) foster mobility as a service, ii) rethink curb design and street space allocation, iii) manage and reduce congestion, iv) establish data-sharing guidelines and agreements and v) reposition evenues.

Aoyama–Leon (2021) examined the urban emergence of AVs from a governance point of view, based on which cities must perform four complementary functions for a successful AV deployment: regulator, mediator, data catalyst and promoter. With a similar approach, Zhou et al. (2021) highlighted the impact of mobility transformation on land use and urban development. The governance approach towards AV readiness was also employed by Grindsted et al. (2022), who analysed 39 planning documents from 10 European capitals from the perspective of AVs according to the UN objectives in terms of sustainable cities and communities. Their principal conclusion is that specific interventions are needed on the part of local governments if they want AV technology to contribute to the objectives of sustainable development.

Campisi et al. (2021) approached AV readiness from the point of view of smart cities and identified the criteria for optimising urban mobility by paying particular attention to the future development of AVs. Seuwou et al. (2020) also examined AV readiness from the perspective of the mobility of future smart cities and identified six factors: consumer acceptance; the cost of vehicles; statutory and liability issues; social and ethical questions; cyber, data security and data protection-related concerns; and infrastructure.

Milakis–Müller (2021) focused on the social dimension of the spread of AVs in the context of AV readiness and identified three key areas: social acceptance, social impact and the regulation of AVs and policy management concerning the spread of AVs.

Methodology and analysis

Based on the studies that examined urban AV readiness, we can conclude that the existence of the critical mass of the population is a significant aspect in terms of AV readiness (Fraedrich et al. 2019, Milakis–Müller 2021, Aoyama–Leon 2021) and that the integration of AVs into the existing transport system is an important pillar of AV readiness (Chajka-Cadin et al. (2020), Grindsted et al. 2022, Jiang et al. 2022, Riggs et al. 2019, Seuwou et al. (2020)). It can also be stated that urban AV readiness is mostly assessed with questionnaires designed for experts (Khan et al. 2019, Fraedrich et al. 2019, Freemark et al. 2020, Chajka-Cadin et al. 2020, Dale-Johnsson 2019, Brovarone et al. 2021) and completed by the cities' decision-makers and the technical specialists of local governments.

Based on the above, we assessed the AV preparedness of Hungarian cities using a questionnaire sent to the cities' decision-makers and the technical specialists of local governments. When selecting the cities to be included in the analysis, we relied on the aspects of the critical mass and the transport system described in the related literature, so our screening criteria were the following:

– cities with a population of more than 20,000 and
– cities with a public transport system

A total of 61 cities in Hungary meet both of these selection criteria. In these cities, mayors and deputy mayors acting as decision-makers and professionals, who, according to the official website of the given city, run an urban development or transport development department/office received personalised questionnaires. These questionnaires were sent to their official e-mail addresses. Only six cities failed to complete the questionnaire.

Table 2

Cities questioned for the research

Ajka	**Hajdúböszörmény**	**Pécs**
Baja	**Hajdúszoboszló**	**Salgótarján**
Békéscsaba	**Hatvan**	**Siófok**
Budaörs	**Hódmezővásárhely**	Sopron
Budapest	**Jászberény**	**Szeged**
Cegléd	**Kaposvár**	**Székesfehérvár**
Debrecen	Kazincbarcika	**Szekszárd**
Dunaharaszti	**Kecskemét**	**Szentendre**
Dunakeszi	**Kiskunfélegyháza**	**Szentes**
Dunaújváros	**Kiskunhalas**	**Szigetszentmiklós**
Eger	**Komló**	**Szolnok**
Érd	**Makó**	**Szombathely**
Esztergom	**Miskolc**	**Tata**
Fót	**Mosonmagyaróvár**	**Tatabánya**
Göd	**Nagykanizsa**	**Törökszentmiklós**
Gödöllő	**Nagykőrös**	**Vác**
Gyál	**Nyíregyháza**	Várpalota
Gyöngyös	**Orosháza**	Vecsés
Győr	**Ózd**	**Veresegyház**
Gyula	**Pápa**	**Veszprém**
		Zalaegerszeg

Note: cities that returned a completed questionnaire are highlighted in bold.

Our questionnaire was a combination of questionnaires by Fraedrich et al. (2019), Freemark et al. (2020), Chajka-Cadin et al. (2020) and Dale-Johnson (2019), considering the possibility of adapting and applying it to Hungarian cities. Consequently, our research is also replicable for other case studies.

We investigated three issues that are related to urban mobility: first is the current situation, the extent to which ready-made solutions are available or are being developed; second is the timeframe the respondents feel they must be able to deal with the given solution or issue and to intervene; and third is the extent of factors hindering the development of a vision for AVs and its implementation. We also created an artificial variable in each dimension.

In the case of questions examining the current state of future plans and the vision of urban mobility, the settlements were assigned a point between 0 and 4 to the responses for each question based on whether the given solution already exists (3), is in progress (2), does not exist but is being planned (1) and is not planned (0). Highlighting three questions (planning documents regarding the preparation for the appearance of AVs in cities; clearly visible road surface markings on each road, including the edges of road surfaces; the complete elimination of factors, such as overhanging tree branches, that might obstruct image recognition in front of traffic signs), we created an artificial variable comprising the sum of the numerical values assigned to the responses; this way, the value can fall between 0 and 9.

Regarding intervention time – short term (less than 3 years), medium term (3–10 years), long term (more than 10 years) – we assigned a score between 1 and 4 to the responses, where a higher numerical value indicates a longer time period. Those stating they would never need intervention were assigned the numerical value of 4. In the case of the 17 questions in this group – the creation of a self-driving test zone on city streets; authorising permanent street tests to a certain AV company; revision of road use practices (tolls, special lanes, areas closed to traffic etc.); redesigning and remodelling road sections as it is important to designate and create previously unknown road lanes (e.g. exit and entry zones); due to the lower demand for parking spaces, the city uses former parking spaces for different purposes (e.g. green belts); making roads suitable for AV traffic (clearly visible road markings and signs, road conditions, the installation of sensors and beacons etc.); telecommunication network developments required by AV technology (5G, antenna systems etc.); launching public consultation aimed at promoting the public's acceptance of AVs; polling the population about the use of areas freed up as the result of the introduction of AVs; imposing stricter conditions for residential car ownership; the introduction of new tax(es) (e.g. to force empty AVs out of the city); AVs for testing purposes will appear in our city; the first non-testing driverless autonomous vehicle will appear in our city; more than 20% of the vehicles in our city will be autonomous; an autonomous vehicle fleet manager will appear in our city with a sharing-based service; AVs will reduce the number of vehicles on the road; the introduction of AVs will result in a lower demand for parking spaces – the value of the artificial variable of the expected time period falls between 17 and 68.

We also assigned a numerical value between 1 and 5 to the responses regarding complicating factors, where a higher value indicates a greater difficulty. In this calculation, to assess potential difficulties, we created a variable from eight questions – lack of information in terms of AV technology; and lack of social acceptance regarding AVs; lack of personnel on the local level with adequate knowledge and experience related to AV technology; data storage issues; issues concerning access to data; data security issues; cyber security issues; lack of a regulatory environment, which is the sum of the points given to each question and can therefore take a value between 8 and 40.

We investigated the correlations between the current situation, intervention time frame, difficulties and settlement size at the level of the artificial variables we created. It can be concluded that there is a negative, medium-strength relation ($r = -0.41$) between the current situation, the existence of solutions and plans and the expectations, that is the expected intervention time frames, whereas the other correlation coefficients (with absolute values below 0.3) indicate a weak relation.

Based on the questions that relate to the current situation, visions for the future, the timeframe needed for implementation and the perceived difficulties, we ranked the cities with the help of multi-dimensional scaling including the use of one dimension. The adequacy of this ranking was tested with the S-stress indicator. If the value of this indicator is below 0.05, it means that the given figure perfectly maintains the distance between the settlements calculated based on the responses. If the value of the S-stress indicator is between 0.05 and 0.1, the graphic representation is considered adequate, whereas that between 0.1 and 0.2 is acceptable but only with reservations. The name of the axis derived in the process was given on the basis of the rank correlation coefficients between the axis and the variables that form the basis of the process. The axis was named according to the variables that have the strongest (at least strength 0.5) relation with the axis.

We aim to predict the expected time period by using a neural network based on the difficulties, the current situation and certain indicators collected from the website of the Hungarian Central Statistical Office. In the neural network, input variables form the input layer, whereas target variables form the output layer. Between the two, one or more hidden layers are formed consisting of nodes. It is given as the product sum of the values arriving at the nodes of the first layer, the values of the input variables and the scalars assigned to the variables with the addition of a constant (bias) value. In each subsequent layer, the incoming data to the nodes of the previous layer are a linear combination of the signals from the nodes of the previous layer and the weights assigned to them by adding one constant member to each.

Results

The relationship between the responses and settlement indicators

The pairwise relationship between the responses to the questionnaire, the artificial variables characterising the current situation, the time frame and the difficulties and certain indicators that characterise the given settlement downloaded from the Hungarian Central Statistical Office information database was described using Spearman's rank correlation coefficient. The indicators examined were the following[3]:

- size of the internal area (km^2)
- budget balance of local governments per inhabitant (1,000 HUF/person)
- length of state and municipal public roads per inhabitant (m/person)
- the proportion of roads within the city (%)
- number of registered businesses per 1,000 inhabitants in the trade and vehicle repairs sectors of the national economy – GFO\'14 (TEÁOR\'08: G economy sector) (item/person)
- number of registered businesses per 1,000 inhabitants in the transport and storage sectors of the national economy – GFO\'14 (TEÁOR\'08: H economy sector) (item/person)
- number of passenger cars per one inhabitant according to the operator's place of residence (item/person)
- number of buses per 1,000 inhabitants (item/1,000 persons)
- number of trucks per 1,000 inhabitants (item/1,000 persons)

We found that except for two variables (the internal area of the settlement and the number of buses per 1,000 inhabitants), there is a weak (weaker than 0.3) relationship between all pairs of the questions investigated. The internal area of the settlement indicates a relationship weaker than medium strength with only four questions. We can thus conclude that the larger the internal area of the settlement, the more likely the settlement has a bicycle or scooter sharing service, access to urban mobility in a single application or development of these technologies. Additionally, the larger the internal area of the settlement, the shorter the expected time period until the appearance of AVs for testing purposes and the authorisation of permanent road tests.

The relationship for the number of buses per 1,000 inhabitants is seven variables weaker than moderate. We can conclude that the higher the number of buses per 1,000 inhabitants, the more likely the settlement has access to urban mobility in a single application or is developing such technology, and the settlement expects a shorter time period for intervention, the appearance of AVs for testing or

[3] In the Hungarian statistical system, the range of indicators related to urban mobility and its ecosystem at the municipal level is extremely limited. This is why we chose to combine the questionnaire with the data available in the statistical database and examined their correlation. Our aim with the latter method was to find out which of the 'traditional' data are related to the artificial variables of the questionnaires.

non-testing purposes, the authorisation of permanent road tests and a self-driving fleet manager; moreover, we can conclude that the proportion of AVs would be higher than 20%.

Table 3

Correlations with a strength of at least 0.3

Variables	Internal area of the settlement (km²)	Number of buses per 1,000 inhabitants (item/1,000 persons)
Current situation regarding bicycle and/or scooter sharing services	0.49	
Current situation regarding the complete synchronisation of mobility options available in the city in a single application	0.311	0.335
Time period – autonomous vehicles (AVs) for testing purposes will appear in our city	−0.418	−0.321
Time period – authorising permanent road tests for an AV development company	−0.32	−0.385
Time period – the first non-testing driverless AV will appear in our city		−0.412
Time period – more than 20% of the vehicles in our city will be autonomous		−0.446
Time period – an AV fleet manager will appear in our city offering sharing-based services		−0.437
Time period		−0.386

Based on the responses given, we also compared the mean and the median of the artificial variables that describe the current situation, the expected time period and possible difficulties between different groups (legal status of the settlement, large region and population). As for the current situation, the median score of the settlements was 3, whereas the average was 3.3 on the 0–9 scale, which indicates that the settlements do not really have ready-made solutions; instead, they are in progress or are to be planned in the future; it is less common that settlements do not plan to take any steps. The capital is the first in line (with an average of 4.0), whereas the average of cities with county rights is 3.6, and that of cities is 3.

Table 4

Differences between settlement groups

Indicator	Legal status of the settlement	Current situation_ future plan	Timeframe	Difficulty
Average	capital	4.0	41.0	12.0
	county seat, city with county rights	3.6	47.8	21.9
	city	3.0	51.3	21.5
	total	3.3	49.8	21.5
N	capital	1	1	1
	county seat, city with county rights	21	21	21
	city	33	33	33
	total	55	55	55
Standard deviation	capital			
	county seat, city with county rights	1.8	5.4	7.7
	city	1.7	7.3	7.0
	total	1.7	6.8	7.2
Median	capital	4.0	41.0	12.0
	county seat, city with county rights	4.0	49.0	23.0
	city	3.0	51.0	22.0
	total	3.0	50.0	23.0

When interpreting the results, it must be considered that the coefficient of variation of the responses in different groups is approximately 50%. In terms of location, after Budapest, the Transdanubia region has the highest average (3.6), whereas the Central Hungary region excluding Budapest has the lowest value (2.8), but at this point, the standard deviation is relatively high compared to the average (71%). At the same time, based on median values, we cannot make a distinction between the three large regions (Table 5).

Regarding the time period, the coefficient of variation of the groups ranges between 11% and 15%, which, in turn, shows a greater homogeneity than the current situation. The average score of the settlements was 49.8, whereas the median of the scores was 50 on the 17–68 scale, which shows that although most of the settlements are planning to take steps, it is not a short-term plan. Budapest indicated a shorter-than-average timeframe (41), whereas the large regions (excluding Budapest) plan to intervene and face the challenges in almost the same timeframe.

In the case of difficulties, the average score is 21.5 (on a scale of 8–40), which shows that the various factors signify neither too slight nor too great difficulties.

Among the settlements, Budapest stands out with an average value of 12, whereas with the other groups, the value is between 21 and 22.

Table 5

Differences between large regions

Indicator	Large region	Current situation_future plan	Timeframe	Difficulty
Average	Budapest	4.0	41.0	12.0
	Great Plains and North	3.3	50.6	22.2
	Transdanubia	3.6	47.3	21.4
	Central Hungary	2.8	52.4	21.1
	total	3.3	49.8	21.5
N	Budapest	1	1	1
	Great Plains and North	23	23	23
	Transdanubia	18	18	18
	Central Hungary	13	13	13
	total	55	55	55
Standard deviation	Budapest			
	Great Plains and North	1.5	6.8	5.9
	Transdanubia	1.9	5.4	8.0
	Central Hungary	2.0	7.7	8.6
	total	1.7	6.8	7.2
Median	Budapest	4.0	41.0	12.0
	Great Plains and North	3.0	51.0	23.0
	Transdanubia	4.0	48.0	23.0
	Central Hungary	3.0	54.0	21.0
	total	3.0	50.0	23.0

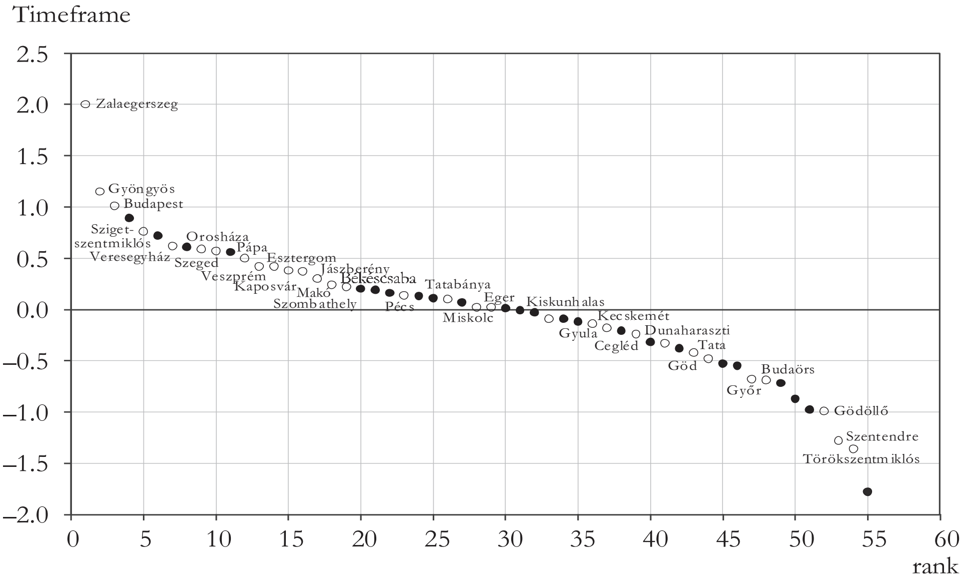
One-dimensional scaling

One-dimensional scaling can be employed to establish the order of the cities. In this case, the S-stress value is 0.189, which indicates that the representation is acceptable but with reservations. Based on Spearman's rank correlation coefficient, the order of the cities shows a moderate negative relationship with making roads suitable for autonomous vehicle traffic ($r = -0.66$), the authorisation of permanent road tests ($r = -0.64$) and the creation of AV test zones ($r = -0.60$) as original indicators and shows a strong negative relationship ($r = -0.837$) with the timeframe given for intervention by the cities as an artificial variable[4] (Figure 1).

[4] The artificial variable is the sum of the points given to the questions of the 28 direct variables, which can thus take a value between 8 and 40. Half of the cities gave at least 23 points to this question.

Figure 1

Ranking of AV preparedness of Hungarian cities



Note: black circles mean that the given cities did not agree to the indication of the name of their settlement.

Examining the order of the cities through the ranks, their averages and medians, we can conclude that the first half of the list (the first 27 places) includes 12 Transdanubian, 11 Great Plains and Northern settlements and the capital and three other large region settlements in Central Hungary. Transdanubian settlements are found at the beginning of the list, and Central Hungarian settlements are at the end of the list. Based on the ranking of medians, it seems that Transdanubia is slightly ahead of Central Hungary excluding Budapest.

Table 6

Characteristics of settlement rankings per large regions

Large region	Rank average	Number of settlements	Standard deviation of ranks	Median of ranks
Budapest	3.0	1	0.0	3.0
Great Plains and North	28.3	23	13.7	28.0
Transdanubia	22.9	18	14.6	20.5
Central Hungary	36.4	13	18.5	42.0
Total	28.0	55	16.0	28.0

Twelve out of the 21 county seats and cities with county rights examined plus the capital are in the first half of the list, whereas 20 of the other 33 cities examined are in the second half of the list (starting from the 28th place).

Table 7

Characteristics of settlement rankings per large regions

Large region	Rank average	Number of settlements	Standard deviation of ranks	Median of ranks
Capital	3.0	1	0.0	3.0
County seat, city with county rights	23.3	21	14.0	23.0
City	31.8	33	16.2	34.0
Total	28.0	55	16.0	28.0

The relationship between the rank of the resident population and the internal area of the settlement was investigated using Spearman's rank correlation coefficient. We found a weak negative relationship in both cases (−0.29). These results indicate that although it can be statistically demonstrated that larger settlements are ahead in preparation and expect that the appearance of AVs would take a shorter period of time, this relationship is weak.

Estimating the timeframe with a neural network

We sought to forecast the intervention time range regarding the expectations based on the current situation, possible difficulties and the above-listed data collected from the Hungarian Central Statistical Office information database. To achieve this, we utilised automated model building using IBM SPSS 28. While running the programme, we randomly selected 70% of the observations for model building and 30% for testing. During the process, a one-layer model was created with four nodes in the hidden layer.

Table 8

Estimated scalars (coefficients) in the neural network

Predictor		Predicted				
		hidden layer 1				output layer time interval
		H(1:1)	H(1:2)	H(1:3)	H(1:4)	
Input layer	(bias)	−0.228	−1.442	0.684	−0.075	
	current situation_future plan	−0.437	0.387	0.421	−0.379	
	difficulties	−1.003	0.589	−0.503	0.434	
	internal area	−0.703	−0.117	0.455	0.386	
	budget balance	−0.993	−0.766	−0.504	−0.030	
	public roads	0.090	0.297	0.122	0.182	
	proportion of roads	−0.816	−1.670	0.380	0.114	
	registered business1	0.360	−0.729	0.068	0.117	
	registered business2	0.171	0.091	0.362	0.439	
	passenger cars	−0.154	−0.525	0.153	0.106	
	buses	−0.595	0.571	−0.096	−0.133	
	trucks	0.263	0.781	0.601	−0.336	
	personal injury	−0.182	0.072	−0.801	0.154	
	accidents	−0.329	0.246	0.042	−0.247	
Hidden layer 1	(Bias)					−0.198
	H(1:1)					0.864
	H(1:2)					−1.127
	H(1:3)					−0.818
	H(1:4)					0.499

The process examines the importance and relative importance of the variables compared to the variable with the greatest impact. We can conclude that the number of trucks per 1,000 inhabitants, the current situation, the existence of plans and the number of registered businesses per 1,000 inhabitants that operate in the trade and vehicle repairs sectors have the greatest impact when estimating the timeframe.

Table 9

Importance of variables in the neural network

Variable	Importance	Normalised importance, %
Number of trucks per 1,000 inhabitants (item/1,000 persons)	0.157	100.0
Current situation_future plan	0.119	75.8
Number of registered businesses per 1,000 inhabitants in the trade and vehicle repairs sectors of the national economy- GFO\’14 (TEÁOR\’08: G economy sector) (item/person)	0.106	67.5
Total number of accidents caused by vehicles per 1000 inhabitants (case/1,000 persons)	0.090	57.3
Budget balance of local governments per one inhabitant (1,000 HUF/person)	0.088	56.5
The proportion of roads within the city (%)	0.078	49.9
Number of buses per 1,000 inhabitants (item/1,000 persons)	0.076	48.5
Total number of road traffic accidents with personal injuries per 1,000 inhabitants (case/1,000 persons)	0.073	46.9
Difficulties score	0.056	35.7
Number of passenger cars per 1 inhabitant according to the operator’s place of residence (item/person)	0.053	34.1
The internal area of the settlement (km^2)	0.051	32.3
Length of state and municipal public roads per inhabitant (m/person)	0.029	18.5
Number of registered businesses per 1,000 inhabitants in the transport and storage sectors of the national economy – GFO\’14 (TEÁOR\’08: H economy sector) (item/person)	0.024	15.4

To test the adequacy of the model – based on the analogy of the multiple correlation coefficient taken from linear regression models – we calculated the correlation coefficient between the actual value and the estimated value (where the estimation was based on the model) of the timeframe variable, the value of which is 0.74, indicating that the set of variables used has a stronger than moderate relationship with the predicted variable. However, based on the responses and the model, it seems that the responses concerning the expectations are not always consistent with the difficulties perceived and with the values of the applied settlement indicators, and other external variables might also play a role in predicting the timeframe.

Summary

In our research, we examined the AV preparedness of Hungarian cities from the perspective of the cities’ decision-makers and professionals. In cities with public transport and with a population of more than 20,000 inhabitants, the persons involved in the research were those working in key positions and whose opinions could have an impact on the AV preparedness of the given city. Data were collected using a questionnaire, through which we analysed the cities’ AV preparedness. The sample includes 55 cities, which represents a 90% coverage in terms of the response rate.

The three methodologies applied allowed us to gain a deeper understanding of the relationship between the cities' AV preparedness. First, we carried out a test concerning the relationship between the responses to the questionnaire and the statistical data of the cities so that we could explore the correlations and relationships. We found that, except for two variables (the internal area of the settlement and the number of buses per 1,000 inhabitants), there is a weak (weaker than 0.3) relationship between all question pairs investigated. A significant finding is that the larger the internal area of the settlement, the shorter the expected time period until the appearance of AVs for testing purposes and the authorisation of permanent road tests.

We then employed one-dimensional scaling to rank cities in terms of their AV preparedness. The third method was the neural network, through which we could make forecasts based on the responses and the cities' data. Using this method, we identified the most significant factors that have an impact on the cities' AV preparedness. Consequently, most likely, the number of trucks per 1,000 inhabitants, the current situation, the existence of plans and the number of registered businesses per 1,000 inhabitants in the trade and vehicle repairs sectors are the most significant factors when forecasting expectations.

The two major limitations of our study are that on the one hand, there remains very little available information about the observations on the urban testing of AVs and on the other hand, the traditional statistical data available at the city level are not or are only indirectly related to the urban deployment of AVs. As a follow-up to this research, it may be worthwhile to conduct international comparative analyses and record the changes that occur over time.

The results of the study enable us to understand to what extent Hungarian cities are ready for the future spread of AVs. Creating the infrastructural, technological and regulatory conditions is essential to make use of the advantages of AVs and to effectively respond to the challenges since the cities' AV preparedness has a significant impact on the successful spread of AVs.

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REFERENCES

ALAM, M. J.–HABIB, M. A. (2018): Investigation of the impacts of shared autonomous vehicle operation in Halifax, Canada, using a dynamic traffic microsimulation model *Procedia Computer Science* 130: 496–503. https://doi.org/10.1016/j.procs.2018.04.066

AULD, J.–SOKOLOV, V.–STEPHENS, T. S. (2017): Analysis of the effects of connected-automated vehicle technologies on travel demand *Transportation Research Record* 2625 (1): 1–8. https://doi.org/10.3141/2625-01

ALAZZAWI, S.–HUMMEL, M.–KORDT, P.–SICKENBERGER, T.–WIESEOTTE, C.–WOHAK, O. (2018): Simulating the impact of shared, autonomous vehicles on urban mobility – a case study of Milan. In: WIEßNER, E.–LÜCKEN, L.–HILBRICH, R.–FLÖTTERÖD, Y-P.–ERDMANN, J.–BIEKER-WALZ, L.–BEHRISCH, M. (eds.): *SUMO 2018 – Simulating autonomous and intermodal transport systems* 2: 94–110. https://doi.org/10.29007/2n4h

ALFONSO, J.–NARANJO, J. E.–MENENDEZ, J. M.–ALONSO, A. (2018): Vehicular communications *Intelligent Vehicles* 103–139. https://doi.org/10.1016/B978-0-12-812800-8.00003-5

AOYAMA, Y.–LEON, L. F. A. (2021): Urban governance and autonomous vehicles *Cities* 119: 103410. https://doi.org/10.1016/j.cities.2021.103410

ATZORI, L.–FLORIS, A.–GIRAU, R.–NITTI, M.–PAU, G. (2018): Towards the implementation of the social internet of vehicles *Computer Networks* 147: 132–145. https://doi.org/10.1016/j.comnet.2018.10.001

BEZAI, N. E.–MEDJDOUB, B.–AL-HABAIBEH, A.–CHALAL, M. L.–FADLI, F. (2021): Future cities and autonomous vehicles: analysis of the barriers to full adoption *Energy and Built Environment* 2 (1): 65–81. https://doi.org/10.1016/j.enbenv.2020.05.002

BROVARONE, E. V.–SCUDELLARI, J.–STARICCO, L. (2021): Planning the transition to autonomous driving: a policy pathway towards urban liveability *Cities* 108: 102996. https://doi.org/10.1016/j.cities.2020.102996

CHAJKA-CADIN, L.–PETRELLA, M.–PLOTNICK, S. (2020): *Intelligent transportation systems deployment: findings from the 2019 connected vehicle and automated vehicle survey* US Department of Transportation, Washington.

CHAPIN, T.–STEVENS, L.–CRUTE J.–CRANDALL, J.–ROKYTA, A. – WASHINGTON, A. (2016): *Envisioning Florida's future: transportation and land use in an automated vehicle world. Final report* Florida State University Department of Urban & Regional Planning, Tallahassee.

CAMPISI, T.–SEVERINO, A.–AL-RASHID, M. A.–PAU, G. (2021): The development of the smart cities in the connected and autonomous vehicles (CAVs) era: from mobility patterns to scaling in cities *Infrastructures* 6 (7): 100. https://doi.org/10.3390/infrastructures6070100

DALE-JOHNSON, D. (2019): *Preparing for autonomous vehicles: a survey of local governments* NAIOP Research Foundation, Hemdon.

DUARTE, F.–RATTI, C. (2018): The impact of autonomous vehicles on cities: a review *Journal of Urban Technology* 25 (4): 1–16. https://doi.org/10.1080/10630732.2018.1493883

DUPUIS, N.–COOPER, M.–BROOKS, R. (2015): *City of the Future. Technology & Mobility* National league of cities, center for city solutions and applied research, Washington DC.

FAGAN, M.–COMEAUX, D.–GILLIES, B. (2021): *Autonomous vehicles are coming: five policy actions cities can take now to be ready* Taubman Center for State and Local Government, Cambridge.

FAGNANT, D. J.–KOCKELMAN, K. M. (2016): Dynamic ride-sharing and fleet sizing for a system of shared autonomous vehicles in Austin Texas *Transportation* 45: 143–158. https://doi.org/10.1007/s11116-016-9729-z

FRAEDRICH, E.–HEINRICHS, D.–BAHAMONDE-BIRKE, F. J.–CYGANSKI, R. (2019): Autonomous driving, the built environment and policy implications *Transportation Research Part A: Policy and Practice* 122: 162–172. https://doi.org/10.1016/j.tra.2018.02.018

FREEMARK, Y.–HUDSON, A.–ZHAO, J. (2020): Policies for autonomy: how american cities envision regulating automated vehicles *Urban Science* 4 (4): 55. https://doi.org/10.3390/urbansci4040055

GRINDSTED, T. S.–CHRISTENSEN, T. H.–FREUDENDAL-PEDERSEN, M.–FRIIS, F.–HARTMANN-PETERSEN, K. (2022): The urban governance of autonomous vehicles – in love with AVs or critical sustainability risks to future mobility transitions *Cities* 120: 103504. https://doi.org/10.1016/j.cities.2021.103504

GUAN, J.–ZHANG, S.–D'AMBROSIO, L. A.–ZHANG, K.–COUGHLIN, J. F. (2021): Potential impacts of autonomous vehicles on urban sprawl: a comparison of Chinese and US car-oriented adults *Sustainability* 13 (14): 7632. https://doi.org/10.3390/su13147632

JIANG, L.–CHEN, H.–CHEN, Z. (2022): City readiness for connected and autonomous vehicles: a multi-stakeholder and multi-criteria analysis through analytic hierarchy process *Transport Policy* 128: 13–24. https://doi.org/10.1016/j.tranpol.2022.09.012

KESSELRING, S.–FREUDENDAL-PEDERSEN, M.–ZUEV, D. (2020): *Sharing mobilities: new perspectives for the mobile risk society* Routledge, New York and London.

KHAN, J. A.–WANG L.–JACOBS, E.–TALEBIAN, A.–MISHRA, S.–SANTO, C. A.–GOLIAS, M.–ASTORNE-FIGARI, C. (2019): Smart cities connected and autonomous vehicles readiness index *SCC '19: Proceedings of the 2nd ACM/EIGSCC Symposium on Smart Cities and Communities* 8: 1–8. https://doi.org/10.1145/3357492.3358631

KIM, K.–ROUSSEAU, G.–FREEDMAN, J.–NICHOLSON, J. (2015): *The travel impact of autonomous vehicles in metro Atlanta through activity-based modelling* The 15th TRB National Transportation Planning Applications Conference, Atlantic City NJ.

KPMG (2018): *Autonomous Vehicles Readiness Index. Assessing countries' openness and pre-paredness for autonomous vehicles* KPMG International, Amstelveen.

LAU, S. F. G.–VAN AMEIJDE, J. (2021): City centres in the era of self-driving cars: possibilities for the redesign of urban streetscapes to create pedestrian-oriented public spaces. In: GLOBA, A.–VAN AMEIJDE, J.–FINGRUT, A.–KIM, N.–LO, T. T. S. (eds.): *PROJECTIONS – Proceedings of the 26th CAADRIA conference* 2: 609–618., The Chinese University of Hong Kong, Hong Kong. https://doi.org/10.52842/conf.caadria.2021.2.609

LILJAMO, T.–LIIMATAINEN, H.–PÖLLÄNEN, M.–VIRI, R. (2021): The effects of mobility as a service and autonomous vehicles on people's willingness to own a car in the future *Sustainability* 13 (4): 1962. https://doi.org/10.3390/su13041962

LIPSON, H.–KURMAN, M. (2016): *Driverless: intelligent cars and the road ahead* Mit Press. Cambridge, MA.

LITMAN, T. (2017): Autonomous vehicle implementation predictions: implications for transport planning *Implications for Transport Planning. 8 September 2017*. Victoria Transport Policy Institute.

MANIVASAKAN, H.–KALRA, R.–O'HERN, S.–FANG, Y.–XI, Y.–ZHENG, N. (2021): Infrastructure requirement for autonomous vehicle integration for future urban and suburban roads – current practice and a case study of Melbourne *Australia Transportation Research Part A: Policy and Practice* 152: 36–53. https://doi.org/10.1016/j.tra.2021.07.012

MARTINEZ, L. M.–VIEGAS, J. M. (2017): Assessing the impacts of deploying a shared self-driving urban mobility system: an agent-based model applied to the city of Lisbon, Portugal. *International Journal of Transportation Science and Technology* 6 (1): 13–27. https://doi.org/10.1016/j.ijtst.2017.05.005

MILAKIS, D.–MÜLLER, S. (2021): The societal dimension of the automated vehicles transition: towards a research agenda *Cities* 113: 103144. https://doi.org/10.1016/j.cities.2021.103144

NARAYANAN, S.–CHANIOTAKIS, E.–ANTONIOU, C. (2020): Shared autonomous vehicle services: a comprehensive review *Transportation Research Part C: Emerging Technologies* 111 (2): 255–293. https://doi.org/10.1016/j.trc.2019.12.008

OVERTOOM, I.–CORREIA, G.–HUANG, Y.–VERBRAECK, A. (2020): Assessing the impacts of shared autonomous vehicles on congestion and curb use: a traffic simulation study in the Hague, Netherlands *International Journal of Transportation Science and Technology* 9 (3): 195–206. https://doi.org/10.1016/j.ijtst.2020.03.009

RIGGS, W.–RUHL, M.–RODIER, C.–BAUMGARDNER, W. (2019): Designing streets for autonomous vehicles. In: MEYER, G.–BEIKER, S. (eds.): *Road vehicle automation 6. AVS 2018. Lecture Notes in Mobility* pp 111–122., Springer, Cham. https://doi.org/10.1007/978-3-030-22933-7_12

ROJAS-RUEDA, D.–NIEUWENHUIJSEN, M. J.–KHREIS, H.–FRUMKIN, H. (2020): Autonomous vehicles and public health *Annual review of public health* 41 (1): 329–345. https://doi.org/10.1146/annurev-publhealth-040119-094035

SEUWOU, P.–BANISSI, E.–UBAKANMA, G. (2020) : The future of mobility with connected and autonomous vehicles in smart cities. In: FARSI, M.–DANESHKHAH, A.–HOSSEINIAN-FAR, A.–JAHANKHANI, H. (eds.): *Digital twin technologies and smart cities. Internet of things* pp 37–52., Springer, Cham. https://doi.org/10.1007/978-3-030-18732-3_3

SOHRABI, S.– KHREIS, H–LORD, D. (2020): Impacts of autonomous vehicles on public health: a conceptual model and policy recommendations *Sustainable cities and society* 63: 102457. https://doi.org/10.1016/j.scs.2020.102457

SMAHÓ M. (2021): Autonóm járművek a jövő városában. In: CSIZMADIA, Z.–RECHNITZER, J. (szerk.): Az önvezető járművek világa: Társadalmi hatások és kihívások Akadémiai Kiadó, Budapest.

SPURLING, N.–MCMEEKIN, A. (2014): Interventions in practices: sustainable mobility policies in England. In: STRENGERS, Y.–MALLER, C. (eds.): *Social practices, intervention and sustainability* pp. 78–94., Routledge, London.

STRAUB, E. R.–SCHAEFER, K. E. (2019): It takes two to Tango: automated vehicles and human beings do the dance of driving – four social considerations for policy *Transportation research part A: policy and practice* 122: 173–183. https://doi.org/10.1016/j.tra.2018.03.005

TAVOR, S.–RAVIV, T. (2023): Anticipatory rebalancing of RoboTaxi systems *Transportation Research Part C: Emerging Technologies* 153: 104196. https://doi.org/10.1016/j.trc.2023.104196

THAKUR, P.–KINGHORN, R.–GRACE, R. (2016): *Urban form and function in the autonomous era* Australasian Transport Research Forum (ATRF), Melbourne.

THRELFALL, R. (2018): *Autonomous vehicles readiness index* Klynveld Peat Marwick Goerdeler (KPMG) International.

ZALI, N.–AMIRI, S.–YIGITCANLAR, T.–SOLTANI, A. (2022): Autonomous vehicle adoption in developing countries: futurist insights *Energies* 15: 8464. https://doi.org/10.3390/en15228464

ZHAO, Y.−KOCKELMAN, K. M. (2018): Anticipating the regional impacts of connected and automated vehicle travel in Austin, Texas *Journal of Urban Planning and Development* 144 (4): 04018032. https://doi.org/10.1061/(ASCE)UP.1943-5444.0000463

ZHOU, M.–LE, D.–NGUYEN-PHUOC, D. Q.–ZEGRAS, P. C.–FERREIRA, J. J. (2021): Simulating impacts of automated mobility-on-demand on accessibility and residential relocation *Cities* 118: 103345. https://doi.org/10.1016/j.cities.2021.103345

ZHOU, Y.–XU, M. (2023): Robotaxi service: the transition and governance investigation in China *Research in Transportation Economics* 100: 101326. https://doi.org/10.1016/j.retrec.2023.101326

ZOMAREV A.–ROZHENKO M. (2020): Impact of self-driving cars for urban development *Foresight and STI Governance* 14 (1): 70–84. https://doi.org/10.17323/2500-2597.2020.1.70.84

INTERNET SOURCE

WORLD ECONOMIC FORUM [WEF] (2020): *Autonomous vehicle policy framework: selected national and jurisdictional policy efforts to guide safe AV development* World Economic Forum, Cologny. https://www3.weforum.org/docs/WEF_C4IR_Israel_Autonomous_Vehicle_Policy_Framework_2020.pdf (downloaded: July 2023)

WEBSITES/DATABASES

https://www.dmv.ca.gov/portal/vehicle-industry-services/autonomous-vehicles/autonomous-vehicle-testing-permit-holders/

https://waymo.com/blog

HUNGARIAN CENTRAL STATISTICAL OFFICE: Dissemination database. https://statinfo.ksh.hu/Statinfo/haDetails.jsp?query=kshquery&lang=en