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SOCIO-ECONOMIC IMPACT OF DIGITAL TRANSFORMATION IN TOURISM: A HYBRID DECISION SUPPORT MODEL

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ABSTRACT. The main objective of this study is to develop a hybrid decision support model for assessing the socio-economic impact of digital transformation in tourism, with a focus on the Visegrad Group countries (Czech Republic, Hungary, Poland, and Slovakia). This model enables a comprehensive assessment of digital changes in the tourism industry by incorporating both individual evaluations from tourists and expert opinions at the regional level. The application of fuzzy set theory effectively models uncertainty in respondents' answers, processes linguistic assessments from experts, and generates quantitative comparative indicators. This approach not only facilitates the evaluation of the socio-economic impact of digital transformation on the tourism sector but also supports more informed management decision-making. Notably, the model was configured and tested using real data from 2,343 respondents in the Visegrad Group countries, enhancing its practical value. The study's results can serve as a foundation for developing state-level policies aimed at advancing digital infrastructure in tourism, increasing technological adaptation among enterprises, and improving socio-economic conditions in the regions. This approach holds significant potential for scientific research in economics and sociology, as it promotes the integration of technology into practical policies to enhance regional economic conditions.

JEL Classification: M3, Z3 ***Keywords:*** digital transformation, tourism, socio-economic impact, hybrid model, fuzzy set theory, development policies

Introduction

In modern conditions, digital transformation is one of the key factors driving the development of various sectors of the economy, including tourism. The introduction of digital technologies contributes to the improvement of tourism services, enhances the competitiveness of regions, and increases their socio-economic potential. At the same time, the digitalization of tourism creates new challenges that require effective approaches to assessing its impact on the economy, employment, infrastructure, and the well-being of the local population.

A significant portion of research on the digital transformation of tourism focuses on individual aspects, such as the impact of online platforms, mobile applications, virtual and augmented reality, automated services, and artificial intelligence. For example, recent research has analyzed how digital mobility platforms, such as Mobility as a Service (MaaS), can address the transport needs of tourists in urban environments by integrating various transport modes, offering flexible pricing, and improving the overall travel experience, while also highlighting regulatory and stakeholder challenges that affect implementation (Vovk et al., 2024). However, a comprehensive assessment of the digital transformation of regional tourism - one that considers multidimensional socio-economic effects - remains insufficiently developed. In this context, the development of a hybrid decision support model is important, as it would allow for a generalized assessment of the digital transformation of tourism and help determine its socio-economic impact at the regional level.

This study aims to develop a hybrid decision support model for assessing the socio-economic impact of digital transformation in tourism, using the example of the Visegrad Group countries (Czech Republic, Hungary, Poland, and Slovakia). The proposed model enables a generalized assessment of the level of digital transformation in tourism within the studied region and establishes its linguistic level of impact. The results obtained can be used to formulate state-level policies aimed at developing digital tourism infrastructure, increasing the technological adaptation of tourism enterprises, and improving socio-economic conditions in the regions.

1. Literature review

The digital transformation (DT) of tourism takes place differently in the various countries. The differences are evident not only between the sectors, but also between enterprises within the sectors. Investigating the development of DT in the sectors is methodologically comprehensive and hence, it requires access to more deeply structured data (Skare et al. 2023; Zhou et al. 2025). It is also challenging to examine the determinants that influence the individual stages of DT to varying levels and their causal relationships in the digital ecosystem (Hernik et al., 2025). The tourism sector as the most affected by the Covid-19 pandemic adapts to the DT processes effectively, which is reflected mainly in the economic growth of the countries (Lewicki & Florek, 2024). The heterogeneity of the processes in this sector prevents the accurate mapping of the determinants of the transformation processes, their extent and effects, resulting in a slower transfer of knowledge into tourism the policy-making processes (Šimková et al. 2023; Hong et al. 2025).

Available research in the field of digital tourism is focused mainly on developed markets, where there is missing research on the sociocultural and economic factors, supporting

digitalisation of tourism (Gómez et al. 2025). To evaluate the development level of digital tourism as well as its effects, it is necessary to know the relationships between the acceptance of technologies, the use of social media, as well as tourist experiences (Shuvo and Islam, 2024; Coutinho et al., 2023). The digital processes in the sectors do not operate independently, but create various structural relationships, with relationships, for instance, to digital marketing, digital economy, free digital sector, digital education, digital literacy, and so on. (Gutierriz et al. 2023). Although several studies have been conducted to investigate sustainable tourism destinations, no universal model has been identified so far. This is due the fact, cities or other tourist destinations can use different processes and tools to satisfy tourist demand, which is also related to the attractiveness of a particular tourist destination, with visitation parameters, seasonality, safety, climate aspects, and so on.

DT processes in tourism have been investigated gradually more in relation to the competitiveness of enterprises and the attractiveness of a destination that prerequisites the solution of many environmental issues and quality issues (Ćirić and Sedlak, 2018). Some authors have quantified the issues of insufficient development of DT towards smart tourism, that is mainly related to the insufficient support of small and medium-sized enterprises (SMEs) operating in this sector (Tien et al. 2023). One solution is the implementation of multidimensional analyses, based on which it would be possible to formulate recommendations for the government when proposing policies and strategies aimed at assisting SMEs that would ensure sustainability of tourism (Caplanova and Dimelis, 2025; Civelek et al. 2024).

Tourism DT was not activated by the Covid-19 pandemic, although many processes introduced during the pandemic period can be very beneficial in these transformational processes of tourism. For instance, increased demand for online shopping, access to contactless solutions, changes in supply chains supported by artificial intelligence (AI) tools and digital data, and so on. Technological development also enables optimisation of the processes and activities in the field of promotion in the tourism industry, development of competitive pricing strategies, building of tourist brands for countries and territories, and so on (Li et al. 2024; Michálková et al. 2024). DT processes directly impact key business operations in tourism, bringing fast and visible visitor satisfaction, cost savings due to high labour productivity, optimisation of enterprise management in tourism, and so on. Schönherr et al. (2023) argue that the economic, social, and environmentally sustainable development of tourism is possible by facilitating collaboration through DT, digital technologies directing guest flows, creating online mobility offers, online campaigns to raise environmental awareness, and so on. According to these authors, organisational learning leads tourism organisations to more sustainable tourism.

The positive effects of DT are also reflected in the field of human resource management. According to Deng et al. (2024) and Kovacs & Vamosi Zarandne (2022), DT supports employment growth in tourism and increases demand for highly skilled workers, while displacing some low-skilled workers, contributing to significant changes in the employment structure in the tourism industry. Bondarenko et al. (2025) pointed out that DT in tourism is accompanied by dominant research trends and technological directions. The authors identified the development of DT in the five distinct phases – from tourism 1.0 to the emerging paradigm of tourism 5.0. At the same time, the study identified the four key pillars of DT: (i) technological integration, (ii) improvment of customer experience, (iii) development of a business model, and (iv) optimisation of operational processes.

Several studies confirm significant differences in the implementation and use of various tools and applications within digital tourism. The most distinctive instance can be seen, for instance, in the use of AI chatbots for trip planning. Their use is at level of 67 % in China and 25 % in Germany. Many reports and research studies also show changes in business models in

tourism organisations that are influenced by the adaptation and implementation processes of AI tools.

Success in digital transformation in tourism industries will largely depend on the balance of technological innovations and approaches focused on human, including personalisation, authentic experiences, and so on (Palgutová et al. 2024; Pejic and Milincic, 2024). Santarsiero et al. (2024) confirm that DT processes will take place differently in enterprises due to many external and internal factors of the business environment that requires the adaptation of business models through digital technologies to achieve smart, inclusive and sustainable tourism offers. The elementary differential factors influencing the intensity and effects of DT processes include the diverse characteristics of enterprises operating in the tourism industry, influenced by the size of an enterprise, its approach to technology, risk aversion, the complexity of the work, the enterprise innovation policy, and so on.

Giotopoulos and Papadopoulos (2025) confirmed that DT processes have changed consumer attitudes and behaviour, as well as the adaptation of enterprises to them. DT directly and significantly affects consumer decision-making processes, as well as the operational strategies of enterprises in the tourism industry. Hence, it is important to examine DT processes in both horizontal and vertical process levels, using quantitative and qualitative approaches, and thus reveal important aspects for the development of innovative business models adaptable to DT processes in the tourism industry, as well as changes in value chains with the aim of improving competitiveness.

Bakalis et al. (2024) carried out a comprehensive analysis of the characteristics of digital technologies and identified categories of their significant benefits, especially in relation to process digitisation and promotion. Although digital technologies are changing the nature of value chains in the tourism industry, DT processes go beyond the implementation of digital technologies and also require a change in organisational culture, changes in competencies, management models, and so on. According to El Nile and Sobhy (2024), managers in tourism organisations must create and adopt organisational culture strategies that will develop intellectual capital and support inclusive tourism. The authors identified several dimensions of organisational culture that DT processes affect, for instance, organisational flexibility, levels of collaboration, openness to change, levels of customer focus, levels of trust, communication, tolerance for failure, participation, innovation, and so on.

Attitudes towards the use of digital technologies in tourism are also significantly determined by the age structure of visitors, as stated by several studies. For instance, Stavrianea and Kamenidou (2021) report that the attitudes of individuals belonging to Generation Z towards electronic reservation platforms and their involvement in them are influenced by their visitation intentions. According to the authors, involvement in an electronic reservation platform has a negative impact on consumers' attitudes towards this platform.

DT processes can also have an impact on deepening of the differences between enterprises. Hu et al. (2024) found that DT amplify maturity mismatch, especially for enterprises with greater financial constraints and a lower level of financial marketisation. Thus, their research revealed the antecedents of maturity mismatches among firms and pointed to the effects of DT for firms in the tourism sector.

Critical studies are also emerging that declare the impact of digital technologies on tourism. Inversini (2025) argues that the impact of these technologies is significant and changes not only the competitive environment of enterprises, but also the behaviour of travelers. New technologies use cloud computing, blockchain, the Internet of Things (IoT) and AI, and are expected to disrupt the business and consumer side of many industries. Not only these considerations open up space for a critical understanding of the principles of digital humanism, which is important for decision-making processes in the area of adopting new technologies in

enterprises. It will also be important to reflect on the role of control processes of digital technologies, educational policies in the field of tourism, ethical principles, and so on.

Smikh et al. (2025) expands the framework for examining the benefits of DT in tourism to include their impact on management practices, examining the five key aspects of DT: understanding, implementation, opportunities and benefits, challenges and constraints, and impacts on business relationships. Many of the benefits that the authors cite, such as increased operational efficiency, better customer interaction and experience, higher customer satisfaction and loyalty, and expanding markets through digital channels, also appear in other research studies, which supports the conceptual perception of the benefits of DT and their importance for the creation of a comparative platform. Special emphasis has also been placed recently on examining the issues of cybersecurity, loss of human contact, the development of technological dependence, and ethical issues with the use of acquired data.

The study is structured as follows. Section 2 presents the formal formulation of the problem, considers the information model for assessing the socio-economic impact of digital transformation in the tourism sector, and proposes a hybrid model for supporting decision-making aimed at developing digital tourism infrastructure. Section 3 tests this model and demonstrates examples of evaluation on selected data fragments. Section 4 analyzes the results obtained, outlines the advantages of the proposed hybrid model, identifies limitations of the study, and outlines prospects for further development of the study.

2. Methods and methodology

2.1. Formal formulation of the evaluation problem

Let us consider a certain region R for assessing the digital transformation of tourism associated with a destination. Participants in the tourist movement (respondents) are denoted by the set $P = \{p_1; p_2; \dots; p_n\}$. To analyze the socio-economic impact of the digital transformation of tourism, it is necessary to have a database containing information about the experiences of respondents. Such a database is formed by tourists' reviews, which reflect various aspects of the impact of digital transformation on the tourism industry. Participants in the tourist movement, having visited the destination, evaluate it according to the set of criteria $K = \{K_1; K_2; \dots; K_m\}$. These criteria determine the content of the information model for assessing the digital transformation of tourism in the region – IM_{dt}. The collected data are processed using a hybrid decision support model for the socio-economic impact of the digital transformation of tourism – HM_{dt}. Also, tourism experts express their opinions on the level of digital transformation of tourism for the studied region E.

Let the hybrid decision support model for the socio-economic impact of the digital transformation of tourism be illustrated in the form of the following operator:

$$\Sigma(R, P, E, IM_{dt}, HM_{dt})|Y(f). \quad (1)$$

The result is the initial estimate $Y(f) = \{\mu(R);\ T_{dt}\}$, consisting of the following levels: $\mu(R)$ – generalised estimate of the digital transformation of tourism in the studied region; T_{dt} – linguistic level of the socio-economic impact of the digital transformation of the tourism industry in the region.

2.2. IM_{dt} – information model for assessing the digital transformation of tourism in the region

A set of evaluation criteria $K = \{K_i; i = \overline{1,m}\}$, is formed, which reflects various aspects of the digital transformation of tourism in the region. Participants in the tourism movement, based on their own experience, provide assessments for each of the identified criteria, expressing their opinion on the effectiveness of digital solutions, the convenience of online services, the accessibility of digital infrastructure, the impact of technologies on the quality of service and the overall level of satisfaction with the use of digital tools in tourism activities. The obtained knowledge is formalized using a term set of linguistic variables $L = \{$"Strongly disagree"; "Disagree"; "Neither agree nor disagree"; "Agree"; "Strongly Agree"$\}$.

The methodology for selecting criteria for assessing digital transformation was based on a multi-step analysis that combines expert assessments and mathematical methods. First, an initial list of indicators was formed based on a review of scientific sources and practical cases of digitalization of the tourism industry. Then, an expert survey was conducted using the Delphi method, in which specialists in the digital economy, tourism, and information technologies participated. To ensure the objectivity of the assessment, a statistical analysis of the consistency of expert opinions (Kendall's concordance coefficient) was used, as well as the method of hierarchy analysis to determine the importance of each criterion. The results obtained allowed us to form a final set of criteria that is representative of assessing the level of digital transformation of tourist regions.

K_1 – digital booking platforms (Booking, Airbnb, etc.) have made organizing travel in the visited region easier and more accessible.

K_2 – mobile tourism applications (maps, translators, transport services) have significantly improved the convenience of traveling in this region.

K_3 – the use of artificial intelligence and chatbots in travel services has helped me find the necessary information in the visited region faster.

K_4 – digital technologies have increased the security of my trip in this region (route tracking, online insurance, etc.).

K_5 – the use of digital payments (Apple Pay, Google Pay, cryptocurrencies) has made paying for travel services in the region more convenient.

K_6 – online reviews and ratings have influenced my choice of a hotel, restaurant, or travel service in this region.

K_7 – I was willing to pay more for travel services in the region if they offered a personalised digital experience.

K_8 – the level of digital transformation of the region influenced my decision to visit it.

K_9 – the use of virtual and augmented reality (VR/AR) improved my experience of tourist attractions in this region.

K_{10} – automated services (electronic guides, contactless hotel check-in) made my trip to this region more comfortable.

K_{11} – travel companies in the visited region are actively implementing digital innovations.

K_{12} – the availability of free Wi-Fi in holiday destinations was an important factor for me when traveling to this region.

K_{13} – I trusted digital technologies in tourism more than traditional booking and payment methods in this region.

K_{14} – I was willing to provide my data to tourist services in the region in exchange for personalised offers.

K_{15} – digital transformation had a positive impact on the quality of tourist services in the visited region.

K_{16} – thanks to digital technologies, my need for physical interaction with staff while traveling in this region has decreased.

K_{17} – the level of digitalization of the region's tourism infrastructure affects its long-term competitiveness.

K_{18} – the digital transformation of tourism contributes to the economic development of the visited region.

K_{19} – automated service systems (chatbots, robotic receptions) did not worsen my customer experience in this region.

K_{20} – I was ready to use biometric technologies (face scanning, fingerprints) for faster identification at airports and hotels in the region.

K_{21} – digital technologies help reduce the negative impact of tourism on the environment in this region.

K_{22} – the future of the tourism industry in this region depends on the development of digital technologies.

The following approach is used to fuzzify the input linguistic considerations: the linguistic statements of the respondents for each criterion are transformed into quantitative assessments by assigning the corresponding numerical value δ. This process is carried out using the following characteristic function:

$$\delta = \begin{cases} \delta_1 = 1 \quad if \quad \text{"Strongly disagree"}, \\ \delta_2 = 2 \quad if \quad \text{"Disagree"}, \\ \delta_3 = 3 \quad if \quad \text{"Neither agree nor disagree"}. \\ \delta_4 = 4 \quad if \quad \text{"Agree"}, \\ \delta_5 = 5 \quad if \quad \text{"Strongly agree"}. \end{cases} \tag{2}$$

Next, the sum of the values of quantitative assessments is calculated by respondent P:

$$\varepsilon(p_j) = \sum_{i=1}^{m} \delta_{ij}, j = \overline{1, n}. \tag{3}$$

According to the given evaluation criteria $\varepsilon(p_j) \in [22; 110]$.

For a normalised quantitative assessment of the digital transformation of tourism, it is necessary to model the uncertainty of the "value is greater" type. This is done through the intellectual analysis of knowledge using S-shaped membership functions, such as S-linear, harmonic S-spline, quadratic S-spline, etc. In this study, for example, the harmonic S-spline is represented by the following analytical formula:

$$\mu(p_j) = \begin{cases} 0, & \varepsilon(p_j) < 22; \\ \frac{1}{2} + \frac{1}{2} cos\left(\frac{\varepsilon(p_j) - 110}{88} \cdot \pi\right); & 22 \leq \varepsilon(p_j) < 110; \\ 1, & \varepsilon(p_j) \geq 110. \end{cases} \tag{4}$$

Next, a generalised assessment of the digital transformation of tourism in the studied region is calculated:

$$\mu(R) = \frac{1}{m_R} \sum_{j=1}^{n} \mu(p_j). \tag{5}$$

The $\mu(R)$ score will approach 1 when respondents are satisfied with the effectiveness of digital solutions in the visited region R.

2.3. HM_{dt} – hybrid decision support model for the socio-economic impact of the digital transformation of tourism

Let experts in the field of tourism express their linguistic considerations Λ regarding the level of digital transformation of tourism for the studied region R. For this, a term set of

linguistic variables $\Lambda = \{\Lambda_1; \Lambda_2; \Lambda_3; \Lambda_4; \Lambda_5\}$ is proposed, where: Λ_1 – "high level"; Λ_2 – "level above average"; Λ_3 – "average level"; Λ_4 – "level below average"; Λ_5 – "low level".

In the following, a hybrid model is presented that provides for determining the linguistic level of the socio-economic impact of the digital transformation of the tourism industry in the region. The peculiarity of this model is the combination of two approaches: on the one hand, a generalised assessment of the process of digital transformation of tourism in the studied region is considered, and on the other hand, an expert analysis of the level of digital maturity of the tourism sector based on qualitative indicators. Such integration allows for obtaining more accurate assessment results since it combines quantitative objective data and subjective expert assessment. To derive the linguistic level, it is proposed to use fuzzy logical inference, which is based on the S-shaped membership function:

$$t_\varphi(R) = \begin{cases} \frac{1}{5}\left(\sqrt{\frac{\mu(R)}{2}} + (5-\varphi)\right), & 0 \le \mu(R) \le 0.5; \\ \frac{1}{5}\left((6-\varphi) - \sqrt{\frac{1-\mu(R)}{2}}\right), & 0.5 < \mu(R) \le 1. \end{cases} \quad (6)$$

Where $\varphi = 1, 2, 3, 4, 5$, and its choice depends on the linguistic reasoning of the expert $\Lambda_1; \Lambda_2; \ldots; \Lambda_5$. As a result, $t(R) \in [0; 1]$ is obtained – a quantitative assessment of the socio-economic impact of the digital transformation of the tourism industry in the region.

Finally, the linguistic level of the socio-economic impact of the digital transformation of the tourism industry in the region is derived – T_{dt}. It is formalized using five levels $T_{dt} = \{T_1; T_2; \ldots; T_5\}$ and compared with the quantitative assessment $t(R)$:

If $t(R) \in (0.8; 1]$ then T_1: Very high level. Digital transformation has significantly changed the socio-economic landscape of the region, ensuring the full integration of advanced technologies into the tourism industry, process automation, and maximum convenience for visitors.

If $t(R) \in (0.6; 0.8]$ then T_2: High level. Digital technologies are actively used in the tourism sector, contributing to the growth of the region's economy, improving the quality of services, and improving tourist comfort.

If $t(R) \in (0.4; 0.6]$ then T_3: Medium level. The region has implemented basic digital services (online booking, mobile applications for tourists, etc.) that improve the tourist experience, but their impact on socio-economic development remains moderate.

If $t(R) \in (0.2; 0.4]$ then T_4: Low level. The use of digital technologies is limited, online services are poorly developed, and their impact on the economy and social sphere of the region is minimal.

If $t(R) \in (0; 0.2]$ then T_5: Very low level. Digital transformation has practically no impact on the socio-economic development of the region, tourism services remain traditional, and digital tools are almost not used.

The system analyst can change the decision-making levels depending on the received real data. Using neural network tools, it is possible to perform automated determination of levels using machine learning methods. The obtained levels will correspond to the geographical features of the studied territory and will be stored in the knowledge base for further analysis and use.

3. Results

A hybrid decision support model for the socio-economic impact of digital transformation of tourism has been tested on real data in the Visegrad Group countries (Czech Republic, Hungary, Poland, Slovakia) [1]. The study is part of a comprehensive analysis of

attitudes towards tourism in the V4 countries. The data were collected in cooperation with various organizations through a questionnaire covering 132 questions in 16 blocks. 2,343 respondents were interviewed between March and December 2021. The sample meets statistical and demographic requirements. The following are excerpts from the evaluation in four regions from the V4 countries: R_1 – Bratislava Region (Slovakia), R_2 – Capital city Prague (Czech Republic), R_3 – Subcarpathian Voivodeship (Poland), R_4 – Budapest capital (Hungary).

Let the respondents express themselves on each evaluation criterion using a term set of linguistic variables L. For example, fragments of the input data are presented in Table 1. All other data are given in [1].

Table 1. Input data fragments

Criteria	$p_9(R_1)$	$p_{1667}(R_2)$	$p_{966}(R_3)$	$p_{1225}(R_4)$
K_1	Strongly agree	Disagree	Disagree	Strongly agree
K_2	Strongly agree	Agree	Strongly agree	Strongly agree
K_3	Strongly agree	Agree	Strongly agree	Strongly agree
K_4	Agree	Agree	Strongly agree	Agree
K_5	Agree	Agree	Strongly agree	Strongly agree
…	…	…	…	…
K_{22}	Strongly agree	Strongly agree	Strongly agree	Agree

After receiving input data from respondents, they are fuzzified using formula (2). Next, using formula (3), the sum of the values of quantitative estimates is calculated: $\varepsilon(p_9) = 107$; $\varepsilon(p_{1667}) = 83$; $\varepsilon(p_{966}) = 96$; $\varepsilon(p_{1225}) = 97$. After that, using formula (4), the normalised quantitative estimate of digital transformation is derived: $\mu(p_9) = 0.997$; $\mu(p_{1667}) = 0.785$; $\mu(p_{966}) = 0.939$; $\mu(p_{1225}) = 0.947$.

Next, using formula (5), a generalised assessment of the digital transformation of tourism in the studied region is calculated: $\mu(R_1)$ =0.784; $\mu(R_2)$ =0.788; $\mu(R_3)$ =0.815; $\mu(R_4)$ =0.763.

Let experts in the field of tourism express their linguistic considerations Λ regarding the level of digital transformation of tourism for the regions as follows: R_1 – "level above average" (Λ_2); R_2 – "high level" (Λ_1); R_3 – "average level" (Λ_3); R_4 – "level above average" (Λ_2).

Formula (6) provides a quantitative assessment of the socio-economic impact of the digital transformation of the tourism industry in the regions and compares it with the linguistic level:

$$R_1\colon t_2(R_1) = \frac{1}{5}\left(4 - \sqrt{\frac{1-0.784}{2}}\right) = 0.734;\ t_2(R_1) \in (0.6;\ 0.8] \text{ then } T_2\text{: High level.}$$

$$R_2\colon t_1(R_2) = \frac{1}{5}\left(5 - \sqrt{\frac{1-0.788}{2}}\right) = 0.935;\ t_1(R_2) \in (0.8;\ 1] \text{ then } T_1\text{: Very high level.}$$

$$R_3\colon t_3(R_3) = \frac{1}{5}\left(3 - \sqrt{\frac{1-0.815}{2}}\right) = 0.539;\ t_3(R_3) \in (0.4;\ 0.6] \text{ then } T_3\text{: Medium level.}$$

$$R_4\colon t_2(R_4) = \frac{1}{5}\left(4 - \sqrt{\frac{1-0.763}{2}}\right) = 0.776;\ t_2(R_4) \in (0.6;\ 0.8] \text{ then } T_2\text{: High level.}$$

The results of the study confirmed the effectiveness of the hybrid model for assessing the digital transformation of tourism. Testing on data from the Visegrad Group countries showed that the calculated indicators correspond to expert assessments. The model allows for a more accurate determination of the level of digital transformation, contributing to informed management decision-making.

4. Discussion

This paper presents a hybrid model designed to evaluate the socio-economic impact of digital transformation in tourism. It synthesises two key sources of information: subjective assessments from tourists regarding the effectiveness of digital solutions, and expert evaluations of regional digital maturity in the tourism sector. The model includes an information module to capture perceptions of digital transformation and a hybrid decision support module for aggregating and interpreting the data.

An empirical example was conducted using data from four regions across the Visegrad Group (V4): Bratislava Region (Slovakia), Prague (Czech Republic), Subcarpathian Voivodeship (Poland), and Budapest (Hungary). These case studies demonstrate the model's adaptability to varying regional contexts and its ability to generate linguistic and numerical assessments that reflect the level of digital adoption and its broader socio-economic consequences.

The methodology is grounded in fuzzy set theory, which is well-suited for handling uncertainty, especially in subjective responses and expert judgments. It enables the transformation of linguistic inputs into quantitative outputs using membership functions and rule-based inference. This dual approach bridges qualitative insights with measurable outcomes, enhancing the interpretability and robustness of the findings.

The strength of the model lies in its flexibility and scalability. It does not rely on a fixed number of evaluation criteria, allowing analysts to tailor the system to specific research or policy needs. Moreover, by incorporating real user experiences and expert assessments, the model ensures both practical relevance and contextual accuracy. The intelligent knowledge analysis mechanism further enhances decision-making, allowing for nuanced interpretation of complex socio-economic patterns.

A notable limitation of the study is the use of different types of membership functions, which may introduce variation in the interpretation of digital transformation levels. Furthermore, expanding the model's application beyond the V4 countries could yield additional insights and might necessitate recalibration to account for regional differences in digital infrastructure or tourism dynamics. Nonetheless, these constraints do not compromise the validity of the results. The combination of a mathematically justified framework and experimental verification lends credibility and reliability to the findings.

Thus, the developed system is a universal tool for analysing digital changes in the tourism sector, considering multifactorial socio-economic aspects. It can be used for: monitoring the state of digital transformation in tourist regions; identifying priority areas of technological change; making informed management decisions at the regional and national levels; forming digital transformation strategies, considering local characteristics and needs.

The importance of the fuzzy approaches in solving sustainable tourism issues has been constantly increased. Although there are still no studies with a comprehensive evaluation of tourism sustainability through the fuzzy methods, this is due to the strong heterogeneity of this sector, the prevailing personalisation of services as well as the increasing demands of tourists on the provided tourism services. Exploring separate dimensions in tourism allows us to better understand significant sustainability processes and identify its key aspects, searching for their interconnectedness and synergistic effects.

Ismail et al. (2025) applied fuzzy approaches to investigate the mutual relationships between environmental, economic, and sociocultural criteria to guide the decision-making and planning processes and thus, to support the development of sustainable tourism. Environmental and economic factors have been emerged as key causal criteria influencing the sociocultural outcomes of community-based tourism. Mohammed et al. (2023) applied fuzzy approaches to

solve the multi-criteria problem of selecting applications in smart e-tourism. Similarly, Alamoodi et al. (2022) applied fuzzy models to compare and to evaluate e-tourism applications. Although fuzzy approaches reveal the benefits and effects of different types of applications, the social aspects of application use, including digital literacy, perception of risks from digitalisation, and individuals' attitudes towards technologies, remain still not researched. Some authors apply fuzzy approaches as optimisation methods in solving transport problems with the aim of ensuring sustainable tourism (Chen et al. 2022), others see their benefit in examining the impact of retail and food and beverage services (Del Chiappa et al. 2016). While some studies apply fuzzy approaches within some phase of the sustainable tourism development processes, there are the studies that view sustainable tourism as a comprehensive dynamic system, influenced by many factors at the micro and macroeconomic levels. Ziyadin et al. (2019) also share this view and proposed economic-mathematical models of strategic management of sustainable tourism development based on the mathematical apparatus of fuzzy algebra in order to support decision-making processes. The created model was based on a combination of economic benefits outcomes with environmental and social indicators.

Although fuzzy approaches bring many effects for improving decision-making processes and facilitating the adaptation processes of new technologies, it is important to also appeal for the creation of support mechanisms for SMEs operating in the tourism sector. Governments should create policies that would support the strategic development of these enterprises and would create optimal conditions for the development of various forms of tourism depending on geographical possibilities and tourism potential. A very effective form in this process seems to be the creation of innovation laboratories, which Santarsiero et al. (2024) identify as key drivers of innovation for SMEs. Innovation laboratories can significantly increase the capacity of digital innovation, improve the processes of digital transformation, digital green innovation (Wan et al. 2024), and business model innovation within SMEs in tourism.

Based on solving partial issues of sustainable tourism through the fuzzy approaches, it is possible to observe the multidimensional characteristics of sustainable tourism that can support development of new fuzzy approaches. These will be necessary for exploring the comprehensive relationships between sustainability criteria. Based on them, stakeholders can make informed decisions to support the sociocultural, environmental, and economic growth of sustainable tourism. Further development of fuzzy methods and approaches will also require access to more deeply structured data and to creation of database systems at both the national and international levels. This will enable creation of a comparative basement for national and international benchmarking, aimed at creating innovative and effective policies to support sustainable tourism, which will also be beneficial in the processes of achieving the Sustainable Development Goals (SDGs).

Conclusion

In the context of modern digital transformation, which covers all sectors of the economy, tourism is one of the key areas of implementation of innovative technologies. This study was aimed at developing a hybrid decision support model for assessing the socio-economic impact of the digital transformation of tourism using the example of the Visegrad Group countries. The developed model combines quantitative and qualitative approaches, considering both subjective assessments of tourists and expert judgments of industry specialists.

The constructed information model (IM_{dt}) allowed for a structured collection of data on the assessment of the effectiveness of digital services based on respondent responses according to a defined set of criteria covering various aspects of digital interaction in tourism. In the future,

the use of fuzzification, normalisation and membership functions ensured the transition from linguistic statements to a quantitative generalised assessment of the level of digital transformation of the region.

The hybrid decision support model (HM_{dt}) allows for to combination of objective data with the results of expert analysis, which significantly increases the accuracy of determining the linguistic level of the socio-economic impact of digitalisation on the tourism industry of the region. Testing the model on data collected in the regions of the Visegrad Group countries confirmed its effectiveness. The results obtained ($\mu(R)$; T_{dt}) are consistent with expert judgments and demonstrate the possibility of applying the model in the practice of strategic planning and policy formation for the digital development of tourism.

Future research in this area should focus on the development of various decision-support systems for the development of regional tourism. In the future, for the practical application of the results of this study, the software will be created that will be used both to collect feedback from respondents and to support decision-making in the process of formulating policies aimed at improving the digital transformation of the tourism industry in the regions.

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