"Known Unknowns": Reducing Digital Inequalities in the Silver Economy

Mário L. D. José, Fernando A. F. Ferreira, Constantin Zopounidis, Michalis Doumpos, and Neuza C. M. Q. F. Ferreira

Abstract—**Because of the world's aging population, Europe's over-50 segment has grown significantly. This demographic trend has created a major economic opportunity known as the silver economy. Technology plays an important role in the development of products and services targeting this older market segment, yet technological innovation has compromised these individuals' quality of life by aggravating already existing social disparities. Limited access to and use of technology is known as digital inequality, which is a matter of growing concern that is pushing experts to develop initiatives that mitigate the impact of this disparity. However, decision makers first need to be fully aware of the challenges associated with this endeavor, which arise out of the inherent complexity of digital inequality and the uncertainty produced by technological disruptions. This study addresses this decision problem by adopting a constructivist, socio-technical approach that combines cognitive mapping and decision-making trial and evaluation laboratory techniques in a neutrosophic context. Data were collected from an expert panel with experience in real-world cases. The members analyzed different strategies and their effectiveness in terms of reducing digital inequalities in the silver economy. The results were analyzed and validated by the Head of Data and Analytics at Nippon Telegraph and Telephone Data Europe and Latin America. No prior research was found that has used the same combination of operational research methods to address this decision problem. The findings include recommendations for how to facilitate the development of initiatives that increase digital literacy in a silver economy context.**

Index Terms—**Cognitive mapping, decision-making trial and evaluation laboratory (DEMATEL), digital inequality, multiple criteria analysis, neutrosophic logic.**

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I. Introduction

The aging world population has considerably increased the number of individuals aged 50+ years in the European Union (EU) [1], which has had a significant economic and social impact. Products and services need to be created to meet the needs of this older market segment, so technology is crucial for the success of the new silver economy. Ongoing technological innovation has, however, only intensified many people's reduced access to and use of technology, which has, in turn, worsened previously existing social, cultural, socio-demographic, and geographical inequalities [2], [3]. This phenomenon is known as digital inequality, which is a complex problem due to the reciprocal influences between social disparity determining factors. Digital inequality significantly undermines senior citizens' use of technology, their access to the benefits derived from these tools in multiple areas (e.g., healthcare, mobility, or socialization), and thus these individuals' quality of life. Initiatives need to be implemented that can reduce these disparities [4], [5], [6].

Although a variety of existing studies and models have focused on improving strategies to reduce digital inequalities in the silver economy, this prior research suffered from several key limitations. The first is a lack of clarity regarding the way proposed initiatives reduce digital inequalities in this context, while the second is inadequate analysis of causal relationships between strategies [7]. To overcome these limitations, the present study adopted a constructivist approach to develop a multicriteria analysis system that supports decision making by identifying which initiatives can more effectively reduce digital disparities and examining the relevant cause-effect relationships. This research specifically sought to answer the following questions.

1) How can initiatives that reduce digital inequalities be identified, and how are these strategies interrelated?
2) Which initiatives have a significant enough impact that they should be given priority as part of efforts to reduce digital inequalities in the silver economy?

In addition, six supplementary objectives were pursued. First, a literature review was conducted of publications on the topic under study, and, second, a panel was formed of experts in relevant areas. Third, methods were applied that facilitated the panel members' sharing of knowledge and expertise in order to structure the decision problem and develop a cognitive map during two group work sessions. Fourth, these experts assessed the causal relationships identified between the real-world initiatives identified earlier in the structuring phase, using the decision-making trial and evaluation laboratory (DEMATEL) technique combined with neutrosophic logic. Fifth, neutrosophic values were defined and then aggregated after the second session. Last, a validation session was conducted with an external, neutral specialist to evaluate the potential implementation of the proposed analysis system in real-life decision making.

The methodology applied was based on a constructivist approach that combined cognitive mapping and DEMATEL in a neutrosophic context to overcome some of the limitations of prior research. As mentioned previously, these methods were utilized by a panel of experts in the research topic during two group sessions, which were held online due to the coronavirus disease-19 (COVID-19) pandemic. In the first session, cognitive mapping was applied so that, based on the panel's discussions, appropriate initiatives could be identified and included in a multicriteria evaluation system. In the second session, the DEMATEL technique was applied using neutrosophic logic to measure the truthfulness, falseness, and indeterminateness associated with the nature of decision making and to analyze the cause-effect relationships between the initiatives noted in the group cognitive map. This methodological framework facilitated the creation of a decision-support tool designed to determine which strategies reduce digital inequalities in a silver economy context.

The results make important contributions with regard to digital inequality among older people of which the first is a model that can represent this issue in the most complete, realistic, and intuitive way possible. Second, the techniques adopted overcome some limitations found in previous investigations by encouraging an expert panel to discuss and share different points of view based on their knowledge of and experience in this subject matter. Third, the methods applied pay attention to the uncertainty and indeterminateness inherent to experts' opinions, thereby offering added value by reflecting decision makers' different viewpoints and expertise more completely. Fourth, the proposed model ensures conscious decision making and thus supports competent professionals' efforts to develop initiatives that more effectively reduce digital inequality among older individuals. Last, no prior research was found that has used the same methodological combination in this study context, supporting the assumption that the proposed framework is a novelty in the fields of the silver economy and operational research/management science (OR/MS).

The rest of this article is organized as follows. The next section contextualizes concepts related to the silver economy, technology, and digital inequality. Section three discusses the methodologies adopted, while section four focuses on their application and main results. Finally, section five summarizes the insights gained, as well as offering suggestions for future research.

II. Related Literature and Research Gaps

The aging world population is an unprecedented phenomenon that has transformed societies due to increasing average life expectancy and decreasing fertility rates [1]. This demographic trend has led to a progressively more noticeable growth both in the number and relative proportion of the population segment aged +60 years worldwide, including a gradually rising number of people aged over 64 years and a shrinking working population [8]. As a result, individuals aged +50 years already constitute 39% of the European population [9], and this percentage is expected to rise to 46% by 2054 [10].

Due to these impacts, many organizations and researchers (e.g., [11], [12], [13]) think that population aging will compromise the sustainability of pension and healthcare systems, suggesting, on the one hand, that the only solution is to reduce the scope and scale of relevant systems. On the other hand, the World Health Organization [8] and the European Parliament [14] highlight the need to treat this phenomenon as an opportunity for economic growth that will require business and social innovations that must be underpinned by policy reforms and profound cultural changes [15]. Thus, the senior population's growing size constitutes a significant opportunity to leverage the silver economy. The latter *"encompasses a unique cross-section of economic activities related to* [the] *production, consumption, and trade of goods and services relevant for older people, both public and private, and including direct and indirect effects"* [9, p. 6].

The economic impacts of the silver economy can be quantified as follows. First, it represents a total consumption of around €3.7 trillion, which is expected to increase to €5.7 trillion in 2025. Second, this trend will add up to €6.4 trillion of the European gross domestic product (GDP) by 2025, which is equivalent to 31.5% of the GDP. Third, the labor gap will be reduced as a result of the 88 million jobs (i.e., 37.8% of all EU employment) associated with the silver economy by 2025 [9]. Last, public expenditure on health and pension systems will decrease as a consequence of an aging population more prone to illness [16]. The silver economy seeks to meet senior citizens' needs and cater to their consumption patterns through products and services. This part of the overall economy must include a more active aging policy [9], which is defined as *"the process of optimizing opportunities for health, participation and security in order to enhance quality of life as people age"* [17, p. 12]. To do this, the silver economy has to seek solutions that promote older individuals' access to healthcare and social services, extend senior citizens' participation in socioeconomic activities, and ensure the protection and care of people who have lost their autonomy [1].

This approach entails introducing innovative solutions (e.g., health monitors, smart homes, and autonomous vehicles) in distinct sectors (e.g., health, housing, tourism, leisure, and mobility), which are driven by technological change [7]. Technology is, therefore, a fundamental tool for creating products and services that improve older individuals' quality of life [14]. Technological innovation can contribute to more prosperous societies by meeting the needs of this market segment with the

TABLE I
PRIOR STUDIES: CONTRIBUTIONS AND LIMITATIONS

AUTHORS	METHODS	CONTRIBUTIONS	LIMITATIONS
Ordonez *et al.* [27]	Sociodemographic questionnaire and Addenbrooke's cognitive examination-revised	▪ The results highlight the role of initiatives in promoting digital skills among older people who use technology. ▪ Senior citizens' access to relevant information via computers stimulates their mental health and cognitive abilities.	▪ The sample size is quite small.
Lian and Yen [28]	Unified theory of acceptance and use of technology (UTAUT)	▪ The authors developed an analysis model to identify facilitating and hindering factors affecting older adults' online shopping.	▪ The findings cannot be extrapolated to represent all senior citizens due to the sample being restricted to elderly individuals in Taiwan with some degree of digital competence. ▪ The research did not cover all the drivers and barriers related to online shopping.
Cimperman *et al.* [29]	UTAUT	▪ This study proposed a model that anticipates acceptance behaviors among older users regarding future high-tech solutions still to be developed.	▪ This study is based on users' perceptions of a non-existent technology, which offers less assurance that this technology will actually be accepted. ▪ No in-depth analysis was conducted on age's moderating effect on causal relationships in the model.
Castilla *et al.* [30]	Technology acceptance model and focus group	▪ This study confirmed the usefulness of a social network with a linear navigation structure in terms of promoting digital skills acquisition among those aged +60 years.	▪ The minimum age range in the inclusion criteria was changed to adapt to the available sample. ▪ The sample excluded participants with severe physical or cognitive limitations or with extremely low academic qualifications, which prevented any analysis of the influence of variables such as age or academic qualifications on social network use. ▪ The results can only be generalized to elderly people living in rural areas.
Tirado-Morueta *et al.* [31]	UTAUT	▪ Programs promoting access to technology and digital literacy reduce the obstacles linked to age and fewer socioeconomic resources that limit digital inclusion.	▪ The reduced number of activities considered restricted the analysis of the participants' digital activities in their daily life. ▪ The data were collected with a self-administered questionnaire.
Tsertsidis *et al.* [32]	Literature review	▪ The results contribute to a better understanding of the factors determining the acceptance of digital technologies among senior citizens. ▪ The authors demonstrated the important role of digital-inclusion initiatives in increasing technology acceptance. ▪ This study confirmed older population segments' acknowledgement of technology's benefits.	▪ The literature review only covered studies conducted in the United States and Europe. ▪ The small sample size limits the results' extrapolation.
Kim and Feng [33]	Online survey and follow-up behavioral measurement	▪ Older adults show less reciprocity in online social interactions in comparison to young adults. ▪ The presence of digital skills has a positive impact on reciprocity behavior in online interactions among both young and older adults.	▪ The sample is quite small.

highest quality products and services at the lowest cost possible [18].

Technology's impact on current knowledge-based lifestyles is undeniable. Technological innovations have had a positive effect on people's connectivity, the dissemination of knowledge, and economic growth by improving production methods, consumption patterns, and economic structures [2], [19]. However, technology also has a negative impact because it is an *"active reproducer and potential accelerator of social inequality"* [20, p. 3]. Inequalities reflect existing differences in status, rights, and opportunities, which are determined by social, cultural, socio-demographic, and geographical factors [21]. In recent decades, gaps have opened up due to varying degrees of access to—and use of—information technologies [5], which makes a clear definition of digital inequality extremely important. This concept refers to differences in the material, cultural, and cognitive resources required to make good use of information and communication technologies (ICTs) [22], [23], as well as variations in individuals' capacity to translate their use of digital networks into tangible offline results [24].

Digital inequalities can take different forms that include, among others, the presence or absence of physical access, as well as its type and quality (i.e., whether devices are available and Internet connections provide access to the latest content) [24]. Another inequality is the absence of motivation due to limited digital experience, little interest, and even hostility toward ICTs. A third form of digital inequality is the degree of digital competence in terms of *"the use of computers to obtain, evaluate, store, produce, present and exchange information, communicate and participate in collaborative networks"* [25, p. 15]. Two more possible disparities are the (non)existence of opportunities to use ICTs and/or the (in)effective use of ICTs and inequalities regarding the benefits derived from using technology.

In recent decades, concerns about digital inequalities have increased, thereby reinforcing the need for research on this topic [23]. Various studies have identified a significant rise in these inequalities among older adults [4]. This population segment's quality of life can improve when technology is used [26], so the relevant experts must leverage the initiatives in place to reduce these inequalities in a variety of contexts (e.g., health, leisure, and social interactions). Digital inequality is a multidimensional phenomenon that reflects technological, economic, and social perspectives. Thus, related strategies should seek to reduce digital and offline disparities simultaneously. Designing successful initiatives in this area is a complex endeavor due to inequalities' multiple interlocking dimensions, technology's rapid evolution, and the range of areas in which strategies are applied. The impacts of these strategies should, therefore, be analyzed to ensure that interventions that do more to reduce digital inequality are prioritized. Previous studies of this topic and their respective contributions and limitations are presented in Table I.

The studies summarized in Table I cover a variety of attempts to reduce digital inequalities among older population groups.

The existing research has clearly made significant contributions to reducing these disparities, but limitations are also evident. As mentioned previously, these restrictions can be divided into two distinct groups: 1) the unclear way in which strategies to reduce digital inequalities are proposed; and 2) the absence of analyses of the dynamics of causal relationships between the suggested tactics. The present research thus assumed a constructivist stance, combining cognitive mapping and DEMATEL techniques in a neutrosophic context to develop a multicriteria analysis system that overcomes limitations identified in previous studies.

III. Methodological Background

Experts must often make decisions about how to solve complex problems (i.e., issues that involve judgments based on multiple criteria and various decision makers' values and preferences), but this process is conditioned by uncertainty and risk. To deal with these types of problems, various approaches have been developed to promote open communication between decision makers and improve their understanding of the problem at hand, thereby enhancing the quality of the final decision [34]. These methods imply the need to use techniques based on constructivist principles. These decision-making processes should include the following three phases:

1) structuring;
2) evaluation;
3) recommendation.

A. Problem-Structuring Methods (PSMs), Cognitive Mapping, and Neutrosophic Logic

The structuring phase seeks to transform a complex unstructured or semi-structured problem into a clear, transparent representation of its components for all those involved in the decision-making process. This recursive, dynamic procedure allows participants to assume a constructivist learning stance so that *"problem owners are encouraged to view the situation from different perspectives and to facilitate the synthesis of information"* [35, p. 2]. This phase focuses on making *"the problem under analysis* […] *comprehensible"* [36, p. 6], so the steps followed avoid any techniques that may oversimplify the decision problem in order to prevent the loss of valuable information.

PSMs seek *"to structure and tackle complex and uncertain problem situations through the use of group facilitation and participatory modelling"* [37, p. 1] as a way to generate models that help decision makers understand the relevant problems. This process elicits communication among the experts involved to ensure they *"learn about their own and other perspectives"* [38, p. 146]. To this end, PSMs facilitate the following:

1) a more holistic understanding of the decision problem;
2) the formulation of potential solutions;
3) the formation of a consensus (i.e., a shared awareness of stakeholders' different perspective) [39].

Among the existing PSMs, four methods stand out as the most useful in the present research context:

1) soft systems methodology;
2) strategic options development and analysis;
3) strategic choice approach;
4) cognitive mapping [40].

The current study applied cognitive mapping due to its ease of use and ability to include a broad set of criteria [35], [41]. This method was developed to facilitate group work in decision-making processes by promoting discussion among experts about the problem in question and building a visual representation of the ideas generated by group members [42], [43]. In addition, cognitive mapping helps decision makers identify and select the criteria to be included in the multicriteria analysis system [41]. Cognitive mapping thus has both a descriptive function (i.e., generating a visual representation that improves decision makers' understanding of a problem) and a reflection function (i.e., supporting the development of new ideas). However, the cognitive maps generated have been criticized for their inability to represent incomplete, imprecise, uncertain, and inconsistent information [44]. To compensate for this weakness, the present study also applied the principles of neutrosophic logic.

Smarandache developed the neutrosophic logic to overcome limitations linked to representations of indeterminateness. The author introduced the notion of neutrosophic logic as a way to strengthen the *"decision-making process* […] *by considering all aspects of decision*[s] *(i.e., agree, not sure and disagree)"* [45, p. 885]. According to this logic, opinions about the criteria identified can be treated as a logical variable x, which is represented as a neutrosophic set composed of the following three components:

1) the degree of truth (T);
2) the degree of indeterminacy (I);
3) the degree of falsity (F).

The total of the T, I, and F percentages assigned by decision makers can differ from 100%.

Neutrosophic components are also understood as any real standard or nonstandard subset of $[^{-}0, ^{+}1]$ (i.e., $T \rightarrow [^{-}0, ^{+}1]$; $I \rightarrow [^{-}0, ^{+}1]$; and $F \rightarrow [^{-}0, ^{+}1]$) [46]. This approach allows decision makers to quantify, for example, the possibility that a statement is true (i.e., T) as 0.5, its degree of uncertainty (i.e., I) as 0.2, and the possibility that the statement is false (i.e., F) as 0.6 (i.e., x (0.5, 0.2, 0.6)) [47].

Neutrosophic values were incorporated into the DEMATEL application during the second phase of the present empirical research (see Section IV-B). Subsequently, a crispification procedure was followed to obtain a single value for each assessment in question (i.e., transforming T, I, and F into a single value). Equation (1) was used to carry out the crispification of the neutrosophic weights:

$$w_k = \frac{1 - \sqrt{\left((1 - \mathrm{T}_k)^2 + (\mathrm{I}_k)^2 + (\mathrm{F}_k)^2\right)/3}}{\sum_{k=1}^{r}\left\{1 - \sqrt{\left((1 - \mathrm{T}_k)^2 + (\mathrm{I}_k)^2 + (\mathrm{F}_k)^2\right)/3}\right\}}. \tag{1}$$

Equation (1) can be applied as long as two conditions are respected, so that *"each $w_k = (T_k, I_k, F_k)$ is represented by a neutrosophic number"* [48, p. 85]. First, all weights should be greater than or equal to zero (i.e., $w_k \geq 0$), and, second, the crispified neutrosophic weights w of all assessments/comparisons have to add up to 1 (i.e., $\sum_{k=1}^{r} w_k = 1$, in which r represents the number of assessments conducted by the decision makers) [48].

Neutrosophic logic increases the *"interpretability of the uncertainty generated by* [...] *imprecise, inconsistent and incomplete information"* [49, p. 2]. In the current study, the combination of this approach with the DEMATEL technique contributed to a more realistic representation of the decision problem under research through the inclusion of uncertainty in the decision-making process.

B. DEMATEL

DEMATEL is a multicriteria decision analysis technique that helps decision makers resolve complex decision problems by promoting their understanding of the causal relationships between multiple criteria. Developed in the 1970s by Gabus and Fontela [50], this OR/MS method *"is considered one of the best models to visualize and solve the complicated interrelationship*[s] *among factors"* [51, p. 340] using a structural model and the knowledge of a group of experts. DEMATEL generates graphical representations of the path and intensity of direct and indirect cause-effect relationships between multiple criteria and identifies critical factors (i.e., the variables with the most impact on the decision problem's context) [51].

DEMATEL applications begin with the quantification of factors' direct influence on each other by a group of experts E who evaluate a complex problem involving n factors. Each decision maker creates a direct matrix $n \times n$, in which each value represents what the experts think is the strength of each determinant's direct influence on the remaining factors, denoted as w_{ij} (i.e., the extent to which factor i affects factor j). This procedure uses a five-point scale developed by Gabus and Fontela [50] (i.e., 0 = "no influence"; 1 = "little influence"; 2 = "medium influence"; 3 = "strong influence"; and 4 = "very strong influence"). The result is initial direct-influence matrix Z (i.e., $Z = [a_{ij}]\ n \times n$), in which the matrix's diagonal values are 0 when i=j. Next, the normalized direct-influence matrix X is constructed by normalizing the matrix Z:

$$X = \frac{Z}{\lambda}, \lambda = \max\left(\max_{1\leq i\leq n}\sum_{j=1}^{n} z_{ij}, \max_{1\leq j\leq n}\sum_{i=1}^{n} z_{ij}\right). \quad (2)$$

Equation (3) subsequently facilitates the construction of total-relation matrix $T\ n \times n$:

$$T = \lim_{h\to\infty}\left(X^1 + X^2 + \ldots + X^h\right) = X\,(I - X)^{-1} \quad (3)$$

in which I is an identity matrix and $h \to \infty$. Vectors R and C are defined by (4) and (5), which represent the totals of total-relation matrix T's rows and columns, respectively:

$$R = \left[\sum_{j=1}^{n} t_{ij}\right]_{n\times 1} = [r_i]_{n\times 1} \quad (4)$$

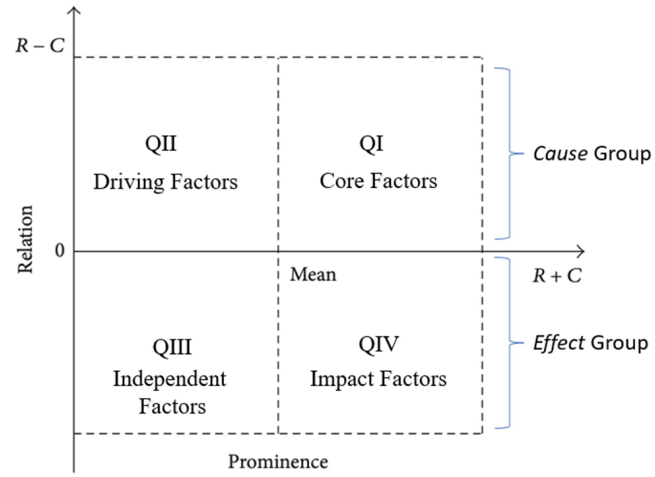

Fig. 1. Influential relationship map quadrants (source: Adapted from Si et al. [53]).

$$C = \left[\sum_{i=1}^{n} t_{ij}\right]'_{1\times n} = [c_j]'_{1\times n}. \quad (5)$$

In (4), r_i represents the total of the ith row of matrix T and thus reflects the total direct and indirect effects that factor F_i has on other criteria. Similarly, c_j is the total of the jth column of matrix T, which describes the total direct and indirect effects that factor F_j receives from other criteria [36]. To eliminate elements of relatively little significance in matrix T, a threshold (α) value is calculated:

$$\alpha = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}[t_{ij}]}{N}. \quad (6)$$

The α value is obtained by averaging all the values of the elements in matrix T, which is done by adding the values and dividing the total by the number ($N = n^2$) of items in matrix T [36]. Finally, an influential relationship map (IRM) (i.e., DEMATEL diagram of cause–effect relationships) is generated that visualizes the factors' degree of impact on the decision-support model by mapping the coordinate sets $(r_i + c_i,\ r_j - c_j)$ [52]. As Fig. 1 shows, the horizontal axis represents $R + C$ (i.e., termed "prominence") and the vertical axis is $R – C$ (i.e., termed "relationship"). These axes define four quadrants. Quarter one (QI) includes the core factors, which are considered to have high prominence and strong relationships. Quarter two (QII) contains the driving factors (i.e., determinants), which have less prominence but strong relationships. Quarter three (QIII) includes the independent factors, which have less prominence and weak relationships. Finally, quarter four (QIV) encompasses the impact factors, which have high prominence but weak relationships.

IV. Application and Results

To address some of the limitations of previous studies, this research sought to apply a more empirically robust approach based on a combination of OR/MS methods and techniques.

Cognitive mapping was used in the structuring phase, followed by DEMATEL in a neutrosophic environment in the evaluation phase. These methods facilitated the development of a decision-support model that provides a fuller understanding of how to reduce digital inequalities in a silver economy context and identifies initiatives with greater or lesser impact on these disparities.

A. Contextual Framework

Structuring a problem *"is most effective when open communication between participants with different perspectives is possible"* [38, p. 146]. A panel of experts *"with specialized know-how in the area under study"* [43, p. 13] first has to be recruited. According to Braga et al. [36] and Carayannis et al. [42], decision-maker panels should have from 5 to 12 members. Thus, in the present study, the panel was composed of 10 professionals with expertise in relevant subjects, who worked in different areas (i.e., education, health, public administration, and project management) and in different regions of Portugal. In addition, two older adults were present—one still working and the other retired. Due to the constructivist and process-oriented nature of the present study, the group meetings were not organized to achieve representativeness or make generalizations but rather to promote a strong focus on process [54], [55].

The two sessions corresponded to a separate phase of the decision-making process (i.e., structuring and evaluation) and lasted approximately four hours. The sessions were held online to comply with the restrictions associated with the COVID-19 pandemic and to facilitate the participation of experts from different regions of Portugal. Notably, all 10 decision makers were present in the first session, but only 8 could attend the second session, which met the essential conditions for the study to continue (i.e., a panel consisting of 5 to 12 members) [43]. A facilitator and a technical assistant were also present to help the decision makers interact in the online platforms and to record the outcomes.

B. Methodological Application

The first session focused on structuring the decision problem under analysis (i.e., initiatives that best reduce digital inequalities in a silver economy context). The group work thus centered around collecting the elements needed to create a cognitive map and *"capture and represent* […] *various points of view"* [56, p. 653]. The session started with a brief overview of the conceptual framework underlying the methodologies to ensure the experts were fully informed about the methods before starting the structuring phase. Next, the following trigger question was asked of the decision makers to stimulate their interaction and discussion: *"Based on your values and professional experience, what initiatives do you think could increase the integration of individuals over 50 years old into the digital society?"* To help the panel answer this question, the "post-its technique" was used to encourage them to write *"on post-it notes the decision criteria that* […] *are important to the decision problem under discussion"* [43, p. 14]. This procedure was carried out in the Miro platform (see https://www.miro.com). The decision makers recorded each initiative on a separate note. Every post-it also included a plus (+) or minus (–) sign to indicate a positive (i.e., the initiative reduces digital inequality) or negative (i.e., the initiative increases digital inequality) causality relationship, respectively. A significant number of strategies were identified (i.e., around 180) before this procedure was considered to be complete. The second step consisted of organizing the post-its (i.e., initiatives) according to the specific areas covered (i.e., clusters). The panel members were tasked with placing all the post-its into the appropriate clusters—with the option of assigning initiatives to more than one cluster when needed. After a lengthy discussion, the five clusters identified were labeled as follows: *Digital Literacy* (C1); *Strategy- and Results-Based Monitoring* (C2); *Motivations* (C3); *Resources* (C4); and *Relationships* (C5). The last procedure comprised an internal analysis of each cluster in which the decision makers ranked initiatives according to their relative importance. That is, the items considered to be the most significant were placed at the top, while the intermediate ones appeared in the middle and the least important at the bottom. At the same time, they were able to eliminate repeated initiatives.

After the first session ended, the results (i.e., strategies and clusters identified) were input into the *Decision Explorer* software (http://www.banxia.com), which generated a group cognitive map. To ensure that this cognitive map was representative of the panel's opinions, the members collectively confirmed the contents were correct at the beginning of the second work session.

The second meeting focused on a more detailed evaluation of the initiatives listed in the previous phase. After the map was validated, a brief presentation was given of the methodological approach (i.e., the DEMATEL technique integrated with neutrosophic logic). The facilitator clarified that, because uncertainty exists in the decision-making process, neutrosophic logic is applied as it is *"designed to facilitate* [decision makers'] *understanding of indeterminate or inconsistent information"* [47, p. 5].

The first task of this session was thus to conduct an analysis of the clusters' degree of influence on each other and quantify these relationships using the standard DEMATEL scale (i.e., ranging from 0 or "no influence" to 4 or "very strong influence"). The expert panel then had to identify the probability of their judgments being true (i.e., T), uncertain (i.e., I), or false (i.e., F) in the form of percentages to determine the inter-cluster relationships' neutrosophic values. This procedure continued on with the panel's selection of the most important initiatives within each cluster using the nominal group technique (NGT) and the multivoting method. The decision makers then constructed and analyzed six direct-influence matrices (i.e., one matrix of the relationships between the clusters and five matrices that reflected the clusters' internal links). After the second session ended, the neutrosophic values were subjected to crispification. The next subsection presents the results obtained during and after the two group sessions.

C. Analysis of Results

After the methodological approach was applied, the results needed to be analyzed to create the final decision-support system. As previously mentioned, the first-session output was used

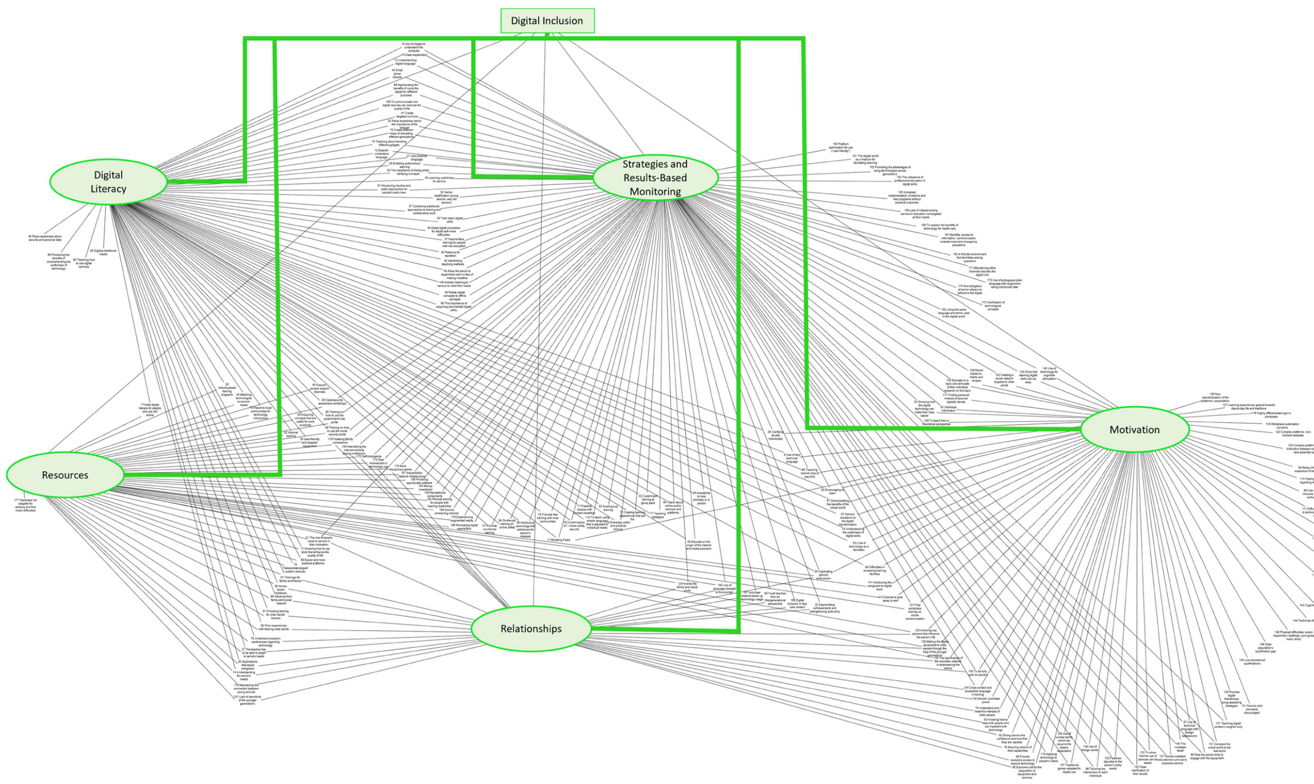

Fig. 2. Group cognitive map.

TABLE II
IDENTIFIED CLUSTERS

C1	Digital Literacy
C2	Strategy- and Results-Based Monitoring
C3	Motivations
C4	Resources
C5	Relationships

TABLE III
MATRIX WITH INFLUENCE AND NEUTROSOPHIC VALUES FOR CLUSTERS

	C1	**C2**	**C3**	**C4**	**C5**
C1	–	2(0.75, 0.5, 0.75)	3(0.65, 0.5, 0.15)	3(0.9, 0.2, 0.3)	3.5(0.9, 0.1, 0.3)
C2	1.5(0.5, 0.9, 0.3)	–	1(0.8, 0.2, 0.2)	3(0.9, 0.2, 0.3)	2(0.6, 0.3, 0.4)
C3	4(0.9, 0.1, 0.1)	2(0.7, 0.1, 0.3)	–	2(0.8, 0.2, 0.1)	2(0.8, 0.1, 0.1)
C4	3.5(0.9, 0.2, 0.1)	2(0.8, 0.1, 0.1)	1.5(0.7, 0.5, 0.3)	–	1(0.8, 0.5, 0.2)
C5	3(0.7, 0.5, 0.3)	2(0.6, 0.5, 0.4)	3(0.7, 0.2, 0.4)	1(0.6, 0.4, 0.3)	–

to generate a group cognitive map. The final version of this map after the decision makers' validation is shown in Fig. 2, which includes 182 evaluation criteria and five clusters (size restrictions prevent a better visualization, but an editable version can be obtained upon request). The identified initiatives and clusters were essential to ensure the evaluation phase was successfully completed.

As mentioned previously, the second group session produced six direct-influence matrices. The first matrix focused on the relationships between the identified clusters (see Table II). The neutrosophic values assigned by the decision makers (i.e., values assigned to the relationships including the probability of the respective judgment being either true (T), uncertain (I), or false (F) in the form of percentages) are shown in Table III.

TABLE IV
CRISP NEUTROSOPHIC VALUES FOR CLUSTERS

	Relationship Analyzed	DEMATEL Scale (X)	Neutrosophic Values			Neutrosophic Crispification		
			T	I	F	Crispification Equation Numerator	Crisp Weight W	Final Value in Matrix Z
Cluster Matrix	C1–C2	2.0	0.75	0.50	0.75	0.45994	0.03255	0.92
	C1–C3	3.0	0.65	0.50	0.15	0.63714	0.04509	1.91
	C1–C4	3.0	0.90	0.20	0.30	0.78398	0.05548	2.35
	C1–C5	3.5	0.90	0.10	0.30	0.80851	0.05722	2.83
	C2–C1	1.5	0.50	0.90	0.30	0.38086	0.02695	0.57
	C2–C3	1.0	0.80	0.20	0.20	0.80000	0.05662	0.80
	C2–C4	3.0	0.90	0.20	0.30	0.78398	0.05548	2.35
	C2–C5	2.0	0.60	0.30	0.40	0.63032	0.04461	1.26
	C3–C1	4.0	0.90	0.10	0.10	0.90000	0.06369	3.60
	C3–C2	2.0	0.70	0.10	0.30	0.74834	0.05296	1.50
	C3–C4	2.0	0.80	0.20	0.10	0.82679	0.05851	1.65
	C3–C5	2.0	0.80	0.10	0.10	0.85858	0.06076	1.72
	C4–C1	3.5	0.90	0.20	0.10	0.85858	0.06076	3.01
	C4–C2	2.0	0.80	0.10	0.10	0.85858	0.06076	1.72
	C4–C3	1.5	0.70	0.50	0.30	0.62141	0.04398	0.93
	C4–C5	1.0	0.80	0.50	0.20	0.66834	0.04730	0.67
	C5–C1	3.0	0.70	0.50	0.30	0.62141	0.04398	1.86
	C5–C2	2.0	0.60	0.50	0.40	0.56411	0.03992	1.13
	C5–C3	3.0	0.70	0.20	0.40	0.68909	0.04877	2.07
	C5–C4	1.0	0.60	0.40	0.30	0.63032	0.04461	0.63
$\sum_{k=1}^{r} w_k^c = 1$, which complies with Equation (1) conditions			Crispification equation denominator			14.130253	1	

TABLE V
DIRECT-INFLUENCE MATRIX Z FOR CLUSTERS

	C1	C2	C3	C4	C5	TOTAL
C1	0.00	0.92	1.91	2.35	2.83	8.01
C2	0.57	0.00	0.80	2.35	1.26	4.98
C3	3.60	1.50	0.00	1.65	1.72	8.47
C4	3.01	1.72	0.93	0.00	0.67	6.33
C5	1.86	1.13	2.07	0.63	0.00	5.69
TOTAL	9.04	5.27	5.71	6.98	6.48	

The neutrosophic matrix values were subsequently subjected to crispification, producing the results included in Table IV.

As shown in Table IV, the final values used to construct the DEMATEL direct-influence matrix were obtained by multiplying the crispification equation numerator by the degree of influence assigned by the decision makers. That is, the DEMATEL scale value (x) was determined for each cause-effect relationship. Using the results in Table IV, all $x(T, I, F)$ values in the matrix were processed to produce the initial direct-influence matrix (see Table V) in two steps. The first was to apply crispification using (1) (see Section III-A) to the neutrosophic values T, I, and F in order to obtain crispified neutrosophic values. The second step was to multiply each crispified neutrosophic value by the relevant degree of influence x to estimate the final crisp weight. These crisp values were then incorporated into the initial direct-influence matrix presented in Table V. Equation (2) (see Section III-B) was used to do the intermediate calculations and produce normalized direct-influence matrix X (see Table VI).

Total-relation matrix T, as mentioned previously, clarifies the relationships between the various clusters. This matrix was

TABLE VI
NORMALIZED DIRECT-INFLUENCE MATRIX X FOR CLUSTERS

Max.	9.04	8.47
1/max.	0.11061293	0.118100
1/s	0.11061293	

	C1	**C2**	**C3**	**C4**	**C5**
C1	0.0000	0.1018	0.2114	0.2602	0.3130
C2	0.0632	0.0000	0.0885	0.2602	0.1394
C3	0.3982	0.1656	0.0000	0.1829	0.1899
C4	0.3324	0.1899	0.1031	0.0000	0.0739
C5	0.2062	0.1248	0.2287	0.0697	0.0000

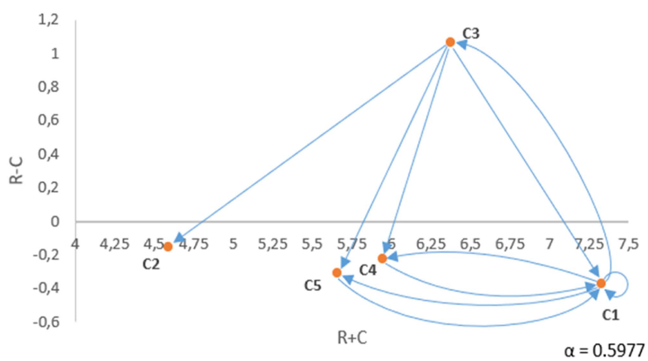

Fig. 3. Influential relationship map for clusters.

constructed using (3) (see Section III-B) and three auxiliary matrices: I; $I - X$; and $I - X^{-1}$. The results are shown in Table VII.

The R values based on Matrix T were obtained by applying (4) (see Section III-B). These values represent each cluster's total influence on the others (see Table VIII). C3 exerts the greatest influence on all the other clusters (i.e., 3.7188). The C values were calculated using (5) (see Section III-B) to quantify the total influence that the other four clusters have on a given cluster. C1 receives more effects from all the others (i.e., 3.8479).

An α value of 0.5977 was obtained using (6) (see Section III-B). This value expediated the identification of the relationships with greater influence and the highest values (i.e., the cells with a value greater than α and marked in green in matrix T) (see Table VII). The results are reflected in the DEMATEL diagram (i.e., IRM) shown in Fig. 3. Table VIII lists the R, C, $R + C$, and $R - C$ values. Fig. 3 reveals the distribution of the five clusters along the IRM axes and the clusters' cause-effect relationships.

The horizontal axis (i.e., $R + C$) presents the clusters by order of prominence since each cluster's $R + C$ value represents the total effects that cluster gives to and receives from the other clusters. A higher value on this axis thus corresponds to a higher impact on the proposed decision-support model. In this case, C1 is the most important cluster in this study with the highest $R + C$ value (i.e., 7.3259), while C2 is identified as the least important, with the lowest $R + C$ value (i.e., 4.5876).

The relative importance of the five clusters is visualized as the cause-effect relationships in Fig. 3, which are, in descending order, as follows: C1 > C3 > C4 > C5 > C2.

The vertical axis (i.e., $R - C$), in turn, indicates the degree of influence that each cluster has within the system in relation to the other factors. This axis divides the clusters up according to their value and position into the causes group (i.e., when $R - C > 0$) or effects group (i.e., when $R - C < 0$). Most of the clusters belong to the effects group as they have a negative $R - C$ value (i.e., weak relationships within the analysis system so that this group is overall influenced by the remaining cluster). Only one cluster belongs to the causes group (i.e., C3), which exerts direct influence on the other clusters. Finally, the diagram confirms that C3 contains core factors, C2 and C5 independent factors, and C1 and C4 impact factors.

An identical procedure was followed to analyze the initiatives within each cluster, starting with C1. Table IX shows the initiatives considered the most important strategies in this cluster, hereafter referred to as subcriteria (SCs) to differentiate them from the five cluster heads. Table X shows the DEMATEL and neutrosophic values assigned by the decision makers for the first cluster, while Table XI presents these values after crispification.

The information presented in Table XII verifies that SC14 exerts the most influence on the other initiatives, with an R value of 3.9344. In contrast, SC8 is the most affected by all the other SCs, with a C value of 3.5647.

The IRM diagram presented in Fig. 4 indicates that the C1 SCs should be prioritized as follows: SC12 > SC8 > SC16 > SC14 > SC7 > SC18 > SC31. SC12 is the most significant initiative, with an $R + C$ value of 7.1141, and SC18 is the least important as its $R + C$ value is 2.7650. SC12, SC14, SC16, SC18, and SC31 present positive $R - C$ values, so they appear in the IRM's upper half and constitute the causes group. That is, these SCs influence the other initiatives more than they are influenced by them. SC7 and SC8 are situated in the bottom half of the diagram (i.e., with negative $R - C$ values), thereby forming the effects group (i.e., SCs mostly influenced by other factors). Finally, the IRM shows that SC12, SC14, and SC16 are core factors in QI; SC18 and SC31 are driving factors in QII; SC7 is an independent factor in QIII; and SC8 is an impact factor in QIV.

TABLE VII
TOTAL-RELATION MATRIX T FOR CLUSTERS

	C1	C2	C3	C4	C5
C1	1.0000	0.0000	0.0000	0.0000	0.0000
C2	0.0000	1.0000	0.0000	0.0000	0.0000
C3	0.0000	0.0000	1.0000	0.0000	0.0000
C4	0.0000	0.0000	0.0000	1.0000	0.0000
C5	0.0000	0.0000	0.0000	0.0000	1.0000

$I - X$

	C1	C2	C3	C4	C5
C1	1.0000	–0.1018	–0.2114	–0.2602	–0.3130
C2	–0.0632	1.0000	–0.0885	–0.2602	–0.1394
C3	–0.3982	–0.1656	1.0000	–0.1829	–0.1899
C4	–0.3324	–0.1899	–0.1031	1.0000	–0.0739
C5	–0.2062	–0.1248	–0.2287	–0.0697	1.0000

$(I - X)^{-1}$

	C1	C2	C3	C4	C5
C1	1.7184	0.5301	0.6708	0.7631	0.7956
C2	0.5191	1.2823	0.3866	0.5712	0.4570
C3	1.0590	0.6016	1.5304	0.7651	0.7626
C4	0.8321	0.5145	0.4964	1.4785	0.5358
C5	0.7193	0.4428	0.5711	0.5067	1.4328

Matrix T

	C1	C2	C3	C4	C5	R
C1	0.7184	0.5301	0.6708	0.7631	0.7956	3.4781
C2	0.5191	0.2823	0.3866	0.5712	0.4570	2.2162
C3	1.0590	0.6016	0.5304	0.7651	0.7626	3.7188
C4	0.8321	0.5145	0.4964	0.4785	0.5358	2.8574
C5	0.7193	0.4428	0.5711	0.5067	0.4328	2.6727
C	3.8479	2.3714	2.6554	3.0846	2.9838	

TABLE VIII
INTERACTIONS BETWEEN CLUSTERS

	R	C	$R + C$	$R – C$
C1	3.4781	3.8479	7.3259	–0.3698
C2	2.2162	2.3714	4.5876	–0.1552
C3	3.7188	2.6554	6.3742	1.0634
C4	2.8574	3.0846	5.9421	–0.2272
C5	2.6727	2.9838	5.6566	–0.3111

The SCs chosen for further analysis by the decision makers for C2 are listed in Table XIII. The neutrosophic and DEMATEL values assigned are shown in Table XIV. Table XV contains the matrix of crisp values.

The information presented in Table XVI reveals that SC23 exerts the most influence over the other initiatives, with an R value (i.e., total influence) of 5.2151. SC169, in contrast, is the most affected by all the other C2 SCs, with a C value of 5.4110. When these two values are added, SC23 stands out as the most important (i.e., $R + C = 9.7889$) as opposed to SC48, which is the least important (i.e., $R + C = 6.7111$).

The IRM in Fig. 5 confirms the following ranking according to greater priority: SC23 > SC20 > SC13 > SC169 > SC111 > SC114 > SC48. The causes group is made up of SC23, SC48, and SC111 as they have positive $R – C$ values and thus are primarily influencers. SC13, SC20, SC114, and SC169, in turn, belong to the effects group, with negative $R – C$ values. The C2 SCs are positioned according to how important their links are in the diagram shown in Fig. 5 and categorized as follows.

TABLE IX
MOST SIGNIFICANT SUBCRITERIA: DIGITAL LITERACY CLUSTER

SC7	Strengthening digital literacy among still active individuals
SC8	Using less technical language
SC12	Using easy-to-understand wording
SC14	Gaining a better understanding of seniors' needs
SC16	Discussing current topics: Internet of things, virtual reality, and cyber security
SC18	Providing everyday useful, practical training
SC31	Using more practical language

TABLE X
MATRIX WITH INFLUENCE AND NEUTROSOPHIC VALUES: DIGITAL LITERACY CLUSTER

	SC7	SC8	SC12	SC14	SC16	SC18	SC31
SC7	–	0.5(0.0, 0.9, 0.3)	0(0.8, 0.3, 0.2)	0(0.8, 0.3, 0.2)	1(0.8, 0.3, 0.2)	1(0.8, 0.3, 0.2)	1.5(0.6, 0.5, 0.4)
SC8	0(0.7, 0.8, 0.2)	–	4(0.8, 0.3, 0.25)	1(0.6, 0.5, 0.2)	2(0.6, 0.4, 0.3)	3(0.8, 0.5, 0.3)	4(0.8, 0.3, 0.25)
SC12	2.5(0.8, 0.3, 0.3)	3(0.7, 0.4, 0.35)	–	2.5(0.75, 0.35, 0.15)	3.5(0.7, 0.3, 0.1)	4(0.8, 0.2, 0.1)	3(0.7, 0.4, 0.35)
SC14	2(0.7, 0.2, 0.2)	4(0.85, 0.15, 0.2)	3.25(0.75, 0.2, 0.25)	–	2.5(0.75, 0.5, 0.2)	3.75(0.8, 0.2, 0.1)	3.25(0.75, 0.2, 0.25)
SC16	2(0.6, 0.5, 0.3)	4(0.8, 0.3, 0.1)	3.75(0.75, 0.25, 0.25)	2(0.6, 0.45, 0.35)	–	1.5(0.7, 0.5, 0.2)	3.75(0.75, 0.25, 0.25)
SC18	1.5(0.6, 0.6, 0.2)	3(0.75, 0.25, 0.15)	3(0.75, 0.25, 0.15)	1(0.65, 0.35, 0.3)	1.5(0.7, 0.3, 0.2)	–	3(0.75, 0.25, 0.15)
SC31	3(0.8, 0.3, 0.2)	3.5(0.75, 0.35, 0.35)	3(0.65, 0.3, 0.3)	3.5(0.7, 0.25, 0.2)	3(0.8, 0.3, 0.1)	4(0.75, 0.15, 0.2)	–

TABLE XI
DIRECT-INFLUENCE MATRIX *Z*: DIGITAL LITERACY CLUSTER

	SC7	SC8	SC12	SC14	SC16	SC18	SC31	TOTAL
SC7	0.00	0.10	0.00	0.00	0.76	0.76	0.85	2.47
SC8	0.00	0.00	2.99	0.61	1.26	1.93	2.99	9.78
SC12	1.82	1.94	0.00	1.84	2.62	3.31	1.94	13.47
SC14	1.52	3.33	2.49	0.00	1.64	3.10	2.49	14.57
SC16	1.18	3.14	2.81	1.20	0.00	0.97	2.81	12.11
SC18	0.85	2.33	2.33	0.67	1.09	0.00	2.33	9.60
SC31	2.29	2.38	2.05	2.61	2.35	3.18	0.00	14.86
TOTAL	7.66	13.22	12.67	6.93	9.72	13.25	13.41	

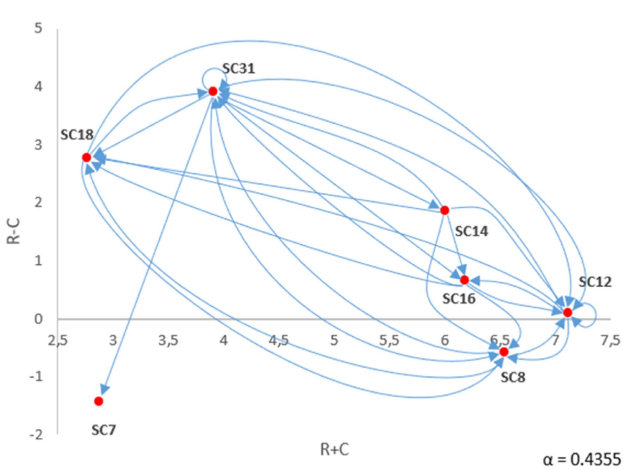

Fig. 4. Influential relationship map for digital literacy cluster.

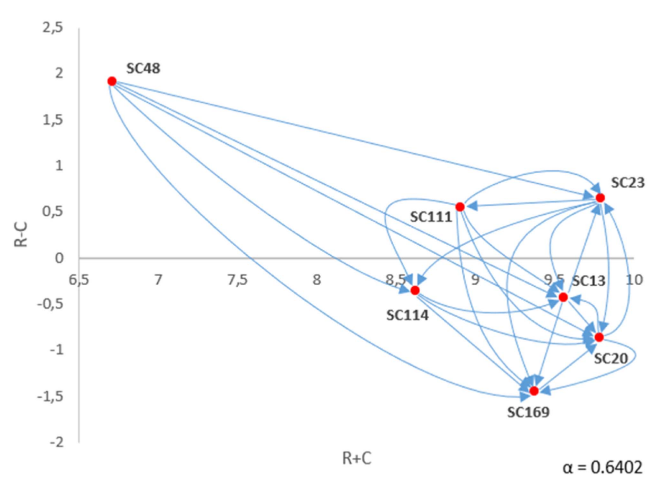

Fig. 5. Influential relationship map for strategy- and results-based monitoring cluster.

TABLE XII
CLUSTER 1: INTERACTION BETWEEN INITIATIVES

	R	*C*	*R* + *C*	*R* – *C*
SC7	0.7265	2.1478	2.8743	–1.4213
SC8	2.9796	3.5647	6.5444	–0.5851
SC12	3.6025	3.5116	7.1141	0.0908
SC14	3.9344	2.0740	6.0084	1.8603
SC16	3.4193	2.7595	6.1788	0.6598
SC18	2.7650	0.0000	2.7650	2.7650
SC31	3.9104	0.0000	3.9104	3.9104

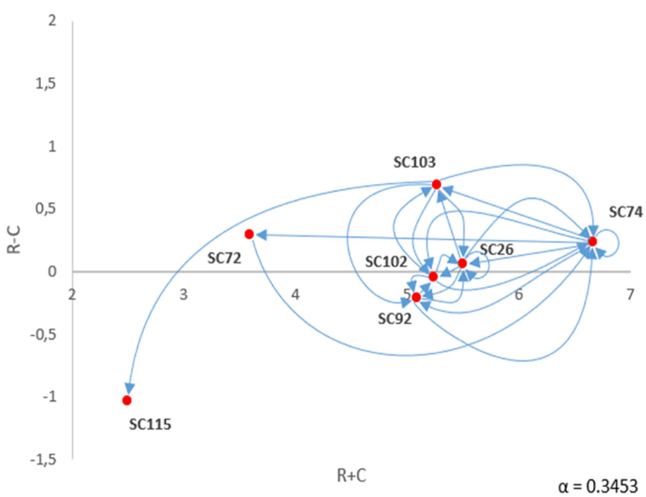

Fig. 6. Influential relationship map for motivations cluster.

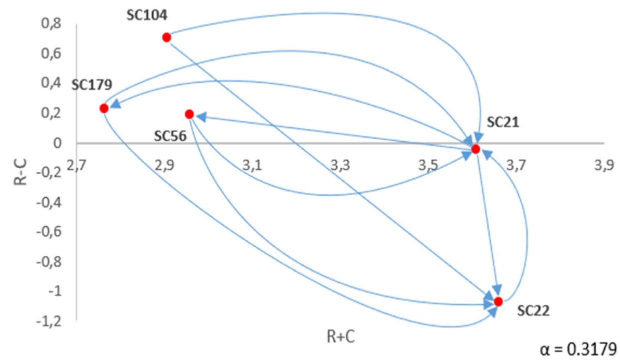

Fig. 7. Influential relationship map for resources cluster.

SC23 and SC111 are core factors in QI, while SC48 is a driving factor in QII. Finally, SC13, SC20, SC114, and SC169 are impact factors in QIV.

C3 was analyzed next based on the SCs presented in Table XVII. Table XVIII contains the DEMATEL and neutrosophic values assigned by the decision makers, and Table XIX is the initial direct-influence matrix.

According to Table XX, SC115 is the initiative that influences the other SCs the least ($R = 0.7336$), and it is the least important factor in the analysis system, with an $R + C$ value of 2.4998. SC74, however, is both the most influential strategy ($R = 3.4510$) and the most influenced by all other criteria ($C = 3.2181$). This SC is also the most important in the system as its $R + C$ value is 6.6691.

Fig. 6 clarifies these SCs' relative importance, ranking them as follows: SC74 > SC26 > SC103 > SC102 > SC92 > SC72 > SC115. The $R – C$ value defines each SC's degree of influence in the decision-support system compared to the other initiatives. Thus, the causes group (i.e., positive $R – C$ value) comprises SC26, SC72, SC74, and SC103. The effects group (i.e., negative $R – C$ value) includes SC92, SC102, and SC115. Finally, the diagram's quartiles show that SC26, SC74, and SC103 are core factors in QI; SC72 is a driving factor in QII; SC115 is an independent factor in QIII; and SC92 and SC102 are impact factors in QIV.

The SCs chosen as the most significant for C4 are given in Table XXI. The expert panel's assignment of neutrosophic values and the crisp values appear in Tables XXII and XXIII, respectively.

Table XXIV reveals that SC104 exerts the greatest influence on the other initiatives ($R = 1.803$), while SC22 receives the most effects from the other C4 SCs ($C = 2.366$). SC22, with the highest $R + C$ value, is the most important in the decision-support system, closely followed by SC21 (i.e., $R + C$ values of 3.6604 and 3.6090, respectively). At the opposite extreme is SC179 with an $R + C$ value of 2.7638.

As Fig. 7 shows, the SCs' order of importance should be as follows: SC22 > SC21 > SC56 > SC104 > SC179. According to the $R – C$ values, the causes (i.e., positive values) include SC56, SC104, and SC179, while SC21 and SC22 are effects. The distribution of SCs in the IRM quartiles shows that SC56, SC104, and SC179 are driving factors in QII and SC21 and SC22 are impact factors in QIV.

The analysis of C5 was based on the most significant SCs listed in Table XXV. Table XXVI is the matrix with the influence and neutrosophic values assigned by the decision-maker panel, while Table XXVII comprises the initial matrix of the crisp values obtained.

Based on the data shown in Table XXVIII, SC35 has the strongest effect on the other C5 SCs, with the highest R value (i.e., 3.6033). SC19 is, in contrast, the most influenced by the other factors, with a C value of 3.5229. The latter initiative is also more important compared to the others (i.e., $R + C = 6.7463$) within the analysis system. SC124 has an $R + C$ value of 4.1023, so this factor is the least important. The priority that should be given to this cluster's SCs is defined by adding R and C, which produced the following ranking of the five interventions: SC19 > SC27 > SC35 > SC79 > SC124.

Except for SC35 and SC124, which belong to the causes group (i.e., positive $R – C$ values), the remaining factors (i.e., SC19, SC27, and SC79) constitute the effects group, who are mostly influenced by the causes group. The IRM presented in Fig. 8 reveals that SC35 is a core factor in QI, and SC124 is a driving factor in QII. Finally, SC19, SC27, and SC79 are impact factors given their positioning in QIV.

TABLE XIII
MOST SIGNIFICANT SUBCRITERIA: STRATEGY- AND RESULTS-BASED MONITORING CLUSTER

SC13	Strengthening senior citizens' understanding of digital language
SC20	Generating more enthusiasm
SC23	Showing how digital technology can make individuals' lives easier
SC48	Using younger teachers with an intergenerational perspective
SC111	Identifying individual motives for becoming digitally literate
SC114	Teaching based on simple language and adjustments to individual needs
SC169	Communicating how digital devices can improve older people's quality of life

TABLE XIV
MATRIX WITH INFLUENCE AND NEUTROSOPHIC VALUES: STRATEGY- AND RESULTS-BASED MONITORING CLUSTER

	SC13	**SC20**	**SC23**	**SC48**	**SC111**	**SC114**	**SC169**
SC13	–	2.5(0.7, 0.15, 0.15)	3.5(0.65, 0.2, 0.3)	1(0.7, 0.7, 0.25)	2(0.8, 0.15, 0.15)	1(0.8, 0.2, 0.1)	3.5(0.75, 0.15, 0.15)
SC20	3(0.65, 0.2, 0.2)	–	2.0(0.7, 0.15, 0.15)	1.5(0.8, 0.2, 0.25)	2(0.8, 0.2, 0.2)	2(0.7, 0.25, 0.35)	3(0.7, 0.2, 0.3)
SC23	2(0.75, 0.3, 0.3)	3.5(0.6, 0.2, 0.25)	–	1.5(0.7, 0.5, 0.45)	2.5(0.75, 0.35, 0.2)	3.5(0.8, 0.2, 0.2)	4(0.7, 0.3, 0.25)
SC48	2(0.65, 0.3, 0.35)	2(0.7, 0.15, 0.15)	2.5(0.8, 0.15, 0.15)	–	1.5(0.7, 0.3, 0.3)	2.5(0.65, 0.15, 0.2)	2.5(0.75, 0.3, 0.25)
SC111	2(0.65, 0.15, 0.1)	3(0.7, 0.15, 0.1)	3(0.7, 0.15, 0.1)	1(0.7, 0.2, 0.3)	–	2(0.7, 0.15, 0.15)	3(0.75, 0.3, 0.35)
SC114	4(0.8, 0.15, 0.15)	3(0.8, 0.15, 0.15)	1(0.7, 0.4, 0.25)	1(0.65, 0.25, 0.3)	2(0.6, 0.2, 0.2)	–	1(0.7, 0.35, 0.4)
SC169	2(0.75, 0.3, 0.25)	2(0.8, 0.3, 0.3)	2(0.7, 0.35, 0.25)	1.5(0.75, 0.3, 0.3)	2(0.75, 0.15, 0.15)	2.5(0.8, 0.3, 0.25)	–

TABLE XV
DIRECT-INFLUENCE MATRIX: STRATEGY- AND RESULTS-BASED MONITORING CLUSTER

	SC13	**SC20**	**SC23**	**SC48**	**SC111**	**SC114**	**SC169**	**TOTAL**
SC13	0.00	1.97	2.48	0.54	1.66	0.83	2.84	10.32
SC20	2.22	0.00	1.58	1.17	1.60	1.39	2.19	10.15
SC23	1.43	2.46	0.00	0.86	1.82	2.80	2.86	12.23
SC48	1.33	1.58	2.08	0.00	1.05	1.88	1.83	9.75
SC111	1.55	2.39	2.39	0.73	0.00	1.58	2.09	10.73
SC114	3.33	2.50	0.68	0.70	1.43	0.00	0.65	9.29
SC169	1.46	1.46	1.39	1.07	1.62	1.87	0.00	8.87
TOTAL	11.32	12.36	10.60	5.07	9.18	10.35	12.46	

TABLE XVI
CLUSTER 2: INTERACTION BETWEEN INITIATIVES

	R	*C*	*R + C*	*R – C*
SC13	4.5668	4.9928	9.5596	–0.4260
SC20	4.4594	5.3250	9.7843	–0.8656
SC23	5.2151	4.5739	9.7889	0.6412
SC48	4.3087	2.4024	6.7111	1.9064
SC111	4.7267	4.1776	8.9043	0.5490
SC114	4.1321	4.4872	8.6194	–0.3551
SC169	3.9611	5.4110	9.3721	–1.4500

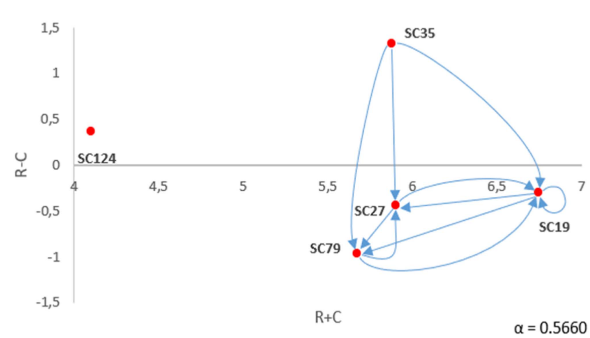

Fig. 8. Influential relationship map for relationships cluster.

D. Consolidation, Discussion, and Recommendations

The structuring and evaluation phases were complemented by a final recommendations phase. This session also took place online (i.e., via Zoom), and it was attended by the Head of Data Science and Analytics at Nippon Telegraph and Telephone (NTT) Data Europe and Latin America. NTT Data is one of the largest ICT companies in the world, offering technological solutions in various sectors (e.g., telecommunications, health-care, and public administration).

TABLE XVII
MOST SIGNIFICANT SUBCRITERIA: MOTIVATIONS

SC26	Answering questions individually
SC72	Offering free training to local communities
SC74	Understanding and matching older people's interests
SC92	Inspiring seniors to feel greater confidence and trust in their digital capabilities
SC102	Using technology as a facilitator
SC103	Adjusting features to meet older individuals' daily needs
SC115	Fostering family connections

TABLE XVIII
MATRIX WITH INFLUENCE AND NEUTROSOPHIC VALUES: MOTIVATIONS CLUSTER

	SC26	SC72	SC74	SC92	SC102	SC103	SC115
SC26	–	0.5(0.7, 0.3, 0.2)	3(0.8, 0.15, 0.15)	3(0.75, 0.3, 0.2)	2(0.75, 0.15, 0.15)	1.5(0.65, 0.15, 0.2)	1.5(0.7, 0.2, 0.2)
SC72	1(0.65, 0.3, 0.35)	–	2.5(0.7, 0.25, 0.25)	0.5(0.7, 0.15, 0.15)	2(0.8, 0.3, 0.3)	1.5(0.7, 0.4, 0.3)	1(0.75, 0.3, 0.3)
SC74	3.5(0.7, 0.25, 0.25)	2(0.65, 0.3, 0.2)	–	3(0.75, 0.35, 0.35)	3(0.8, 0.15, 0.15)	3(0.65, 0.2, 0.3)	1.5(0.6, 0.4, 0.35)
SC92	3(0.65, 0.15, 0.15)	1.75(0.6, 0.3, 0.2)	3(0.7, 0.4, 0.2)	–	1(0.8, 0.4, 0.1)	1(0.75, 0.3, 0.3)	1(0.7, 0.25, 0.15)
SC102	2(0.8, 0.15, 0.15)	1(0.65, 0.2, 0.1)	2.5(0.75, 0.15, 0.1)	2(0.65, 0.25, 0.1)	–	2(0.8, 0.15, 0.15)	0.5(0.65, 0.2, 0.15)
SC103	2(0.65, 0.3, 0.3)	2(0.7, 0.35, 0.25)	3(0.75, 0.3, 0.3)	2(0.8, 0.3, 0.15)	2.5(0.75, 0.25, 0.15)	–	2.5(0.7, 0.2, 0.2)
SC115	0(0.7, 0.15, 0.15)	0(0.8, 0.2, 0.15)	0.5(0.65, 0.2, 0.15)	1(0.7, 0.2, 0.2)	0.5(0.75, 0.25, 0.25)	1(0.7, 0.3, 0.25)	–

TABLE XIX
DIRECT-INFLUENCE MATRIX: MOTIVATIONS CLUSTER

	SC26	SC72	SC74	SC92	SC102	SC103	SC115	TOTAL
SC26	0.00	0.36	2.50	2.24	1.62	1.13	1.14	8.99
SC72	0.67	0.00	1.83	0.39	1.46	1.00	0.72	6.07
SC74	2.56	1.42	0.00	2.04	2.50	2.13	0.92	11.57
SC92	2.29	1.21	2.07	0.00	0.74	0.72	0.76	7.79
SC102	1.66	0.76	2.06	1.49	0.00	1.66	0.38	8.01
SC103	1.36	1.39	2.15	1.55	1.95	0.00	1.90	10.30
SC115	0.00	0.00	0.38	0.76	0.38	0.72	0.00	2.24
TOTAL	8.54	5.14	10.99	8.47	8.65	7.36	5.82	

TABLE XX
CLUSTER 3: INTERACTION BETWEEN INITIATIVES

	R	*C*	*R + C*	*R – C*
SC26	2.7812	2.7191	5.5003	0.0621
SC72	1.9417	1.6496	3.5913	0.2920
SC74	3.4510	3.2181	6.6691	0.2329
SC92	2.4389	2.6444	5.0832	–0.2055
SC102	2.5983	2.6385	5.2368	–0.0402
SC103	2.9773	2.2862	5.2635	0.6912
SC115	0.7336	1.7661	2.4998	–1.0325

The session lasted approximately one hour and had a four-part structure. First, the interviewer explained the study's main purpose and methodologies and then presented the results. Next, the interviewee was asked to give feedback regarding the adopted methodology with reference to the research topic. At the end, this expert was given the opportunity to evaluate the practical applicability of the proposed system.

The session thus began with a brief explanation of the study's objectives followed by a presentation of the methodology applied (i.e., cognitive mapping and DEMATEL applied in a neutrosophic environment). The results were described next, starting with the qualitative method component (i.e., cognitive mapping). The decision maker interviewed observed that this tool *"contributed to producing a list of initiatives that is quite significant and that seem appropriate to the topic"* (in his words). He also felt that *"the areas of concern are well represented and relevant to the subject matter"* (also in his words). However, the interviewee also noted that the fourth cluster (i.e., *Resources*), while appropriate *"because resources can be technological and have an impact on digital inclusion"* (citing the decision maker), was also *"a bit confusing"* (again, in his words). In this expert's opinion, the C4 initiatives could all belong to other clusters. He emphasized, nonetheless, that

TABLE XXI
MOST SIGNIFICANT SUBCRITERIA: RESOURCES CLUSTER

SC21	Determining how people close to senior citizens affect their motivation
SC22	Commending achievements and strengthening autonomy
SC56	Harnessing family and social networks' influence
SC104	Encouraging close contact and accessible language in training
SC179	Maintaining connections between younger and older individuals

TABLE XXII
MATRIX WITH INFLUENCE AND NEUTROSOPHIC VALUES: RESOURCES CLUSTER

	SC21	**SC22**	**SC56**	**SC104**	**SC179**
SC21	–	2.5(0.75, 0.25, 0.25)	2.25(0.75, 0.4, 0.3)	1.5(0.7, 0.25, 0.3)	2(0.7, 0.3, 0.2)
SC22	1.75(0.65, 0.35, 0.15)	–	2(0.65, 0.5, 0.45)	1.25(0.65, 0.4, 0.3)	1.5(0.6, 0.5, 0.3)
SC56	2.5(0.55, 0.45, 0.5)	2.5(0.75, 0.2, 0.1)	–	1(0.7, 0.25, 0.15)	2(0.55, 0.45, 0.5)
SC104	3(0.7, 0.3, 0.2)	3.5(0.75, 0.15, 0.2)	1(0.6, 0.5, 0.4)	–	0.75(0.7, 0.5, 0.4)
SC179	2(0.75, 0.25, 0.3)	2(0.8, 0.15, 0.15)	1.5(0.65, 0.3, 0.35)	1(0.7, 0.3, 0.25)	–

TABLE XXIII
DIRECT-INFLUENCE MATRIX: RESOURCES CLUSTER

	SC21	**SC22**	**SC56**	**SC104**	**SC179**	**TOTAL**
SC21	0.00	1.88	1.52	1.07	1.46	5.93
SC22	1.23	0.00	1.12	0.81	0.89	4.05
SC56	1.33	2.02	0.00	0.76	1.07	5.18
SC104	2.19	2.79	0.56	0.00	0.44	5.98
SC179	1.46	1.66	1.00	0.72	0.00	4.84
TOTAL	6.21	8.35	4.2	3.36	3.86	

TABLE XXIV
CLUSTER 4: INTERACTION BETWEEN INITIATIVES

	R	***C***	***R + C***	***R – C***
SC21	1.7829	1.8260	3.6090	–0.0431
SC22	1.2941	2.3663	3.6604	–1.0722
SC56	1.5726	1.3841	2.9567	0.1885
SC104	1.8030	1.1021	2.9051	0.7009
SC179	1.4949	1.2689	2.7638	0.2260

the results were appropriate due to the methodology adopted, especially as much attention was paid to the panel members' individual and collective know-how and practical experience. This professional thus stressed that *"the people who participated had a structured point of view on the topic"* (in his words).

Regarding the quantitative methods (i.e., DEMATEL in a neutrosophic environment), the interviewee asserted that the results revealed in the inter-cluster diagrams appeared to be suitable. He agreed that *"digital literacy is a very important foundation for the reduction of digital inequalities in this context"* (citing the decision maker). In addition, he pointed out that the classification of the third cluster (i.e., *Motivations*) as a cause makes sense because decision makers should *"take into account what motivates the use of digital resources to achieve digital literacy"* (in his words). He also emphasized that the findings contribute to a fuller *"understanding of what generates the motivation or demotivation to use digital tools"* (also in his words) and that the model indicates *"what leads people to use certain digital resources over others"* (again in his words). The decision maker asserted that, overall, the techniques used *"led to results that make sense and that are interesting from a quantitative standpoint because they reveal that some initiatives carry more weight than others"* (citing the decision maker).

The interviewee observed that the methodologies used in the present study, although context dependent, have the advantage of both *"strong quantitative and qualitative components"* (in his words), and produced suitable results and a notable *"capacity for generating concrete actions based on the data"* (also in his words).

When asked about the applicability of the proposed procedures, the interviewee asserted that *"public and private entities can benefit from having access to this information for exploration purposes"* (citing his words). He said, *"it is possible to use these data to understand the needs of this market segment to subsequently design offers and generate business"* (also in his words). This expert thus underlined that *"it is important to see these results from a business perspective"* (again in his words), suggesting that, later on, decision makers would have

TABLE XXV
MOST SIGNIFICANT SUBCRITERIA: RELATIONSHIPS CLUSTER

SC19	Assuring seniors of their capabilities
SC27	Ensuring teachers are able to adapt to older individuals' needs
SC35	Matching technologies to senior citizens' requirements
SC79	Purchasing user-friendly and appropriately adapted equipment
SC124	Involving older people's family and social circle

TABLE XXVI
MATRIX WITH INFLUENCE AND NEUTROSOPHIC VALUES: RELATIONSHIPS CLUSTER

	SC19	SC27	SC35	SC79	SC124
SC19	–	3.25(0.8, 0.25, 0.25)	2.5(0.7, 0.2, 0.25)	3.25(0.8, 0.2, 0.3)	2(0.75, 0.3, 0.3)
SC27	3.5(0.95, 0.2, 0.1)	–	2(0.6, 0.35, 0.3)	1.75(0.65, 0.3, 0.35)	1.5(0.7, 0.25, 0.25)
SC35	2.5(0.7, 0.3, 0.3)	3.5(0.8, 0.2, 0.2)	–	4(0.9, 0.2, 0.1)	2(0.75, 0.15, 0.15)
SC79	3.5(0.7, 0.25, 0.2)	2.5(0.65, 0.2, 0.3)	1.5(0.6, 0.5, 0.45)	–	0.5(0.65, 0.2, 0.25)
SC124	2(0.65, 0.2, 0.25)	1(0.7, 0.2, 0.2)	2(0.7, 0.15, 0.2)	2(0.8, 0.2, 0.2)	–

TABLE XXVII
DIRECT-INFLUENCE MATRIX: RELATIONSHIPS CLUSTER

	SC19	SC27	SC35	SC79	SC124	TOTAL
SC19	0.00	2.53	1.87	2.48	1.43	8.31
SC27	3.04	0.00	1.30	1.17	1.10	6.61
SC35	1.75	2.80	0.00	3.43	1.62	9.60
SC79	2.61	1.77	0.82	0.00	0.36	5.56
SC124	1.45	0.76	1.55	1.60	0.00	5.36
TOTAL	8.85	7.86	5.54	8.68	4.51	

TABLE XXVIII
CLUSTER 5: INTERACTION BETWEEN INITIATIVES

	R	*C*	*R* + *C*	*R* – *C*
SC19	3.2234	3.5229	6.7463	–0.2995
SC27	2.7330	3.1689	5.9019	–0.4359
SC35	3.6033	2.2731	5.8764	1.3302
SC79	2.3551	3.3194	5.6745	–0.9643
SC124	2.2359	1.8664	4.1023	0.3694

to analyze how the results can be translated into an action plan. Finally, he acknowledged how important further research on this subject is because of Europe's current demographic trends and the potential social and economic impacts of the silver economy.

V. CONCLUSION

Digital inequality is a complex problem affected by multiple interrelated factors, individuals' exposure to technological disruptions that foster uncertainty, and inherent subjectivity of its analysis due to different yet relevant perspectives. To conduct a more empirically rigorous study of this problem, decision makers need to avoid excessive simplification in their search for mathematical optimization and instead construct decision-support models that integrate objective and subjective aspects. By assuming a constructivist, process-oriented stance, the present research produced a holistic, intuitive, and realistic decision-making analysis system that supports a more effective implementation of initiatives that reduce digital inequalities in a silver economy context. To achieve this result, the methodologies applied paid attention to both objective and subjective aspects and combined cognitive mapping and DEMATEL techniques in a neutrosophic context, thereby overcoming various limitations of the existing literature on this subject.

Two research questions were predefined. First, how can initiatives that reduce digital inequalities be identified, and how are these strategies interrelated? Second, which initiatives have a significant enough impact that they should be given priority as part of efforts to reduce digital inequalities in the silver economy? To address these questions, the participants aggregated relevant initiatives into five areas of greatest concern (i.e., digital literacy, strategy- and results-based monitoring, motivations, resources, and relationships), highlighted critical factors, and identified cause-effect relationships between initiatives as shown in the IRM diagrams.

Not unexpectedly, this study also has its own limitations. The adopted constructivist methodology assumes that the proposed model was shaped significantly by the specific context in which it was developed, making the findings only generalizable to other settings when all due caution is used. The exhaustive, time-consuming nature of quantifying the experts' judgement in the second session contributed to the panel members' fatigue. The online group sessions experienced difficulties related to access to or use of technology (e.g., problems using devices, inadequate Internet access, and power outages), which also prolonged these sessions. The outcomes also heavily depended on the profiles of the experts who joined the decision-maker panel. The large number of experts with experience in adult education meant that the panel's composition was less heterogeneous. In addition, a large number of links were identified between some clusters (e.g., C4) in the group cognitive map generated, which resulted in the loss of a clear separate identity of these clusters. Finally, the results are limited to one country (i.e., Portugal) due to the expert panel's composition.

In view of these limitations, three aspects need to be emphasized. First, the NGT and multi-voting method were necessary for the DEMATEL technique to be applied in a neutrosophic environment because of the complexity of the cognitive map. These complementary methods ensured greater clarity in terms of the decision-support model. Second, the main objective of this research was not to construct an optimal analysis system but rather to develop a model that improves decision making regarding how to reduce older individuals' digital inequality. Last, the results indicate the proposed model has great potential in terms of practical applicability.

Given the limitations of previous studies of this topic, the current research adopted methodologies that produced multiple contributions to ongoing efforts to decrease senior citizens' digital illiteracy. The first is clear, transparent procedures that promote the identification of initiatives and cause–effect relationships between these strategies. The second contribution is the incorporation of a methodology that allows decision makers to express indeterminateness and uncertainty regarding their opinions, which brings the model closer to human reasoning patterns. The third contribution is the use of neutrosophic values to produce results that are a better approximation of the actual degree of influence that exists between relevant initiatives. The fourth is a model that reflects the decision problem more completely and transparently, contains a significant set of strategies, and identifies critical interventions that more effectively reduce digital inequalities. The last contribution is that this study is the first to apply the methodologies selected to the problem of how to decrease digital inequalities in the silver economy.

Future research could use other methodologies and/or reapply the methods used in this study with a different panel of experts, paying particular attention to the professions covered. Scholars can also apply the proposed methodological approach to digital disparities in varied contexts, such as rural versus urban areas, contrasting social and cultural population segments, or different geographical regions. In addition, researchers may get interesting results by conducting a translation of the present results into an action plan and its outcome. Finally, other studies are needed to try combining neutrosophic logic with other multicriteria methods.

Digital inequalities in the silver economy comprise a complex, enduring issue that will continue to have significant economic and social impacts. Further research on this topic will thus make positive contributions to the betterment of academic community and society at large.

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