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Synergistic evaluation system of “technology and service” in smart elderly care institutions in China

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Abstract

Background: Smart elderly care faces numerous challenges while aligning with the national strategy of promoting the silver economy. Chief among these challenges is the inconsistent quality of services offered by smart elderly care institutions, which significantly impedes the industry’s further development. Therefore, the objective of this paper is to develop a theoretical framework for assessing the quality of smart elderly care services, refine the evaluation index system for these services, and explore strategies to enhance their quality.

Methods: Based on the Structure–Process–Outcome model, this paper has developed an integrated theoretical framework and employed a combination of modified-Delphi method and Decision-Making Trial and Evaluation Laboratory – Analytic Network Process to establish and assign weights to the service quality evaluation system for smart elderly care institutions in China.

Results: This study develops a “Technology + Service” synergistic theoretical framework and an index system comprising four first-tier indicators, 12 second-tier indicators, and 54 third-tier indicators. The most significant indicators identified are service resources, smart elderly care infrastructure, staffing, service empathy, the rate of health file creation, 3S device coverage rate, and average living space per bed.

Conclusion: The results reveal that service resources, especially the information technology infrastructure and smart equipment are the most crucial aspects of smart elderly care institutions. Additionally, institutions should focus on improving the expertise of their staff and providing psychological care for elderly adults.

Keywords

Smart elderly care, “Technology + Service” synergistic theoretical framework, Modified-Delphi, DEMATEL-ANP

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Introduction

The escalating global population of individuals aged 65 and older has triggered heightened awareness worldwide, particularly in developed nations.1 A case in point is the profound demographic shift observed in China, where the natural population growth rate has plummeted to historic lows at −1.48‰ in 2023, leading to a substantial surge in the elderly population.[2] Furthermore, the trajectory of increasing elderly demographics persists, positioning China as the host to the largest aging population globally. The number of individuals aged 60 and above is expected to reach 478 million in 2025, constituting 35.8% of the total population.[3]

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In response to the escalating demands for social care and the evolution of information technologies, the senior care industry has progressively instituted an innovative form of elderly care service system known as "smart elderly care." It was first proposed by Unit Trust UK as an "Intelligent older system" that can break the boundaries of time and space to provide high-quality senior care service.[4] The core concept of smart elderly care is building a technological network for service participants and leveraging smart technology to address the diverse, personalized, and convenient requirements of the elderly.[5] The smart elderly care industry in China has experienced remarkable growth recently and is anticipated to continue expanding within the aging care sector. Post-2020, smart elderly care is poised to permeate the traditional aging industry, with the industry scale projected to reach 220 trillion RMB by 2050.[6]

Scholars have taken notice of this emerging phenomenon and extensively delved into various aspects of smart elderly care. Prior studies have scrutinized the current status of smart elderly care in China, which has exhibited some notable characteristics: 1) Integration of technology with elderly care service resources.[7,8] 2) Technology spanning the entire lifecycle of elderly care service recipients.[9,10] 3) Technology fostering collaboration among multiple stakeholders in elderly care.[11,12] 4) technology facilitating the organic combination of personalized and human-centered elderly care service.[5,13] Other scholarly focus on discussing service models for smart elderly care, and the primary service models can be categorized as: technology-oriented,[5,14] medical-care integrated,[15,16] and collaborative integrated.[17–19] Research on evaluating the quality of smart elderly care service primarily focuses on: 1) Selection of evaluation indicators. The key indicators include the effectiveness of intelligent facilities,[20,21] the process involved in smart services,[22] and the adoption of intelligent services.[23] 2) Methods for determining indicators. The major methodologies contain the Fuzzy Analytic Hierarchy Process,[24,25] the Decision-Making Trial and Evaluation Laboratory (DEMATEL) method,[26] the Modified Delphi Method,[27]and the DEA method.[28]

In summary, existing research has provided valuable academic insights into the mechanisms, evaluation, and optimization pathways of smart elderly care services. However, further advancements are needed in the following areas: (1) Current studies lack comprehensive analyses of different elderly care service models, particularly from the perspectives of integrating technology with services and coordinating the development of the entire industry chain. This limitation hinders the advancement of a personalized, integrated, and intelligent elderly care service system.[3] (2) Research on the evaluation frameworks for service quality of smart elderly care institutions remains insufficient, making it challenging to incorporate such services into a unified measurement system and achieve comparable evaluations.[29] (3) Existing studies often adopt simplified inductive and deductive approaches to explore service quality pathways at macro and strategic levels, without addressing the complex interrelationships among influencing factors. Therefore, a comprehensive and systematic investigation into innovative service quality frameworks for smart elderly care institutions, the development of evaluation systems, and the identification of factors driving quality improvement is urgently needed. These efforts are critical to achieving high-quality development in smart elderly care and addressing the societal challenges posed by population aging.

Therefore, it is imperative to institute a coherent performance evaluation system aimed at pinpointing deficiencies in service quality and elevating the standard of elderly services. The specific research objectives are outlined below:

1. Develop a "Technology + Service" synergistic theoretical framework to depict and measure the service quality of smart elderly care institutions.
2. Construct a scientific, objective, and feasible service quality evaluation system tailored for smart elderly care institutions.
3. Identify the most crucial indicators via the weight allocation to guide the smart elderly care institutions to enhance service quality.

This paper encompasses both theoretical and applied implications. From an academic perspective, it first introduces the "Technology + Service" synergistic theoretical framework for measuring service quality in intelligent environments. This innovative framework enriches the theoretical foundations and knowledge base for evaluating the serviceability of smart elderly care. Secondly, it examines a new model for smart elderly care services that integrates societal resources, addresses the entire life cycle of the elderly, and consolidates the supply chain of senior care services.

Furthermore, the paper holds practical implications by introducing a strategy to elevate service quality and enhance the development of the smart elderly care industry in China. First, it proposes the development of an evaluation system to assess the effectiveness of service models employed by smart elderly care institutions. This system incorporates dimensions such as equipment intelligence, data sharing, service integration, and service adoption to construct a comprehensive network-based index system. The framework aims to guide governmental departments in enhancing regulatory efficiency and promoting a well-structured blueprint for senior care service systems. Second, the study explores the factors influencing the improvement of service quality in smart senior care. By identifying dynamic and feasible pathways for service quality enhancement, it provides innovative strategies for organizations to strengthen their operational performance. These insights aim to drive sustainable development and inject new momentum into the growth of the smart elderly care industry.

The research is structured as follows: The second part comprises "Literature review," which provides a theoretical foundation for the proposed frameworks and indicator system. "Research design" section offers a concise description of the methodology. "Results" section presents the analysis procedure and the obtained results, followed by "Discussion" section. Finally, "Conclusion" section addresses limitations and outlines future directions for the construction of indicators.

Literature review

The Structure–Process–Outcome model

The Structure–Process–Outcome (SPO) model, deemed by Donabedian[30] as an effective and efficient management tool for nursing and healthcare quality control, asserts that the structure, process, and outcome of a care service program are interrelated and sequential. Donabedian[31] contends that a well-designed structure increases the likelihood of a smooth process, ultimately influencing positive outcomes. By establishing this relationship, it becomes possible to assess the quality of specific aspects of the structure, process, and outcome of care services at each stage.[32] The SPO model stands as a widely adopted conceptual framework for evaluating service quality in the fields of medicine and healthcare. For example, Moore et al.[33] employed the SPO model to assess the integrated trauma system, aiming to enhance patient outcomes. Liu et al.[34] developed a nursing quality index system based on the SPO model for assisted reproduction hospitals. Consequently, the SPO model holds applicability in senior care research, with several academic papers incorporating it into their investigations. For example, Zhang et al.[35] proposed a service quality evaluation system for elderly care institutions based on the SPO model, applying it to six nursing homes in Xiamen, China. Bhattacharyya et al.[36] explored the satisfaction of nursing home services among older individuals, devising a conceptual framework grounded in the SPO model.

The "Technology + Service" frameworks

The synergistic model of "Technology + Service" originates from the Synergy effect which refers to the study of open systems in physics, especially lasers.[37] Ansoff[38] was the first to introduce "Ansoff Synergy Concept" into the study of business management, believing that synergies may exist in a firm's operations, investments, or management activities. The concept emphasizes the synergy between departments and functions within an organization to achieve more efficient performance and innovation. Therefore, Tu et al.[39] summarizes four major models of technology and service development in China: main categories development model, mechanism class development model, system class development model, and value chain development model. And they provide an innovated comprehensive framework that describes the development logic of technology and service synergy as "The fundamental of technology and service value creation—the process of value creation—the outcome of technology and service value" (Figure 1). Smart elderly care institution can be recognized as integrated, service-centered, technology-enabled care.[40] Consequently, the framework of technology and service synergistic development can be applied in the research of smart elderly care service.

Research design

On the basis of "SPO" service quality model, this study innovated the theoretical framework by integrating factors from interdisciplinary studies. It also applied Modified Delphi and DEMATEL – Analytic Network Process (DEMATEL-ANP) methods to construct the evaluation index system and obtain the weights. The research process is illustrated in Figure 2.

Develop the "Technology + Service" theoretical framework

To ensure the complexity and multidimensionality of smart elderly care service quality, this study proposes using the SPO three-dimensional quality theory framework as the theoretical foundation.[41] This framework will be integrated with the Cooperative development Model of Science and Technology Service[42] and social technology theory[11] to initially design the theoretical framework of smart elderly care institutions. This approach aims to support the construction of an innovative smart elderly care service model that is intelligent, integrated, and personalized.

Based on these theories, a new model of smart elderly care is constructed, characterized by an "intelligent information technology structure, collaborative services from multiple perspectives, and high-quality service outcomes" (Figure 3). This model relies on an interactive platform for smart elderly care, integrating the service supply chain comprising suppliers, integrators, and service providers.[10] It considers multiple stakeholders involved in smart elderly care and utilizes societal resources to achieve high-quality service outcomes through the integration of smart devices, platform technology, personalized care scenarios, and a comprehensive service system.[43] This model aims to drive comprehensive innovation and upgrade the service model of smart elderly care organizations.

Define the dimensions of the evaluation system

The selection of the first-tier indicators. The research selects the indicators and constructs the assessment

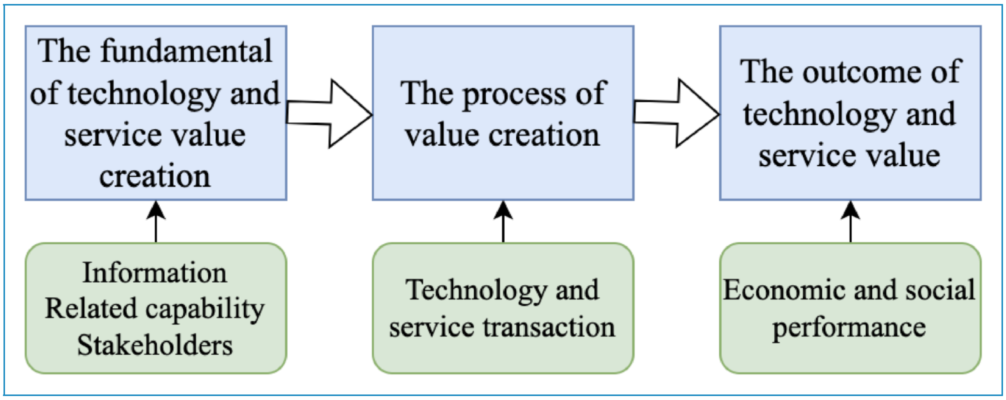

Figure 1. The framework of technology and service synergistic development.

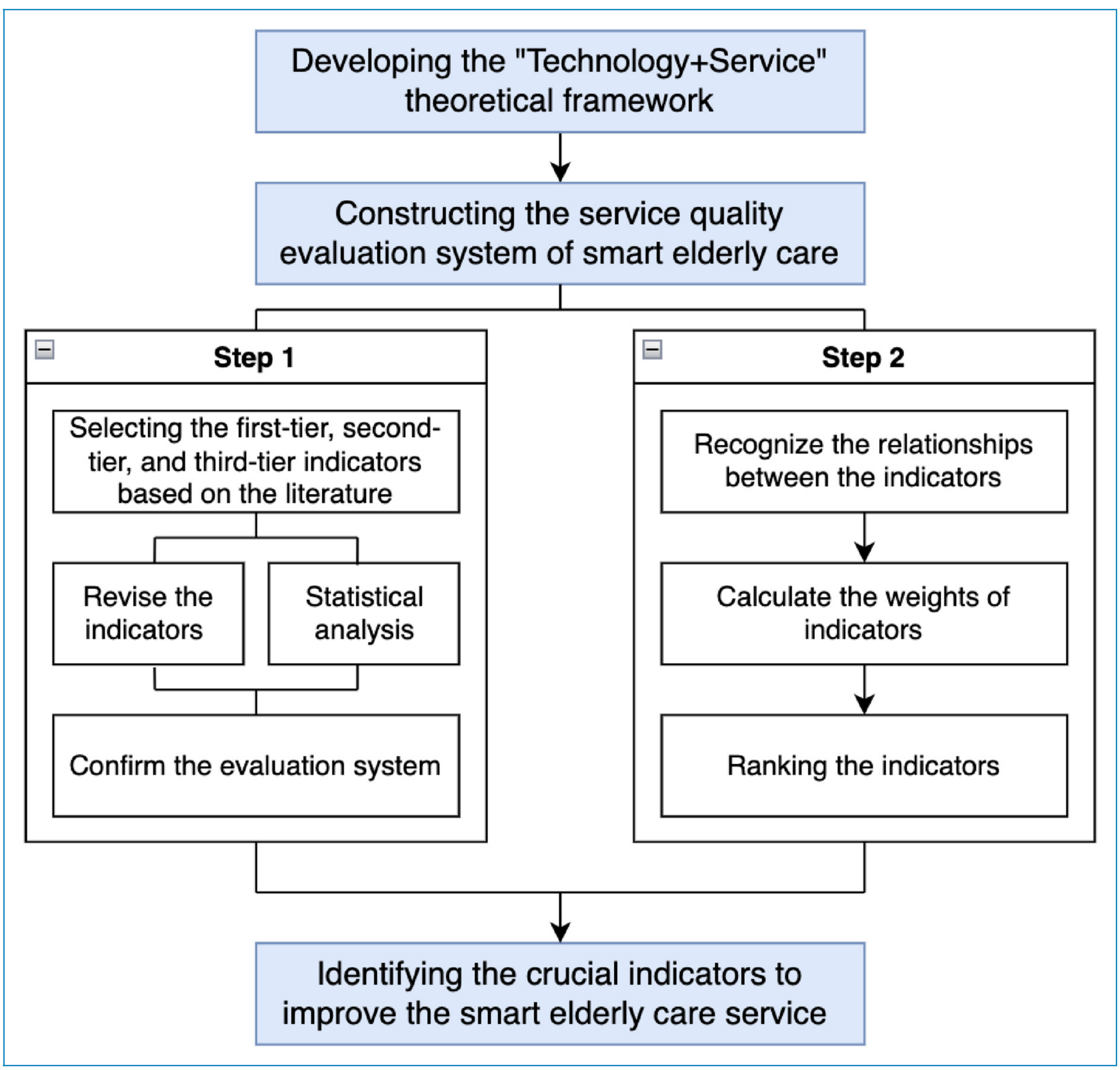

Figure 2. The research process.

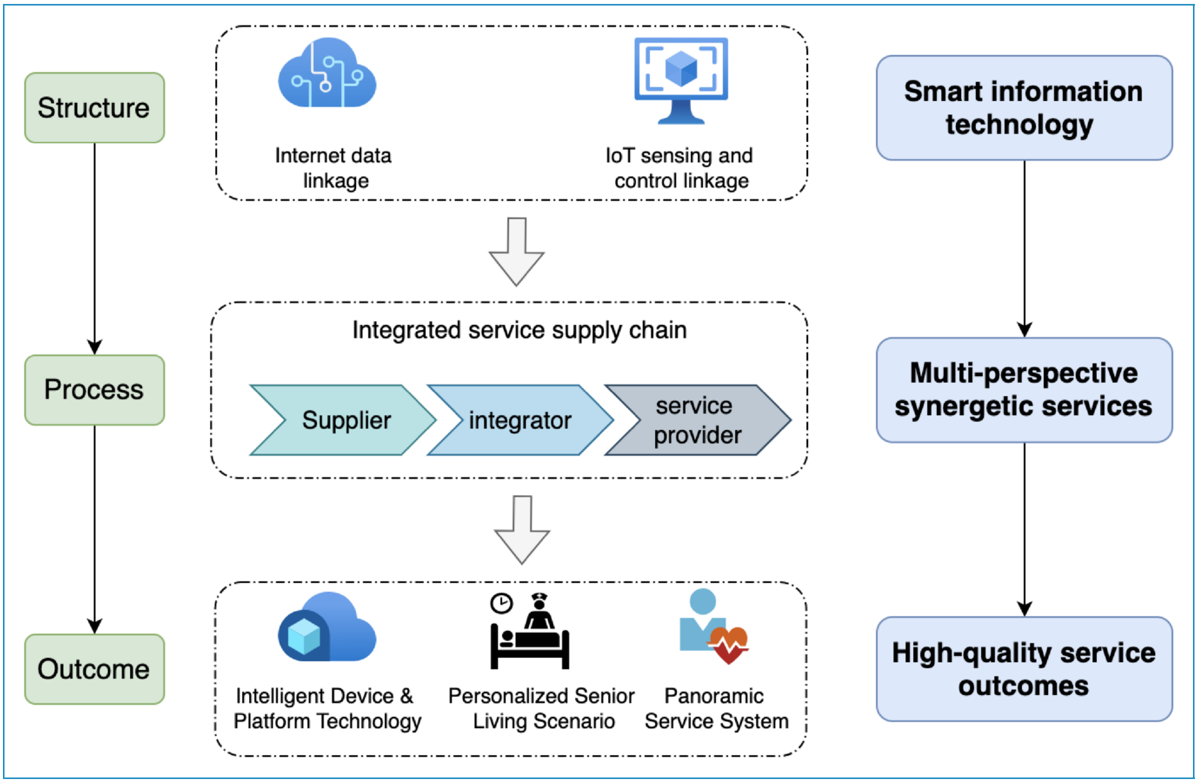

Figure 3. The "Technology + Service" synergistic theoretical framework.

system based on the SPO Model (Donabedian, 1969), the "Assessment indicators system of smart elderly care,"[27,44] the "Service quality assessment index system of nursing home,"[35] the "Service quality evaluation system of medical and nursing care institutions."[45] Thus, it is possible to establish the model of the first-tier indicators as followings: "Infrastructure" indicates the "hard resource" of the smart elderly care institution, such as the network, the fiber, the indoor and outdoor architecture. "Service resource" means the "soft resource" such as the talents, the medical support, and the intelligent equipment. These two dimensions are related to "structure," which refers to the static matching efficiency and relationship of various resources in health care services. "Service content" refers to nursing content and health care management and can reflect the proceeding of "process." "Service outcome" refers to the customer perception and matches the "outcome" dimension that focuses on the final output at the end of the health care service.

The selection of second-tier indicators. The structure of the second-tier indicators, smart elderly care infrastructure, and living services infrastructure, which emphasize the foundation of smart elderly care service, can be attributed to infrastructure.[27] Smart equipment, medical care package, and human resources are the sources and talents that belong to service resource. Service reliability, platform intelligence, privacy protection, service responsiveness, and service empathy, which reflect the effectiveness and efficiency of the service project, can be classified as service content. Intention to use and customer satisfaction, which are the service outcomes, are part of service performance.[46]

The selection of third-tier indicators. This study draws on a range of research studies, including those examining medical and nursing care service systems,[20,22,45] the impact factors of smart nursing service,[26,47,48] the evaluation of service quality in smart community or smart home settings,[28,49,50] and research on the construction of quality evaluation systems in senior care institutions.[27,35,44,51] The factors are then refined and integrated to form the foundation of the third-tier indicators.

Constructing and adjusting the index system

The current study endeavors to formulate a structured service quality evaluation system for smart elderly care institutions through the implementation of the Modified Delphi method.[52] It is similar to the traditional Delphi method, retaining its core principles. However, the key difference lies in the omission of the first round's open-ended questionnaire, which is typically a hallmark of the traditional approach. Instead, the modified version replaces this initial open-ended survey with a structured questionnaire based on relevant findings from past literature, researcher's design planning, or expert interviews. This structured questionnaire serves as the first round of the process.[53]

To achieve this goal, the research design employs a third-round Delphi expert process, which builds on a preliminary evaluation system derived from the relevant literature. The study systematically analyzes data collected from Delphi questionnaires, incorporates insights from expert participants, and identifies primary, secondary, and tertiary indicators to establish the foundational version of the evaluation system. Evaluation indices were selected using the cutoff method,[54] and the total score frequency, arithmetic mean, and coefficient of variation were calculated based on the importance scores of each index. The selection procedure followed these criteria: 1) The higher the positive coefficient of experts, the more engaged the experts are, reflecting greater attention to the study; 2) Expert authority was required to exceed 0.70, considered a threshold for high authority; 3) The Kendall's coefficient of concordance (w) ranges from 0 to 1,[55] and the coordination coefficient ranges from 0.5 to 2.[56] The maximum frequency and arithmetic mean were determined by the formula "Cutoff value = Mean—Standard Deviation," with indicators above this threshold selected. Conversely, the cutoff value for the coefficient of variation was calculated as "Cutoff value = Mean + Standard Deviation," with indicators selected based on scores below this threshold. Indicators were excluded only if they failed to meet all three criteria; otherwise, retention was assessed based on the principles of comprehensiveness, scientific rigor, and practicality.[54]

The Delphi experts who are mainly from nursing care institutions, administrative organizations, and universities are specialized in senior care service or dedicated in relevant fields with more than 10 years' working experience. A total of 15 experts[57] were selected, with most of them coming from Hunan Province and the Great Bay Area. This decision was made due to the fact that the Great Bay Area is considered the most advanced region in terms of elderly care in China. According to the latest data from the National Bureau of Statistics,[58] Guangdong Province, which is part of the Great Bay Area, has the highest income for the basic pension insurance fund at 611 billion yuan. On the other hand, Hunan Province, located in central China, represents the middle class with an average income of 185 billion yuan for the basic pension insurance fund.[58] The detailed criteria are stated in Table 1.

Weight assessment of the evaluation system

After establishing the service quality evaluation system using the Delphi method, the DEMATEL-ANP approach[59] is employed to identify the relationships between the indicators and calculate their respective weights, with the aim of optimizing and finalizing the evaluation system. As a complex system, the construction of the assessment indicator system for smart elderly service quality cannot completely eliminate the correlations between indicators. In fact, these correlations tend to intensify due to the inherent complexity of the system. The ANP model, proposed by Saaty,[60] allows decision-makers to account for the interactions between any two elements in a complex dynamic system. Therefore, using the DEMATEL-ANP model to assign weights to the indicators, in order to assess the quality of smart elderly care services, enables a more comprehensive consideration of these interdependencies, leading to research outcomes that better reflect the real-world context.

Initially, the project utilized the DEMATEL method to create a cause-and-effect diagram that identifies the relationships and correlations between the indicators. After the expert panel completed the questionnaire, the collected data were processed using the arithmetic mean in Excel to generate the direct influence matrix $D = [a_{ij}]_{n\times n}$, where a_{ij} represents the influence of factor F_i on F_j: when $i = j$, $a_{ij}=0$. Subsequently, the direct influence matrix was formalized using equations (1) and (2), and the normalized direct influence matrix X was calculated:

$$X = \frac{A}{s} \tag{1}$$

$$S = \max\{ \begin{matrix} \max \\ 1 \le i \le n \end{matrix} \sum_{j}^{n} a_{ij}, \begin{matrix} \max \\ 1 \le j \le n \end{matrix} \sum_{j}^{n} a_{ij} \} \triangle \mathrm{ABC} \tag{2}$$

The total impact matrix T is obtained by applying equation (3), where I denotes the unit matrix:

$$\begin{aligned} \mathrm{T} &= X + X^2 + X^3 + \cdots + X^k,\ k \to \infty,\ X^k = [0]_{n\times n} \\ &= X(I + X + X^2 + X^3 + \cdots + X^{k-1})(I - X)(I - X)^{-1} \\ &= X(I - X)(I - X)^{-1} = X(I - XX)^{-1} \end{aligned} \tag{3}$$

When the conformational matrix $T_c = [t_{ij}^D]_{n\times n}$ and the conformational total influence relation matrix $T_D = [t_{ij}^D]_{m\times m}$ are obtained by threshold filtering, the column summation and row summation of the two total influence relation matrices can be performed by equations (4) to (6) and displayed as vectors $r = (r_1, \cdots r_{ij} \cdots, r_n)'$ and $s = (s_1, \cdots s_{ij} \cdots, s_n)'$, respectively, so that $i = j$ and $i, j \in \{1, 2, \cdots n\}$, the level axis vector is $(r_i + s_i)$, which represents the total influence strength (centrality) between the facets or indicators; and $(r_i - s_i)$ represents the degree of causality between the facets or indicators:

$$\mathrm{T} = [t_{ij}]_{n\times n}, \quad i, j = 1, 2, \cdots n \tag{4}$$

$$r = [\sum_{j=1}^{n} t_{ij}]_{n\times 1} = [t_i]_{n\times 1} = (r_1, \cdots r_i \cdots, r_n)' \tag{5}$$

$$r = [\sum_{i=1}^{n} t_{ij}]'_{n\times 1} = [t_j]_{n\times 1} = (s_1, \cdots s_i \cdots, s_n)' \tag{6}$$

Table 1. The criteria of selecting the Delphi experts.

Experts' serial number	Title	Source	Criteria
1	Senior Manager	Elderly Care Institution and Nursing Home	More than 10 years' experience in senior care service, more than 5 years in senior care management, or more than 10 years in the senior care market.
2	Senior Manager		
3	Manager		
4	Manager		
5	Manager		
6	Consultant		
7	Department Chief	Administrative Organization	Intermediate title or above, with more than 10 years of relevant working experience.
8	Deputy chief		
9	Deputy chief		
10	Professor	Research Institutions for Elderly Services and Information Technology	More than 5 years of teaching or research in related theories, doctoral degree or above, with senior title or above.
11	Professor		
12	Associate Professor		
13	Associate Professor		
14	Dr. & RA		
15	Dr. & RA		

A higher centrality value indicates greater overall importance of a construct or indicator, while a higher cause value reflects a stronger direct influence of an indicator on others. Based on these results, an influence relationship map, also known as a net relation map, was constructed.

Subsequently, the ANP method was employed to evaluate the system. Using the causality map, a network structure of indicators was developed, and the content of the ANP questionnaire was designed accordingly. Data provided by the experts who completed the questionnaire were organized, and the geometric mean of the relative importance values for each pair of indicators (constructs) was calculated in Excel using the formula ($G = \sqrt[n]{X_1 \times X_2 \times X_3 \cdots X_n}$). These means were then rounded and entered into MATLAB software to construct the unweighted supermatrix.

The unweighted supermatrix was regularized for stability and balance, resulting in the weighted supermatrix. These matrices were integrated, considering their respective influences, to derive the composite weighted supermatrix $W*$ which encapsulates the system's interdependencies and preferences. MATLAB was then used to compute the limit supermatrix through iterative self-multiplication of the weighted supermatrix. This process yielded the mixed weights of the evaluation indices, enabling the relative ranking of indicators with higher correlations and weights. This rigorous approach enhances the objectivity and precision of the evaluation results.[59]

Results

The quality index of institutional smart elderly care service

The evaluation system's architecture grounded in the theoretical underpinnings of "Define the dimensions of the evaluation system" section, initially featured Layer A with four dimensions, Layer B with 15 indicators, and Layer C with 59 indicators. Subsequent to three iterative Modified-Delphi consultations, the system was refined to encompass four dimensions in Layer A, 12 indicators in Layer B, and 54 indicators in Layer C. The comparative structures of the evaluation system in its original and final forms are presented in Appendices A and B. Due to the page limitation, only the third-round results of Modified Delphi are reported.

The basic information of experts is illustrated in Table 2. Three rounds of expert consultations were conducted in this research, and the Gojump firm circulated the questionnaires over the WeChat platform to the same 15 experts who took part in the first and second rounds of the Delphi process. All 15 of the sent surveys were returned, giving the distribution method a response rate of 100%. All of the surveys gathered were found to be legitimate after a careful verification process. The following is a list of the Delphi third-round results:

Table 3 reveals that the Kendall coordination coefficient test yielded a significant result ($p = 0.00 < 0.05$), indicating strong interrater reliability. Layer A's Kendall W value was 0.456, surpassing the 0.2 threshold. Similarly, Layers B and C exhibited coefficients of 0.466 and 0.428, respectively, confirming high correlation and consistency among the 15 evaluators' assessments.

It is clear from Table 4 and Table 5 that all the indicators are appropriate. Although the arithmetic means of "Service resource" (A2) is smaller than 4.34, the coefficient of variation is equal to 0.22, and the standard deviation of "service outcome" (A4) is 0.00 which is smaller than 0.15, all the indicators do not meet the deletion scope. In addition, all 12 indicators of Layer B are excluded from the deletion. They all belong to the range of "arithmetic mean >4.03 or standard deviation >0.14 or the coefficient of variation <0.30." All 54 indicators of Layer C are excluded from the deletion. They all belong to the range of "arithmetic mean >4.08 or standard deviation>0.13 or the coefficient of variation <0.32."

According to Zeng,[56] when the coordination coefficient (Kendall's W) fluctuates from 0.400 to 0.500, the coordination is better. The experts' opinions in the modified Delphi method gradually converge, and the consultation can be stopped. Finally, this study confirms the service quality evaluation system, which includes four basic indicators, 12 secondary indicators, and 54 tertiary indicators.

Table 2. The demographic characteristics of 15 experts.

Characteristic	Number	Frequency (%)
Age		
<30	2	13
31–40	8	53
41–50	4	27
>51	1	7
Working years		
<5	2	13
5–10	6	40
>10	7	47
Education		
Bachelor	4	20
Master	6	40
Doctor	5	40
Level of experience		
Associate professor / manager /deputy chief	7	80
Lecture / consultant	3	20
Professional field		
Nursing care staff	6	40
University teachers and researchers	6	40
Administrative organization staff	3	20

Table 3. The coordination coefficient of evaluation system.

Layer	Number of indicators	Kendall W	χ2	*p*
Layer A	4	0.456	20.500	0.000
Layer B	12	0.466	76.873	0.000
Layer C	54	0.428	340.268	0.000

Table 4. The standard cutoff value of different layers.

Items	Layer-A	Layer-B	Layer-C
M	>4.34	>4.03	>4.08
SD	>0.15	>0.14	>0.13
CV	<0.22	<0.30	<0.32

Table 5. The statistic results of indicators.

Indicator	M	SD	CV	Indicator	M	SD	CV
A1	4.80	0.56	0.12	C20	3.40	1.45	0.43
A2	4.20	0.94	0.22	C21	3.80	1.47	0.39
A3	4.73	0.70	0.15	C22	4.20	1.15	0.27
A4	5.00	0.00	0.00	C23	3.53	1.51	0.43
B1	4.93	0.26	0.05	C24	3.80	1.47	0.39
B2	4.47	0.99	0.22	C25	5.00	0.00	0.00
B3	5.00	0.00	0.00	C26	3.93	1.49	0.38
B4	4.80	0.56	0.12	C27	4.27	0.96	0.23
B5	3.53	1.19	0.34	C28	5.00	0.00	0.00
B6	3.93	1.39	0.35	C29	4.53	0.92	0.20
B7	4.07	1.28	0.31	C30	4.13	1.25	0.30
B8	4.93	0.26	0.05	C31	5.00	0.00	0.00
B9	4.80	0.56	0.12	C32	5.00	0.00	0.00
B10	4.07	1.39	0.34	C33	4.13	1.25	0.30
B11	4.93	0.26	0.05	C34	4.00	1.36	0.34
B12	5.00	0.00	0.00	C35	4.80	0.56	0.12
C1	5.00	0.00	0.00	C36	4.87	0.35	0.07
C2	4.73	0.59	0.13	C37	4.13	1.30	0.32
C3	4.13	1.36	0.33	C38	4.40	0.99	0.22
C4	5.00	0.00	0.00	C39	5.00	0.00	0.00
C5	4.53	0.99	0.22	C40	4.93	0.26	0.05
C6	4.67	0.90	0.19	C41	5.00	0.00	0.00
C7	4.60	0.91	0.20	C42	4.13	1.41	0.34
C8	5.00	0.00	0.00	C43	4.93	0.26	0.05
C9	4.93	0.26	0.05	C44	5.00	0.00	0.00
C10	4.33	1.18	0.27	C45	4.40	0.99	0.22
C11	5.00	0.00	0.00	C46	5.00	0.00	0.00

(continued)

Table 5. Continued.

Indicator	M	SD	CV	Indicator	M	SD	CV
C12	3.93	1.22	0.31	C47	4.80	0.56	0.12
C13	5.00	0.00	0.00	C48	4.13	1.30	0.32
C14	4.13	1.13	0.27	C49	4.73	0.59	0.13
C15	4.00	1.51	0.38	C50	4.87	0.52	0.11
C16	4.87	0.35	0.07	C51	5.00	0.00	0.00
C17	5.00	0.00	0.00	C52	5.00	0.00	0.00
C18	4.27	1.16	0.27	C53	4.80	0.56	0.12
C19	3.80	1.26	0.33	C54	4.40	1.30	0.30

The weights of the evaluation system

Decision-Making Trial and Evaluation Laboratory is employed to structure the interdependencies between dimensions. Analytic Network Process is adopted to calculate the supermatrix and obtain the weights of the indicators.

The results of the first-tier indicators. *Step 1: Construct a direct-relation matrix.* Expert discussions and questionnaires were used to determine the relationship between elements on a two-by-two basis. The same 15 experts were invited to participate in each questionnaire. The questionnaire used the 0–9 scale to reflect the degree of influence between the indicators, with higher values indicating stronger impact relationships, and 0 representing no impact. The arithmetic mean method was used to integrate the experts' preferences from their answers. The values obtained after integration are shown in Table 6.

Based on the above values, the initial direct-relation matrix D of the first-level indicators was obtained:

$$D = \begin{bmatrix} 0.0000 & 8.8667 & 6.2667 & 8.2667 \\ 4.9333 & 0.0000 & 8.2000 & 8.2667 \\ 3.3933 & 7.8667 & 0.0000 & 5.6667 \\ 3.3333 & 3.1333 & 4.3333 & 0.0000 \end{bmatrix}$$

Step 2: Normalize the direct-relation matrix. This normalization leads to a maximum value of rows equal to 23.4000. According to equation (4), two, it yields $\lambda = 0.04$. The direct-relation matrix X is derived by normalizing the matrix D according to the formula:

$$X = \begin{bmatrix} 0.0000 & 0.3789 & 0.2678 & 0.3533 \\ 0.2108 & 0.0000 & 0.3504 & 0.3533 \\ 0.1681 & 0.3362 & 0.0000 & 0.2422 \\ 0.1425 & 0.1339 & 0.1852 & 0.0000 \end{bmatrix}$$

Table 6. The statistical summary of expert preferences.

	Infrastructure	Service resource	Service content	Service outcome
Infrastructure	–	8.8667	6.2667	8.2667
Service resource	4.9333	–	8.2000	8.2667
Service content	3.9333	7.8667	–	5.6667
Service outcome	3.3333	3.1333	4.3333	–

Table 7. The centrality and causality of the first-tier indicators.

Centrality and causality	Infrastructure	Service resource	Service content	Service outcome
$r_i + c_i$	6.2113	6.8774	6.3745	5.7975
$r_i - c_i$	1.6042	0.2328	−0.1759	−1.6611
R	3.90775	3.5551	3.0993	2.0682
C	2.30355	3.3223	3.2752	3.7293

Step 3: Calculate the total relation matrix. The total-relation matrix T is derived from the equation, where I is a fourth-order identity matrix:

$$T = \begin{bmatrix} 0.5765 & 1.1041 & 1.0303 & 1.1966 \\ 0.6952 & 0.7492 & 1.0041 & 1.1067 \\ 0.6027 & 0.9092 & 0.6530 & 0.9344 \\ 0.4293 & 0.5599 & 0.5874 & 0.4917 \end{bmatrix}$$

According to the threshold determination method selected in this paper (threshold value $= \mu - 1.5\sigma$), the threshold value equals 0.4166. It derives the total-relation matrix X*:

$$X^{*} = \begin{bmatrix} 0.5765 & 1.1041 & 1.0303 & 1.1966 \\ 0.6952 & 0.7492 & 1.0041 & 1.1067 \\ 0.6027 & 0.9092 & 0.6530 & 0.9344 \\ 0.4293 & 0.5599 & 0.5874 & 0.4917 \end{bmatrix}$$

Step 4: Construct the causal relationship diagram. The DEMATEL method's total-relation matrix T was used to determine its centrality r + c and causality r-c. The causality diagram was constructed with r-c serving as the vertical axis and r + c serving as the horizontal axis. Table 7 depicts the degrees of centrality and causality among the first-level indicators.

Figure 4 depicts the causal relationship diagram to analyze the relationship between centrality and causality, with the arrows denoting the influence relationship. The

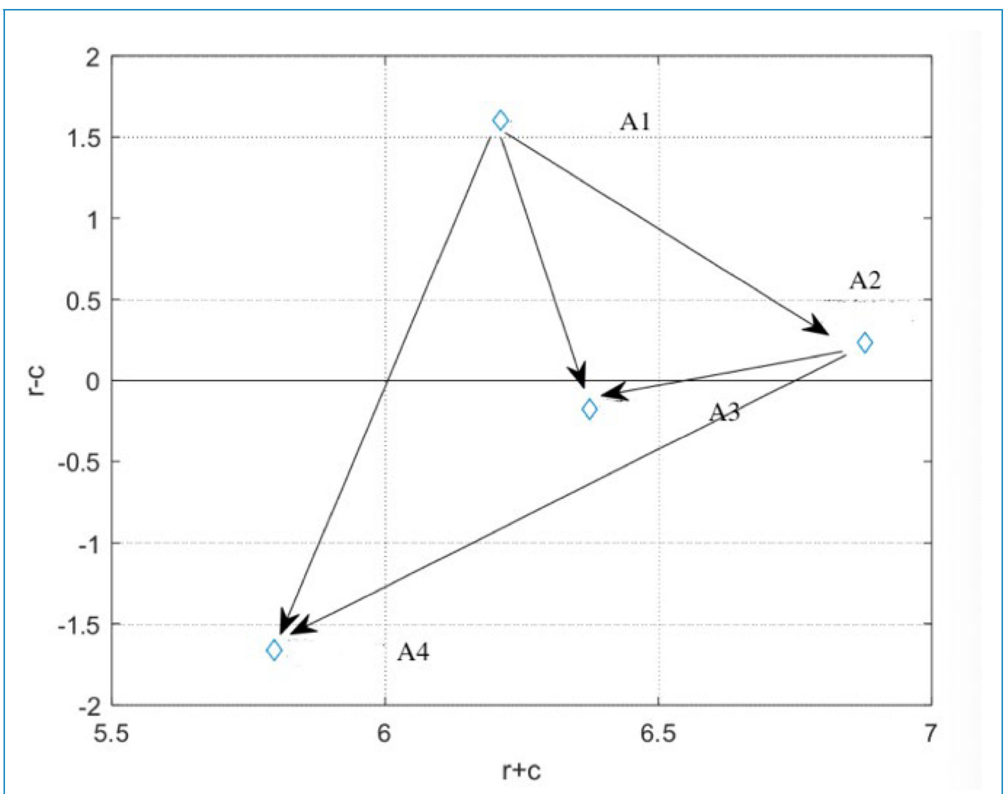

Figure 4. The causal relationship map of first-tier indicators.

horizontal coordinate is the centrality r + c value, the vertical coordinate is the causality r-c value, and the two lines are the mean value of centrality, and the number 0, respectively. The arrows with a centrality value of 0 or less are omitted.[61] And the meanings of the four quadrants are described in Table 8.[62]

According to Figure 4, the ranking of the first-tier indicators based on the centrality value (r + c) is as follows: service resources > service content > infrastructure > service performance. The ranking based on the degree of causality (r-c) is infrastructure > service resources > service content > service performance. Thus, infrastructure (r-c = 1.6042) and service resources (r-c = 0.2328) cause of the other two. Infrastructure is a crucial determinant for evaluating the service quality of smart elderly care, given its impact on the other three indicators.

Table 8. The instructions of four quadrants [62].

Quadrants	Instructions
First	Both centrality and causality are high, the elements are of high importance and are causal factors
Second	Low centrality, high causality; the elements are of low importance and are causal factors
Third	Low centrality and causality; the elements are of low importance and are passive factors
Fourth	High centrality, low causality; the elements are of high importance and are passive factors

The results of the second-tier and third-tier indicators. Also, the total-relation matrix T and X^* can be calculated based on the statistical results of the second-tier and third-tier indicators (Tables 9–15), the causal relationship maps of second-tier indicators are illustrated in Figure 5–8, and third-tier indicators are presented in Figures 11–20. On the basis of the statistical results, the paper identifies the most crucial determinants of each layer and lists some recommendations (Tables 16 and 17).

Due to the limited space of paper, the completed tables are presented in the Appendix. And the digital version has been uploaded to the following address: (https://figshare.com/articles/dataset/The_ANP_results_of_third-tier_indicators/22302307)

The Results of Weight Ranking

The integrated relationships generated by the DEMATEL method described above were programmed using MATLAB to create indicators, establish the influence relationships of elements under a certain criterion, select the elements to be compared, apply the ANP assessment scale (Saaty's 1–9 scales) to compare the elements two by two based on the initial direct relationship matrix of the secondary indicators, enter the importance of the two comparisons, form a judgment matrix, and perform consistency of the judgment matrix test. Following the test, it was determined that the CR value of each judgment matrix is less than 0.1, successfully passing the consistency test. The resultant influence relationship was then computed using the judgment matrix, resulting in the generation of the weighted and limit super matrices.

For the reason of space, only the limit supermatrix is listed in this paper.

The limit super matrix of smart elderly care infrastructure F1:

$$F1 = \begin{bmatrix} 0.3785 & 0.3649 & 0.4337 \\ 0.3172 & 0.3058 & 0.3633 \\ 0.3150 & 0.3038 & 0.3609 \end{bmatrix}$$

The limit super matrix of living services infrastructure F2:

$$F2 = \begin{bmatrix} 0.3697 & 0.3806 & 0.4090 & 0.4472 & 0.4836 & 0.5169 & 0.5568 \\ 0.3569 & 0.3674 & 0.3948 & 0.4316 & 0.4667 & 0.4989 & 0.5374 \\ 0.3212 & 0.3305 & 0.3551 & 0.3883 & 0.4198 & 0.4488 & 0.4834 \\ 0.2903 & 0.2987 & 0.3209 & 0.3509 & 0.3794 & 0.4056 & 0.4369 \\ 0.2737 & 0.2816 & 0.3026 & 0.3308 & 0.3577 & 0.3824 & 0.4119 \\ 0.2431 & 0.2500 & 0.2685 & 0.2936 & 0.3174 & 0.3394 & 0.3655 \\ 0.2269 & 0.2334 & 0.2506 & 0.2740 & 0.2961 & 0.3166 & 0.3410 \end{bmatrix}$$

Table 9. The initial direct-relationship matrix of the second-tier indicators.

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12
B1	0.0000	8.4000	7.9333	8.1333	7.6667	7.7333	7.8000	7.9333	7.7333	7.9333	7.2000	8.0000
B2	6.2000	0.0000	6.7333	6.3333	7.4667	5.8000	7.1333	6.7333	6.7333	7.2667	6.8000	7.0000
B3	4.0667	4.0667	0.0000	5.2000	5.4000	5.6000	5.9333	6.3333	6.8667	7.1333	6.7333	7.5333
B4	5.0000	4.6000	4.4667	0.0000	6.0667	4.2667	5.3333	6.7333	5.9333	7.9333	7.2000	6.8667
B5	6.0000	5.2667	5.9333	4.3333	0.0000	5.3333	5.8000	6.4000	6.2667	6.0000	6.8667	6.0667
B6	4.8667	3.6000	3.8000	4.8667	5.0667	0.0000	5.1333	5.4000	5.8000	6.0667	7.0667	6.8000
B7	4.2667	5.3333	5.4000	4.0667	3.5333	5.6000	0.0000	5.1333	5.0667	6.6000	6.6667	5.2667
B8	4.8667	5.3333	3.7333	5.2000	4.5333	4.6000	5.6000	0.0000	5.4000	6.0000	4.6000	6.4000
B9	4.4667	4.7333	3.5333	4.0667	5.5333	5.2000	5.8667	4.8000	0.0000	5.1333	5.6000	5.7333
B10	5.2000	4.6000	5.8000	4.6667	4.8667	5.2667	4.5333	5.2000	6.4000	0.0000	5.6000	3.9333
B11	5.8667	4.7333	4.0000	6.0000	4.6667	4.6667	4.2667	4.5333	4.6000	5.4000	0.0000	5.1333
B12	5.1333	5.0667	4.6667	5.5333	5.6667	4.0000	3.7333	5.8667	5.1333	4.8667	5.4000	0.0000

Table 10. The total-relation matrix of the second-tier indicators.

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12
B1	0.1900	0.2775	0.2731	0.2832	0.2847	0.2777	0.2876	0.3017	0.3027	0.3181	0.3091	0.3134
B2	0.2314	0.1633	0.2358	0.2384	0.2552	0.2320	0.2533	0.2603	0.2630	0.2797	0.2737	0.2723
B3	0.1879	0.1865	0.1410	0.2043	0.2107	0.2072	0.2170	0.2310	0.2389	0.2513	0.2463	0.2514
B4	0.1979	0.1926	0.1909	0.1480	0.2178	0.1937	0.2111	0.2354	0.2295	0.2596	0.2509	0.2444
B5	0.2086	0.2003	0.2068	0.1969	0.1533	0.2060	0.2175	0.2331	0.2341	0.2412	0.2489	0.2381
B6	0.1837	0.1697	0.1711	0.1883	0.1941	0.1336	0.1954	0.2072	0.2134	0.2250	0.2345	0.2289
B7	0.1746	0.1843	0.1851	0.1773	0.1755	0.1919	0.1368	0.2013	0.2030	0.2275	0.2272	0.2101
B8	0.1801	0.1841	0.1676	0.1880	0.1853	0.1808	0.1970	0.1449	0.2056	0.2206	0.2052	0.2209
B9	0.1723	0.1741	0.1616	0.1723	0.1912	0.1831	0.1956	0.1929	0.1422	0.2068	0.2109	0.2095
B10	0.1831	0.1762	0.1884	0.1824	0.1885	0.1879	0.1864	0.2014	0.2160	0.1557	0.2154	0.1960
B11	0.1864	0.1741	0.1665	0.1926	0.1828	0.1775	0.1793	0.1906	0.1930	0.2099	0.1500	0.2036
B12	0.1811	0.1796	0.1752	0.1898	0.1953	0.1727	0.1762	0.2066	0.2009	0.2069	0.2111	0.1502

Table 11. The total-relation matrix removed the threshold value of the second-tier indicators (threshold value = 0.15).

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12
B1	0.1900	0.2775	0.2731	0.2832	0.2847	0.2777	0.2876	0.3017	0.3027	0.3181	0.3091	0.3134
B2	0.2314	0.1633	0.2358	0.2384	0.2552	0.2320	0.2533	0.2603	0.2630	0.2797	0.2737	0.2723
B3	0.1879	0.1865	0.0000	0.2043	0.2107	0.2072	0.2170	0.2310	0.2389	0.2513	0.2463	0.2514
B4	0.1979	0.1926	0.1909	0.0000	0.2178	0.1937	0.2111	0.2354	0.2295	0.2596	0.2509	0.2444
B5	0.2086	0.2003	0.2068	0.1969	0.1533	0.2060	0.2175	0.2331	0.2341	0.2412	0.2489	0.2381
B6	0.1837	0.1697	0.1711	0.1883	0.1941	0.0000	0.1954	0.2072	0.2134	0.2250	0.2345	0.2289
B7	0.1746	0.1843	0.1851	0.1773	0.1755	0.1919	0.0000	0.2013	0.2030	0.2275	0.2272	0.2101
B8	0.1801	0.1841	0.1676	0.1880	0.1853	0.1808	0.1970	0.0000	0.2056	0.2206	0.2052	0.2209
B9	0.1723	0.1741	0.1616	0.1723	0.1912	0.1831	0.1956	0.1929	0.0000	0.2068	0.2109	0.2095
B10	0.1831	0.1762	0.1884	0.1824	0.1885	0.1879	0.1864	0.2014	0.2160	0.1557	0.2154	0.1960
B11	0.1864	0.1741	0.1665	0.1926	0.1828	0.1775	0.1793	0.1906	0.1930	0.2099	0.0000	0.2036
B12	0.1811	0.1796	0.1752	0.1898	0.1953	0.1727	0.1762	0.2066	0.2009	0.2069	0.2111	0.0000

Table 12. The value of Centrality (r + c) and Cause Degree (r-c) of the second-tier indicators.

Centrality and causality	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12
$r_i + c_i$	5.6960	5.2208	4.8366	4.9332	5.0190	4.6891	4.7476	4.8865	4.8550	5.0796	4.9897	4.9845
$r_i - c_i$	1.1417	0.6960	0.3105	0.2104	0.1503	0.0006	−0.1585	−0.3263	−0.4298	−0.5248	−0.5768	−0.4932

The limit super matrix of smart equipment F3:

$$F3 = \begin{bmatrix} 0.3319 & 0.3590 & 0.4008 & 0.4059 & 0.4377 & 0.4484 & 0.5027 \\ 0.3194 & 0.3455 & 0.3857 & 0.3906 & 0.4213 & 0.4316 & 0.4840 \\ 0.2801 & 0.3030 & 0.3381 & 0.3424 & 0.3693 & 0.3784 & 0.4243 \\ 0.2626 & 0.2840 & 0.3168 & 0.3208 & 0.3459 & 0.3545 & 0.3973 \\ 0.2345 & 0.2536 & 0.2829 & 0.2864 & 0.3088 & 0.3165 & 0.3547 \\ 0.2380 & 0.2573 & 0.2870 & 0.2906 & 0.3133 & 0.3211 & 0.3599 \\ 0.2103 & 0.2274 & 0.2536 & 0.2567 & 0.2767 & 0.2836 & 0.3178 \end{bmatrix}$$

The limit super matrix of medical care package F4:

$$F4 = \begin{bmatrix} 0.3022 & 0.3225 & 0.3339 & 0.3462 & 0.3824 \\ 0.3012 & 0.3214 & 0.3328 & 0.3451 & 0.3811 \\ 0.2792 & 0.2980 & 0.3085 & 0.3199 & 0.3533 \\ 0.2534 & 0.2703 & 0.2798 & 0.2902 & 0.3205 \\ 0.2411 & 0.2572 & 0.2663 & 0.2761 & 0.3049 \end{bmatrix}$$

The limit super matrix of staffing F5:

$$F5 = \begin{bmatrix} 0.3098 & 0.3166 & 0.3437 & 0.3922 \\ 0.2870 & 0.2933 & 0.3183 & 0.3632 \\ 0.2645 & 0.2703 & 0.2933 & 0.3346 \\ 0.2590 & 0.2647 & 0.2873 & 0.3277 \end{bmatrix}$$

Table 13. The initial direct-relation matrix of the third-tier indicators.

	C1	C2	C3	C4	C5	...	C50	C51	C52	C53	C54
C1	0.0000	8.4667	8.2667	7.6667	8.4667	...	8.6667	9.0000	7.8000	8.0000	7.9333
C2	7.5333	0.0000	8.2667	7.5333	7.6000	...	8.7333	5.6667	7.3333	7.8667	8.0000
C3	8.0000	8.5333	0.0000	7.6667	7.6667	...	8.5333	5.3333	7.5333	7.8667	7.7333
C4	8.3333	8.4000	8.0667	0.0000	8.4000	...	8.7333	4.8667	6.8000	8.4000	8.0000
C5	7.8000	8.2667	8.4000	8.0000	0.0000	...	8.2000	4.6667	8.0667	7.8667	8.0667
...	...	...	...	...	...	...	...	...	...	...	...
C50	5.0000	4.0667	4.4667	5.3333	5.2000	...	0.0000	5.2000	5.4667	4.8667	4.2667
C51	4.2667	5.4000	7.0000	5.8000	4.7333	...	5.3333	0.0000	4.8667	4.7333	5.4667
C52	5.2000	4.5333	6.2000	4.2000	5.4667	...	4.9333	5.2000	0.0000	5.8000	4.8000
C53	5.8667	4.9333	3.9333	4.1333	4.2667	...	5.7333	3.4000	5.6667	0.0000	5.0667
C54	5.4667	4.5333	5.0000	5.3333	4.2000	...	5.4000	4.8667	6.2667	4.7333	0.0000

The limit super matrix of service reliability F6:

$$F6=\begin{bmatrix}0.3106 & 0.3261 & 0.3344 & 0.4944 & 0.4108 & 0.4081\\ 0.2942 & 0.3089 & 0.3168 & 0.4681 & 0.3891 & 0.3866\\ 0.2781 & 0.2920 & 0.2994 & 0.4423 & 0.3677 & 0.3653\\ 0.2476 & 0.2600 & 0.2667 & 0.3936 & 0.3274 & 0.3253\\ 0.2286 & 0.2400 & 0.2461 & 0.3632 & 0.3021 & 0.3002\\ 0.2112 & 0.2218 & 0.2274 & 0.3355 & 0.2791 & 0.2774\end{bmatrix}$$

The limit super matrix of platform intelligence F7:

$$F7=\begin{bmatrix}0.2936 & 0.3019 & 0.3343 & 0.3771\\ 0.2759 & 0.2837 & 0.3141 & 0.3543\\ 0.2512 & 0.2583 & 0.2860 & 0.3226\\ 0.2375 & 0.2442 & 0.2704 & 0.3049\end{bmatrix}$$

The limit super matrix of privacy protection F8:

$$F8=\begin{bmatrix}0.2780 & 0.3578 & 0.3144\\ 0.2536 & 0.3263 & 0.2868\\ 0.2322 & 0.2988 & 0.2626\end{bmatrix}$$

The limit super matrix of service responsiveness F9:

$$F9=\begin{bmatrix}0.2566 & 0.3218 & 0.3228 & 0.3068\\ 0.2192 & 0.2749 & 0.2758 & 0.2621\\ 0.2006 & 0.2515 & 0.2523 & 0.2397\\ 0.1699 & 0.2130 & 0.2136 & 0.2029\end{bmatrix}$$

The limit super matrix of service empathy F10:

$$F10=\begin{bmatrix}0.2636 & 0.2432 & 0.2606\\ 0.2442 & 0.2253 & 0.2414\\ 0.2084 & 0.1922 & 0.2059\end{bmatrix}$$

The limit super matrix of intention to use F11:

$$F11=\begin{bmatrix}0.2122 & 0.1903 & 0.2331\\ 0.2008 & 0.1803 & 0.2206\\ 0.1579 & 0.1418 & 0.1734\end{bmatrix}$$

The limit super matrix of customer satisfaction F12:

$$F12=\begin{bmatrix}0.1783 & 0.1362 & 0.1818 & 0.2164 & 0.2213\\ 0.1828 & 0.1393 & 0.1863 & 0.2220 & 0.2270\\ 0.1707 & 0.1303 & 0.1740 & 0.2073 & 0.2120\\ 0.1771 & 0.1351 & 0.1804 & 0.2150 & 0.2199\\ 0.1444 & 0.1104 & 0.1472 & 0.1752 & 0.1792\end{bmatrix}$$

Thus, the weight of each indicator can be calculated as presented in Table 18. The final ranking of the indicators is displayed in Table 19.

According to Tables 18 and 19, the study calculated and presented the weights of key service quality indicators for smart elderly care institutions. In the first-tier indicators, infrastructure (W = 0.3111) was the most important dimension. In the second-tier indicators, smart elderly care infrastructure (LW = 0.5342, GW = 0.1241), living services infrastructure (LW = 0.4658, GW =0.1082), and intention to use (LW = 0.5195, GW = 0.0778) are the key indicators. While in the third-tier indicators, the rate of health file creation (GW = 0.0252), 3S equipment coverage (GW = 0.0242), average living space per bed (GW = 0.0237), outdoor activity space (GW = 0.0235), ICT investment rate (GW = 0.0231), health room per bed (GW = 0.0229), and availability of cultural and sports room (GW = 0.0227) own a more significant weight, which indicates that primarily improving these

Table 14. The total-relation matrix of the third-tier indicators.

	C1	C2	C3	C4	C5	...	C50	C51	C52	C53	C54
C1	0.0754	0.0867	0.0903	0.0954	0.0971	...	0.0979	0.0758	0.0803	0.0850	0.0971
C2	0.0902	0.0659	0.0882	0.0929	0.0931	...	0.0959	0.0669	0.0775	0.0828	0.0950
C3	0.0910	0.0848	0.0696	0.0930	0.0930	...	0.0952	0.0660	0.0778	0.0826	0.0942
C4	0.0921	0.0848	0.0879	0.0762	0.0950	...	0.0960	0.0652	0.0765	0.0841	0.0951
C5	0.0908	0.0844	0.0886	0.0940	0.0761	...	0.0948	0.0647	0.0792	0.0829	0.0952
...	...	...	...	...	...	...	...	...	...	...	...
C50	0.0593	0.0524	0.0559	0.0619	0.0615	...	0.0500	0.0472	0.0523	0.0537	0.0602
C51	0.0578	0.0556	0.0616	0.0631	0.0607	...	0.0622	0.0356	0.0511	0.0536	0.0630
C52	0.0589	0.0527	0.0589	0.0585	0.0613	...	0.0604	0.0466	0.0394	0.0551	0.0605
C53	0.0601	0.0533	0.0536	0.0580	0.0584	...	0.0619	0.0424	0.0519	0.0418	0.0608
C54	0.0583	0.0516	0.0551	0.0597	0.0572	...	0.0601	0.0450	0.0524	0.0517	0.0484

Table 15. The total-relation matrix of the third-tier indicators with the threshold removed (threshold value = 0.15).

	C1	C2	C3	C4	C5	...	C50	C51	C52	C53	C54
C1	0.0754	0.0867	0.0903	0.0954	0.0971	...	0.0979	0.0758	0.0803	0.0850	0.0971
C2	0.0902	0.0659	0.0882	0.0929	0.0931	...	0.0959	0.0669	0.0775	0.0828	0.0950
C3	0.0910	0.0848	0.0696	0.0930	0.0930	...	0.0952	0.0660	0.0778	0.0826	0.0942
C4	0.0921	0.0848	0.0879	0.0762	0.0950	...	0.0960	0.0652	0.0765	0.0841	0.0951
C5	0.0908	0.0844	0.0886	0.0940	0.0761	...	0.0948	0.0647	0.0792	0.0829	0.0952
...	...	...	...	...	...	...	...	...	...	...	...
C50	0.0593	0.0000	0.0559	0.0619	0.0615	...	0.0000	0.0000	0.0000	0.0537	0.0602
C51	0.0578	0.0556	0.0616	0.0631	0.0607	...	0.0622	0.0000	0.0000	0.0536	0.0630
C52	0.0589	0.0000	0.0589	0.0585	0.0613	...	0.0604	0.0000	0.0000	0.0551	0.0605
C53	0.0601	0.0533	0.0536	0.0580	0.0584	...	0.0619	0.0000	0.0000	0.0000	0.0608
C54	0.0583	0.0000	0.0551	0.0597	0.0572	...	0.0601	0.0000	0.0000	0.0000	0.0000

indicators can more effectively prompt the service quality of intelligent elderly care institution.

In this scenario, the necessity of sensitivity analysis in the DEMATEL-ANP approach is obviated. Following three iterations of a refined Delphi process, the data sources have been deemed credible, and the concordance of expert opinions is apparent, signifying a substantial consensus in the model's outcomes.[63,64] Consequently, the preliminary findings of the model are deemed adequate to inform decision-making processes.

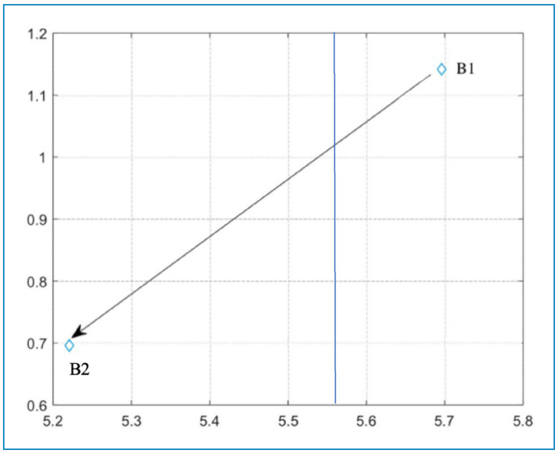

Figure 5. The causal relationship diagram of infrastructure.

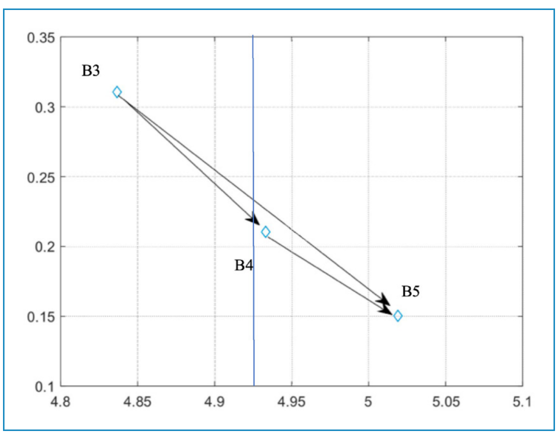

Figure 6. The causal relationship diagram of service resource.

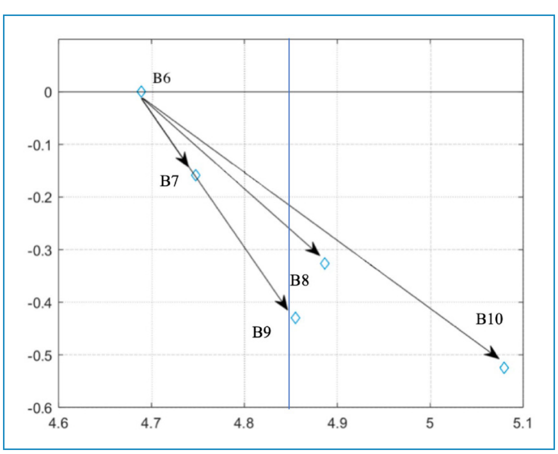

Figure 7. The causal relationship diagram of service content.

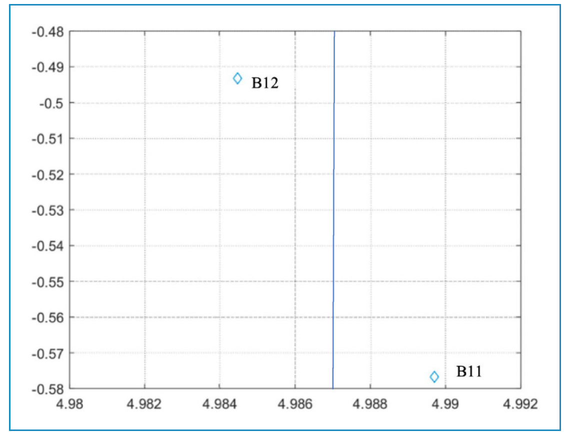

Figure 8. The causal relationship diagram of service outcome.

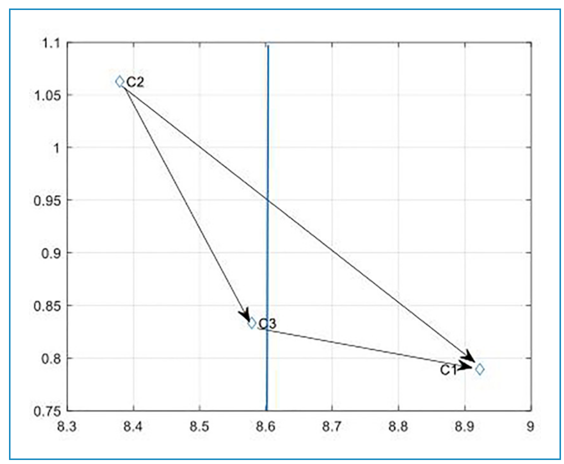

Figure 9. The causal relationship diagram of smart elderly care.

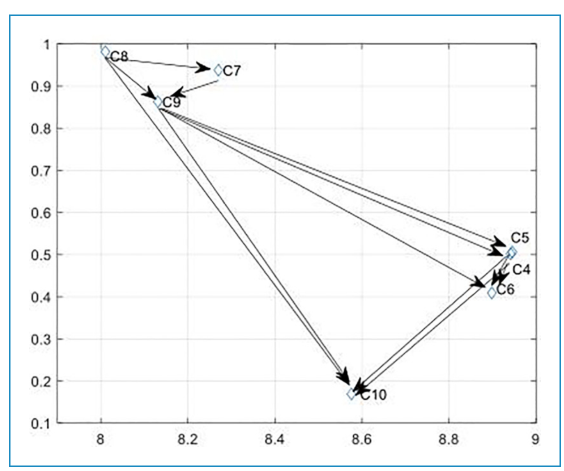

Figure 10. The causal relationship diagram of living services infrastructure.

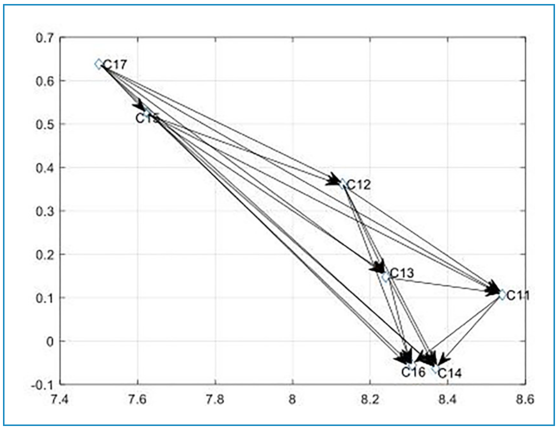

Figure 11. The causal relationship diagram of smart equipment.

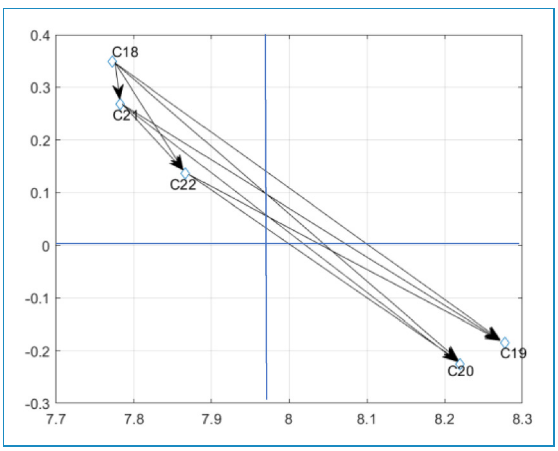

Figure 12. The causal relationship diagram of medical supporting package.

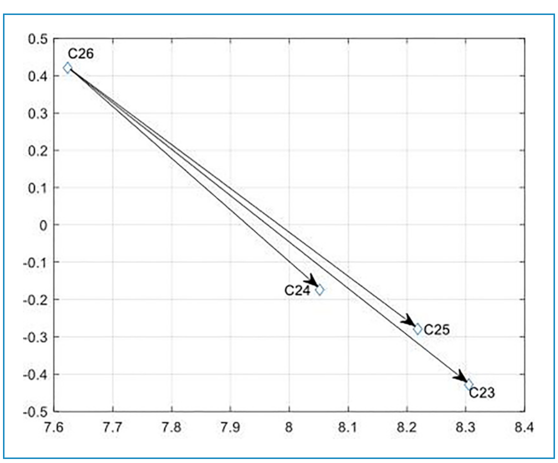

Figure 13. The causal relationship diagram of staffing.

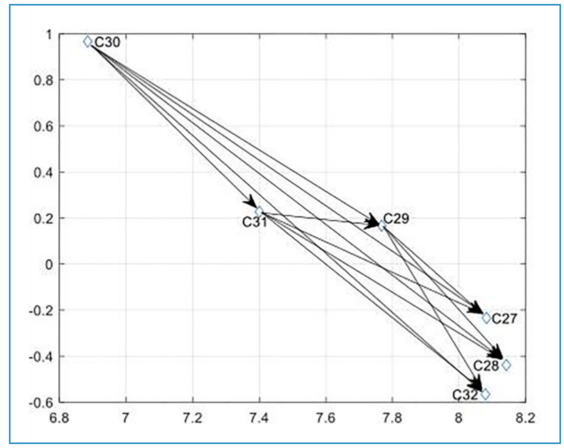

Figure 14. The causal relationship diagram of service reliability.

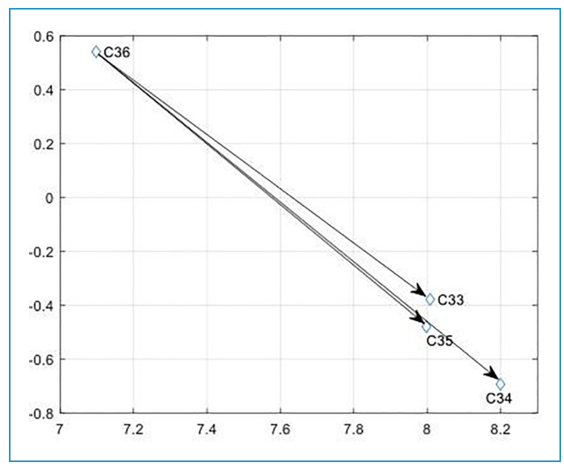

Figure 15. The causal relationship diagram of platform intelligence.

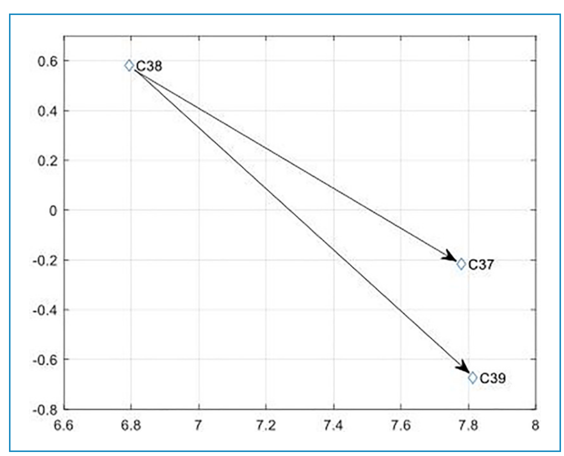

Figure 16. The causal relationship diagram of privacy protection.

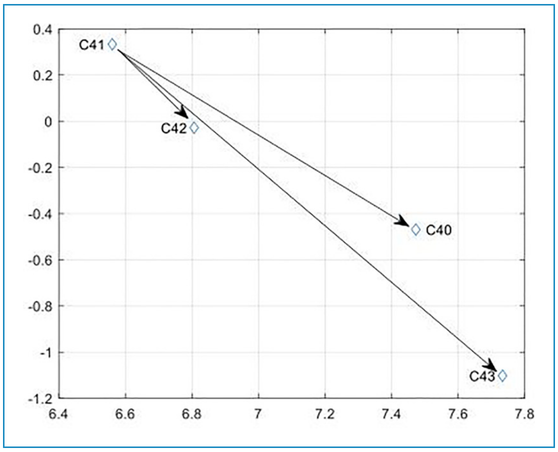

Figure 17. The causal relationship diagram of service responsiveness.

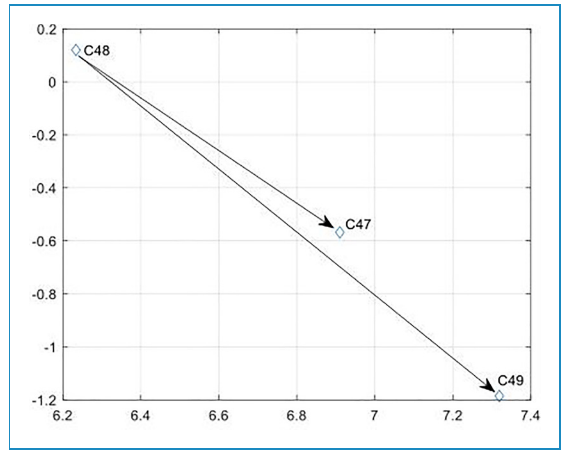

Figure 19. The causal relationship diagram of intention to use.

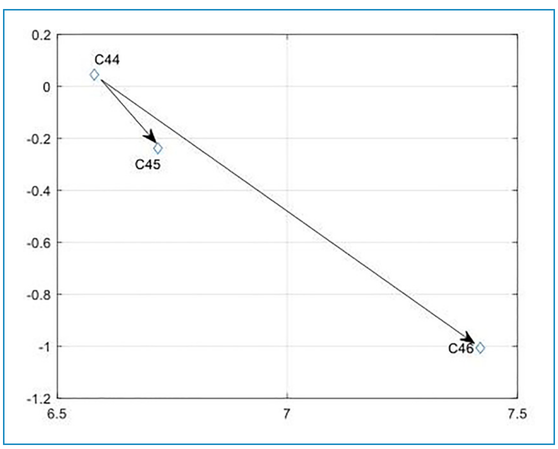

Figure 18. The causal relationship diagram of service empathy.

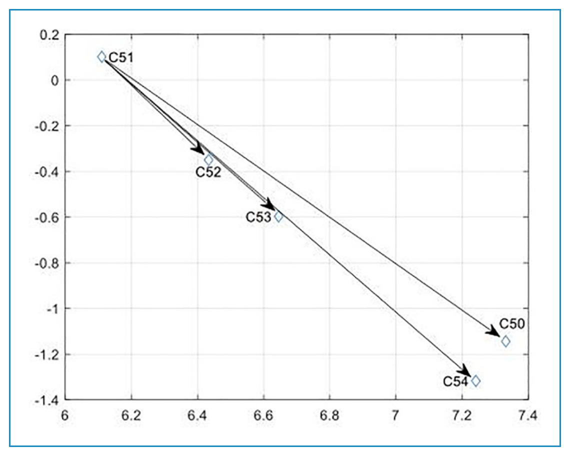

Figure 20. The causal relationship diagram of customer satisfaction.

Discussion

This study integrates the results of weights ranking to present a comprehensive discussion and suggestion for smart elderly care institutions to enhance their service quality:

"Service resource" is the core factor

The first-tier indicators contain four factors, and the centrality ranks as follows: service resource, service content, infrastructure, and service outcome. This finding indicates that service resource is the core factor with the strongest influence capacity. Also, the status of causality and weights presents that the service resource ranks in the top two positions. Zhao and Zhao[27] stated that the "hardware application," mainly refers to intelligence equipment, is the key factor in enhancing the service quality of smart elderly care institutions. Li et al.[26] presented that the "nursing care resource" with the medical service level and smart equipment are the critical quality characteristics. Therefore, this study's results are consistent with those of the above academic works. Thus, we confirm that the Service resource is the core factor among the first-tier indicators. To improve the service quality of smart elderly care, we can solidify the infrastructure and service resources. For instance, leveraging various resources and funds in the field of the big health industry, smart elderly care institutions can vigorously develop elderly companion robots and intelligent interaction platforms to provide personalized spiritual comfort services to elderly users by adding technical functions such as voice interaction, multiperson chat, and video calls. Moreover, institutions can implement Internet of Things (IoT)-based healthcare systems that integrate wearable technologies to monitor clinical health

Table 16. The results of second-tier indicators.

Second-tier indicators (Figure 5–8)	Ranking of Centrality(r + c)	Ranking of Causality(r-c)	Crucial determinants/ suggestions
Infrastructure	Smart elderly care infrastructure > living services infrastructure	Smart elderly care infrastructure > living services infrastructure	Smart elderly care infrastructure
Service resources	Staffing > medical support resource > smart equipment	Smart equipment > medical care package > staffing	Medical support resource and staffing
Service content	Service empathy > privacy > service responsiveness > platform intelligence > service reliability	Service reliability > platform intelligence > privacy > service responsiveness > service empathy	Service reliability
Service performance	Customers' intention to use > customers' satisfaction	All the indicators' causality degrees are negative	Customers' intention to use

parameters, recognize physical activities, and manage chronic diseases, mental health conditions, and cognitive disorders.[65]

Infrastructure and other hard service resources are the key factors

The "Smart elderly care infrastructure" refers to the Wi-Fi, smart network, and 3S (RS, GIS, GPS) building, ranks No.1 of centrality among the second-tier indicators. It is considered the base and foundation of smart elderly care services. Feng and Hei[66] stated that the long-term development of smart aging services is closely related to the level of investment in solid infrastructure. Therefore, investment in smart infrastructure is a key approach to enhancing service quality. The "3S (RS, GIS, GPS) device coverage" ranks second among all the third-tier indicators; it is also an active impact factor that can influence on "Smart network rollout rate" and "ICT capital investment rate." In modern information technology, the collective term "3S" refers to space technology, sensor technology, satellite positioning and navigation technology, computer technology, and communication technology. It is very well integrated with a multidisciplinary strategy for acquiring, processing, managing, analyzing, expressing, disseminating, and using space data.[67] Thus, it is the technical foundation of IoT, VR, and other information technologies applied in smart elderly care industry. Hence, to improve the service quality, one of the effective ways is to develop smart device coverage. Encouraging and guiding the migration of talented individuals in information technology, big data, IoT, cloud, and other relevant fields to the smart elderly service industry can significantly enhance the knowledge and skills of practitioners in this domain.[68]

"Staffing" is the key factor in "service resource"

The quality of employees is always a prevalent issue in the service industry. Moreover, the elderly nursing staffs need basic medical, healthcare management, and nursing knowledge. Chen et al.[51] presented that the "service personnel" is a relatively crucial factor that acquire a weight of 0.392 in their research. Hence, developing a training system for skilled professionals in the big health and elderly service industries can expand the construction of medical and recreational professional technical and service personnel teams. Furthermore, institutions can integrate advanced technologies, including wearable sensors and artificial intelligence,[69] to enhance the quality of nursing care and improve the overall experience of healthcare staff. Additionally, establishing standardized protocols for nursing home staff is essential to ensure the reliability and professionalism of service personnel.

"Service empathy" is the crucial factor in "Service content"

"Service empathy" refers to helpful and caring employees, understanding nurses, and no discrimination. Ko and Chou[70] stated that the dimension of "empathy" acquires a high importance score to measure the service quality of the ICT technology-based nursing home. This finding implies that although technologies are fundamental to smart elderly care, affection, and caring are indispensable factors that can effectively enhance service quality. Smart elderly care systems offer significant convenience and enhance the quality of life for seniors; however, they may inadvertently reduce interpersonal interactions among the elderly.[71] To address this, institutions can leverage the time saved through smart technologies to provide holistic

Table 17. The results of third-tier indicators.

Third-tier indicators (Figure 11–20)	Ranking of centrality(r + c)	Ranking of causality(r-c)	Crucial determinants/ suggestions
Smart elderly care infrastructure	C1 > C3 > C2	C2 > C3 > C1	• Smart network deployment rate can affect the other two factors • "3S device coverage" is the most effective way to develop the construction of intelligent infrastructure
Living services infrastructure	C4 > C5 > C6 > C10 > C7 > C9 > C8	C8 > C7 > C9 > C5 > C4 > C6 > C10	• The physical and mental health of the elderly • The suitable indoor and outdoor activity areas • The suitable living space • The sufficient medical care space
Smart equipment	C11 > C14 > C16 > C13 > C12 > C15 > C17	C17 > C15 > C12 > C13 > C1 > C16 > C14	• The penetration rate of wearable devices is the causal factor • The most important criterion is the prevalence of smart health devices
Medical care package	C19 > C20 > C22 > C21 > C18	C18 > C21 > C22 > C19 > C20	• The availability of home healthcare services is the primary causal factor • The most efficient way is to provide sufficient offline medical care services
Staffing	C23> C25 > C24 > C26	C26 > C24 >C25> C23	• Managerial talents who have qualifications and a sense of intelligent facility can influence other factors • The most effective way is to improve the professions of nursing talents
Service reliability	C28 > C27 >C32 >C29 > C31 > C30	C30 > C31> C29 > C27 > C28 > C32	• Archiving health records is a reliable and professional service activity that can influence other factors • The number of cleaning and nursing services for the disabled elderly is the key factor in improving the service quality.
Platform intelligence	C34 > C33 > C35 > C36	C36 > C33 > C35 > C34	• The intelligent services complemented by human services will affect the other related elements • The sensitivity of the intelligent platform is the most attractive factor to improve service quality
Privacy protection	C39 > C37 > C38	C38 > C37 > C39	• Platform privacy protection is the most important factor • The most effective way to maintain and enhance privacy is to protect transaction and payment privacy
Service responsiveness	C43 > C40 > C42 > C41	C42 > C42 >C40 > C43	• The customers are eager to find out the exact time for the service • They prefer that the staff can correct the errors in the service process immediately
Service empathy	C46 > C45 > C44	C44 > C45 > C46	• The staff's hospitality is the most important criterion • The most important factor is not to discriminate against the elderly
Intention to use	C49 > C47 > C48	C48 > C47 > C49	• Customers are willing to adopt smart elderly care as the most important element • When they recommend the services to others, they have accepted the smart elderly care services
Customer satisfaction	C50 > C54 > C53> C52 > C51	C51 > C52 > C53 > C50 > C54	• Satisfaction with nursing services is the main indicator • Satisfaction with the use of smart devices in nursing facilities is the key factor to improve customer satisfaction

Table 18. The weights of indicators.

First-tier indicators	Second-tier indicators	Global weight	Third-tier indicators	Local weight	Global weight
A1 (0.3111)	B1 (0.5342)	0.1241	C1	0.3621	0.0242
			C2	0.2926	0.0196
			C3	0.3453	0.0231
	B2 (0.4658)	0.1082	C4	0.1490	0.0237
			C5	0.1481	0.0235
			C6	0.1431	0.0227
			C7	0.1414	0.0225
			C8	0.1442	0.0229
			C9	0.1368	0.0217
			C10	0.1374	0.0218
A2 (0.2724)	B3 (0.3273)	0.0839	C11	0.1453	0.0212
			C12	0.1513	0.0221
			C13	0.1480	0.0216
			C14	0.1405	0.0205
			C15	0.1352	0.0198
			C16	0.1406	0.0206
			C17	0.1391	0.0203
	B4 (0.3201)	0.0820	C18	0.1979	0.0193
			C19	0.2105	0.0206
			C20	0.2020	0.0197
			C21	0.1900	0.0186
			C22	0.1997	0.0195
	B5 (0.3525)	0.0904	C23	0.2531	0.0198
			C24	0.2396	0.0188
			C25	0.2396	0.0188
			C26	0.2677	0.0210
A3 (0.2625)	B6 (0.1956)	0.0708	C27	0.1642	0.0199

(continued)

Table 18. Continued.

First-tier indicators	Second-tier indicators	Global weight	Third-tier indicators	Local weight	Global weight
			C28	0.1633	0.0198
			C29	0.1583	0.0192
			C30	0.2080	0.0252
			C31	0.1597	0.0193
			C32	0.1466	0.0178
	B7 (0.1989)	0.0720	C33	0.2513	0.0188
			C34	0.2428	0.0182
			C35	0.2448	0.0183
			C36	0.2610	0.0195
	B8 (0.2030)	0.0734	C37	0.3206	0.0178
			C38	0.3765	0.0209
			C39	0.3029	0.0168
	B9 (0.1940)	0.0702	C40	0.2600	0.0164
			C41	0.2786	0.0176
			C42	0.2557	0.0161
			C43	0.2057	0.0130
	B10 (0.2085)	0.0754	C44	0.3794	0.0169
			C45	0.3243	0.0144
			C46	0.2963	0.0132
A4 (0.1540)	B11 (0.5195)	0.0778	C47	0.3749	0.0136
			C48	0.3186	0.0115
			C49	0.3065	0.0111
	B12 (0.4805)	0.0719	C50	0.2013	0.0114
			C51	0.1573	0.0089
			C52	0.1964	0.0111
			C53	0.2427	0.0138
			C54	0.2023	0.0115

Table 19. The weight ranking results.

Indicator	Weight	Indicator	Weight	Indicator	Weight
C30	0.0252	C2	0.0203	C35	0.0178
C1	0.0242	C15	0.0199	C37	0.0178
C4	0.0237	C17	0.0198	C41	0.0176
C5	0.0235	C20	0.0198	C39	0.0169
C3	0.0231	C22	0.0198	C44	0.0168
C6	0.0229	C23	0.0197	C40	0.0164
C8	0.0227	C27	0.0196	C42	0.0161
C7	0.0225	C28	0.0195	C45	0.0144
C9	0.0221	C36	0.0195	C47	0.0138
C10	0.0218	C18	0.0193	C53	0.0136
C12	0.0217	C21	0.0193	C43	0.0132
C13	0.0216	C24	0.0192	C46	0.0130
C11	0.0212	C25	0.0188	C48	0.0115
C14	0.0210	C29	0.0188	C49	0.0115
C16	0.0209	C31	0.0188	C50	0.0114
C19	0.0206	C33	0.0186	C52	0.0111
C26	0.0206	C32	0.0183	C54	0.0111
C38	0.0205	C34	0.0182	C51	0.0089

care, ensuring the psychological and physical well-being of seniors while also supporting their spiritual needs.

"Intention to use" is the important factor in "Service outcome"

"Intention to use" ranks number five for centrality, which implies that the willingness to accept smart elderly care service is relatively crucial compared to customer satisfaction. It is a special indicator that focuses on the consumers. Pan[45] emphasized that the propaganda and advocacy of smart elderly care effectively reflect the service quality. Thus, for practical industries, to provide personalized and refined elderly services that can enhance service satisfaction and willingness to adopt, it is crucial to identify and categorize the needs of elderly users. Furthermore, Chan et al.[46] emphasize that trust, particularly concerning data protection, positively influences usage intentions. Therefore, prioritizing data privacy and implementing robust data protection measures can significantly enhance the willingness of users to adopt these services.

Conclusion

In summary, this study has developed an evaluation system for the quality of smart aging services, which identifies the professional competencies that smart aging organizations should possess. By combining Modified-Delphi and DEMATEL-ANP, we can further analyze the relationships and linkages between the indicators of service quality assessment to better understand which indicators are the most critical core competencies for improving the service quality of smart elderly care organizations. These findings will be a reference for future professional competency development and assessment of service quality in elderly care facilities.

This study offers potential innovations in four key areas:

By integrating the SPO theoretical framework, the theory of Cooperative Development Model of Science & Technology Service, and social technology theory, this research expands the theoretical underpinnings of smart elderly care institutions. It creatively proposes a "Technology + Service" synergistic theoretical framework," enriching the theoretical and knowledge structure of smart elderly care services.

From the perspective of technology-service synergy, this study explores innovative service models tailored to the new scenarios of smart elderly care institutions characterized by intelligence, integration, and personalization. It integrates multistakeholder and societal resources to construct an evaluation system for service quality, incorporating multifactor collaborative effects. This provides a novel research approach for investigating multiple development paths to enhance service quality in smart elderly care.

The practical significance of this study firstly lies in its development of enriching the factors influencing the quality of smart elderly care services. It points out the direction for the high-quality development of smart elderly care institutions. By applying this evaluation system to actual institutions, weaknesses, leaks, pain points, and difficulties in service quality can be identified in a targeted manner.

It contributes to developing standardized policies for services in the elderly care industry. This study can address the issue of standardization in the elderly care industry by providing a reliable and scientific standard or specification for new private enterprises that enter the industry, which can make the silver hair economy a sunrise industry and mitigate the complex problem of China's aging population. Ultimately, this study can promote the healthy and sustainable development of the intelligent elderly care industry.

There are still some limitations which can be improved by the future research: The method is based on expert scoring of the relationships between model criteria and model indicators, but the lack of regional expansion of experts due to resource constraints impacts the research results. It is necessary to consider a multiregional and extensive collection of research in the future, which will increase the generalizability and guiding nature of the research findings. Therefore, a future study could concentrate on testing the evaluation system's accuracy after there are representative smart elderly care institutions.

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Contributorship: XYL was responsible for the study design and the article's drafting. XXL was responsible for data collecting. YW was responsible for data analyzing and interpreting. KYC was responsible for critically revising. All authors read and approved the final manuscript.

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Appendix

Appendix A. The Original Version of Service Quality Evaluation System

First-tier indicators	Code	Second-tier indicators	Code	Third-tier indicators	Code	Source
Infrastructure (Structure)	A1	Smart elderly care infrastructure	B1	3S (RS, GIS, GPS) device coverage	C1	[27,51]
				Smart grid roll-out rate	C2	
				ICT capital investment rate	C3	
				Total area of aged care buildings	C4	
				Amount of investment in fixed assets	C5	
		Foundation talent structure	B2	Number of nursing professionals	C6	
				Number of medical professionals	C7	
				Proportion of management staff with professional training	C8	
Service Resources (Structure)	A2	Smart elderly care platform	B3	Stable operation of the service platform operating system and fast access speed	C9	[48]
				The platform operating system APP is reasonably designed and fully functional	C10	
				The interface of the platform operating system is easy to understand and easy to use	C11	
				The service platform can share information about the elderly with family members	C12	
		Smart equipment	B4	Penetration rate of smart health devices	C13	[27]
				Prevalence rate of intelligent accident monitoring devices	C14	
				Prevalence rate of smart elderly care devices	C15	
		Service Environment	B5	Room lighting, temperature and humidity and noise	C16	[45,47]
				Area of living room per bed (≥12.0 sqm/bed)	C17	
				Area of outdoor activity space per bed (≥12 m2 per person)	C18	
				Greening rate of outdoor activity space (≥150 m2 of outdoor activity space and ≥60% greening area)	C19	
		Medical service equipment	B6	Availability of medical care at home	C20	[26]
				Availability of medical care offline services	C21	
				Availability of medical care remote services	C22	
				Number of corporate partner hospitals	C23	
				Level of partner hospitals	C24	

(continued)

Appendix A. Continued.

First-tier indicators	Code	Second-tier indicators	Code	Third-tier indicators	Code	Source
				Title of medical staff	C25	
		Living and recreational facilities	B7	Health care room per bed (≥3.0 m2)	C26	[45]
				Ratio of bathrooms for wheelchair users to beds	C27	
				Availability of a cultural and sports activity room	C28	
				Availability of psychological support room	C29	
				Availability of a hospice room	C30	
Service content (Process)	A3	Service reliability	B8	Reasonable nutritional mix of meals provided	C31	[45,49]
				Average daily number of cleaning and nursing services for the elderly with disabilities	C32	
				Professional psychological counselling skills of service personnel	C33	
				Rate of health file creation	C34	
				Staff have professional first aid knowledge and skills	C35	
				Number of times activity areas and objects are disinfected	C36	
				Whether general emergency treatment can be carried out	C37	
		Intelligence of platform	B9	The service platform provides personalized information pushing services	C38	[22,48]
				Sensitivity and false alarm rate	C39	
				The service platform provides diversified services such as APP phone	C40	
				The service platform provides 24-h human service	C41	
		Privacy protection	B10	Protection of user information privacy	C42	(Xu et al., 2021)
				Transaction and payment privacy protection	C43	
				Platform system privacy protection	C44	
		Service responsiveness	B11	On-time delivery of agreed service items	C45	[49]
				Service personnel can respond to your service requests in the first instance	C46	
				The service staff can give you an exact time for the service that cannot be dealt with immediately	C47	
				Service staff are prompt to remedy any errors in the service process	C48	
		Service Empathy	B13	Staff are helpful, careful, and friendly	C49	[20]

(continued)

Appendix A. Continued.

First-tier indicators	Code	Second-tier indicators	Code	Third-tier indicators	Code	Source
				Caregivers are aware of the needs of the elderly	C50	
				No discrimination against the elderly	C51	
Service performance (Outcome)	A4	Social benefits	B14	Number of times staff attended standardized training	C52	[45]
				Benefit measures	C53	
				Number of social events	C54	
		Service satisfaction	B15	Satisfied with the use of smart devices	C55	[48]
				Satisfaction with services of life care	C56	
				Satisfaction with services of safety and care	C57	
				Satisfaction with services of spiritual comfort	C58	
				Satisfaction with health care services	C59	

Appendix B. The Finally Version of Service Quality Evaluation System.

First-tier indicators	Code	Second-tier indicators	Code	Third-tier indicators	Code
Infrastructure	A1	Smart elderly care infrastructure	B1	3S (RS, GIS, GPS) device coverage	C1
				Smart network rollout rate	C2
				ICT capital investment rate (ICT)	C3
		Living services infrastructure	B2	Average living space per bed (≥12.0 sqm/bed)	C4
				Outdoor activity space greening rate (outdoor activity space ≥ 150 m^2 and greening area ≥60%)	C5
				Healthcare room per bed (≥3.0 m^2)	C6
				Bathroom and bed for wheelchair users	C7
				Room for cultural and sports activities	C8
				Psychological counselling room	C9
				Availability of a hospice room	C10
Service resources (Structure)	A2	Smart equipment	B3	Intelligent health management device penetration rate (blood glucose, blood pressure, body fat and other basic devices)	C11
				Intelligent accident monitoring equipment penetration rate	C12
				Intelligent elderly care equipment penetration rate	C13
				Intelligent rehabilitation equipment penetration rate	C14
				Penetration rate of self-help health monitoring equipment	C15
				Penetration rate of grassroots follow-up equipment	C16
				Penetration rate of wearable devices such as watches, bracelets and belts	C17
		Medical supporting resource	B4	Availability of home healthcare services	C18
				Availability of offline medical care services	C19
				Availability of remote medical care services	C20
				Number of partner hospitals	C21
				Grade of the hospital the company is working with	C22
		Staffing	B5	Percentage of nursing professionals	C23
				Percentage of medical professionals	C24

(continued)

Appendix B. Continued.

First-tier indicators	Code	Second-tier indicators	Code	Third-tier indicators	Code
				Percentage of management staff who have received professional training	C25
				Percentage of talents in intelligent facility management	C26
Service content (Process)	A3	Service reliability	B6	Reasonable nutritional mix of meals provided	C27
				Average daily number of cleaning and nursing services for the elderly with disabilities	C28
				Service personnel have professional psychological counselling skills	C29

First-tier indicators	Code	Second-tier indicators	Code	Third-tier indicators	Code
				The rate of health file creation	C30
				Service personnel have professional first aid knowledge and skills	C31
				Whether they can handle general emergencies	C32
		Platform intelligence	B7	Service platform provides personalized information services	C33
				Service platform stability and access speed	C34
				Service platform operation interface is easy to understand	C35
				Service platform can share information with children	C36
		Privacy protection	B8	Protection of user information privacy	C37
				Transaction and payment privacy protection	C38
				Platform system privacy protection	C39
		Service responsiveness	B9	On-time delivery of agreed service items	C40
				Service personnel can respond to your service requests in the first instance	C41
				The service staff can give you an exact time for the service that cannot be dealt with immediately	C42
				Service staff are prompt to remedy any errors in the service process	C43

First-tier indicators	Code	Second-tier indicators	Code	Third-tier indicators	Code
		Service empathy	B10	Staff are helpful, careful and friendly	C44
				Caregivers are aware of the needs of the elderly	C45
				No discrimination against the elderly	C46

(continued)

Appendix B. Continued.

First-tier indicators	Code	Second-tier indicators	Code	Third-tier indicators	Code
Service performance	A4	Intention to use	B11	Customers prefer Smart Aged Care to traditional aged care	C47
				Customers are willing to take up Smart Aging services again	C48
				Customers are willing to recommend Smart Aging services to others	C49
		Customer satisfaction	B12	Satisfaction with the use of the facility's smart devices	C50
				Satisfaction with care services	C51
				Satisfaction with safety and care services	C52
				Satisfaction with services in the area of spiritual well-being	C53
				Satisfaction with health care services	C54