

Research Article

Research on the Vulnerability of Government Procurement of Elderly Care Services: A Complex Network Perspective

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The policy of government procurement of elderly care services has the vulnerability characteristics that all complex systems have. To maintain the policy's robustness, this paper studies the vulnerability of government procurement of elderly care services from the perspective of complex network. Case analysis and sample statistics are used to obtain the vulnerability influencing factors of the policy. Then, complex network diagram of vulnerability influencing factors is constructed through *Pajek* software. The compatibility coefficient is used to investigate the network's overall vulnerability from a macro perspective. From a micro perspective, a vulnerability index of the complex network is applied to measure each node's vulnerability value, and the vulnerability priority of the nodes is established. Results show that government purchasing power and supervisory bodies' diversity are at the first priority. The remaining vulnerability influencing factors are at the second and the third priority.

1. Introduction

With the acceleration of population aging in China, the contradiction between supply and demand of elderly care services has become increasingly prominent. How to innovate the supply mode of elderly care services and effectively allocate the resources of elderly care services is particularly important. China began to implement Government Procurement of Public Services in 1990s. Government procurement of elderly care service means that government purchases elderly care services from qualified service institutions and social organizations through public bidding or direct funding with the financial funds [1]. It is a new and efficient governance mode, making up for the deficiency of the market and governments in supplying the elderly care services. The policy of government procurement of elderly care services aims to meet the diversified needs of the elderly, promote the transformation of government functions, and improve the quality of elderly care services.

With the horizontal and vertical development of government procurement of elderly care services, the "point-to-point" cooperation mode between governments and social

organizations for the aged has gradually developed into a network mode of multiagent cooperation. Policy of government procurement of elderly care services has the characteristics of integrity, relevance, purpose, and environmental adaptability that all complex systems should have. These properties and characteristics determine that government procurement of elderly care services is a complex network, with a certain vulnerability. Vulnerability is the objective attribute of complex systems. The higher the vulnerability, the more significant the negative impact of the complex network's weak link on the system and the greater the consequences. To improve the quality of government procurement of elderly care services and maintain the complex system's stability, it is necessary to analyze the network structure. Only by understanding its network structure and mastering the characteristics of its core vulnerability nodes correctly can we maintain the system's robustness. It is a complex system, promoting the implementation and improvement of the policy.

In the literature that utilizes complex network theory to study complex systems, network nodes are mostly physical entities. Although such practice can abstract connections

between entities, it cannot profoundly reflect the vulnerability factors' interaction. Given the purpose of the vulnerability study in this paper, factors influencing the vulnerability are identified as network nodes. In the context of this study, vulnerability influencing factors refer to the weak factors that affect the effectiveness or overall quality of government procurement of elderly care services. Regarding the definition of vulnerability influencing factors, considering that case studies can thoroughly describe the cases and display a comprehensive grasp of the dynamic changes and situations, this study begins with 68 actual government procurement cases of elderly care services. It breaks through traditional practice by combining a qualitative description of case studies with large sample statistics to obtain scientific and effective vulnerability influencing factors.

In summary, this paper studies the vulnerability of government procurement of elderly care services from a complex network perspective. A method of combining case analysis and sample statistics is used to obtain the vulnerability influencing government procurement factors of elderly care services. On this basis, *Pajek* is applied to construct a network topology diagram of vulnerability influencing factors. The topology measurement index of the compatibility coefficient is then applied to analyze the network topology diagram's vulnerability at the macro level. The vulnerability measurement index of the complex network is used to rank the vulnerability influencing factors from the micro level, establishing the vulnerability priority of factors influencing the effectiveness or overall quality of government purchasing elderly care services.

The main contributions of this paper are as follows:

- (1) It studies the vulnerability of government procurement of elderly care services from the perspective of a complex system, identifying key vulnerability influencing factors, and establishes the vulnerability priority of influencing factors to provide a decision-making basis for managers.
- (2) From the macro level, the network compatibility coefficient is used to examine the network's overall vulnerability. Furthermore, the impact of each node on the network vulnerability is considered from the micro level.
- (3) The traditional qualitative method of case studies is improved by combining the case study with large sample statistics, obtaining vulnerability factors scientifically and effectively. *Pajek* is used to construct the network diagram of vulnerability influencing factors of government purchasing pension service.

The remainder of this paper is structured as follows. A literature review is presented in Section 2. Section 3 determines the vulnerability influencing factors by combining the case study and sample analysis. In Section 4, a vulnerability analysis is conducted. Finally, conclusions are presented in Section 5.

2. Literature Review

2.1. Government Procurement of Elderly Care Services. Scholars have begun to focus on government procurement of elderly care services in recent years, and the research mainly focused on empirical studies about existing problems or countermeasures and performance evaluation. In terms of empirical research, Knapp and Bauer [2] studied the procurement of elderly care services and summarized various problems. These include substandard qualifications of institutions for the elderly, poor cooperative relations between parties, and unclear roles and functions of participants. Ma and Hu [3] took Xi'an, China, as the research object and investigated the existing problems of local government purchasing home-based elderly care services. From the perspective of welfare pluralism, Chen [4] analyzed the situation of local government purchasing elderly care services in Wuhan, Hubei Province, and found the existing problems, such as policy fragmentation, imbalance between supply and demand of elderly care services, and insufficient professionals of elderly care services. In addition to the empirical research on the problems existing in government procurement of elderly care services, there are also empirical exploration on purchase mode [5], public satisfaction [6], and fiscal expenditure efficiency [7] of the policy. In terms of performance evaluation research in government procurement of elderly care services, Yang et al. [8] constructed a performance evaluation framework of elderly care services purchased by governments based on the logic of input-process-output-result. To promote the performance of government procurement of elderly care services, Xu [9] explored the influencing factors of policy performance with the help of SEM model. Drawing on existing research results, Milliken and Devlin [10] constructed an evaluation index system of the influencing factors, which are the ability of social organizations to undertake services, the degree of market competition, the ability of government management, and the external procurement environment. In addition to empirical studies and performance evaluation research, risk research is also the focus of government procurement of elderly care services. From the macro perspective, government procurement of elderly care services contains the monopoly risk [11], rent-seeking risk [12], moral hazard, and adverse selection risk [2]. Specifically, Li and Zhang [13] studied the risks of government procurement of elderly care services from the perspective of elderly care service chain and summarized the specific risks in the demand chain, supply chain, and evaluation chain.

Reviewing the relevant literature, it is found that most of the existing studies focus on the institutions which provide elderly care services without considering government procurement of elderly care services as a whole network from a macroperspective. A complex system with multiagent and multitask government procurement of elderly care services possesses the objective attribute of vulnerability. Therefore, to promote the implementation and improvement of the policy and maintain the complex system's stability, it is essential to study the vulnerability of government procurement of elderly care services from the perspective of a complex network.

2.2. Complex Network. A proposal of the “Seven Bridges problem of Ginsberg” in 1736 indicates the birth of complex networks theory. Regarding the specific application of complex network, two research directions and results are summarized as follows.

- (1) Research on the importance of the node based on complex network theory: Evaluation of node importance is the focus in the field of network science. The commonly used network node importance ranking indicators include degree value [1], betweenness [14], near centrality [15], K-shell value [16], and eigenvector [17]. Scholars have considered various algorithms to improve these commonly used indicators. For example, Lu and Shang [18] proposed the Local Rank algorithm based on the degree value’s centrality, which considered the information contained in the fourth-order neighbors of a node. Lu et al. [19] simultaneously regarded the number of adjacent nodes and the node aggregation coefficient, proposing the Cluster Rank algorithm. An index of H was used to measure individuals’ influence on social networks [20]. Gao et al. [21] proposed a network node importance recognition algorithm based on the adjacent information entropy by studying the relationship between a node and its direct and indirect adjacent nodes. In addition to algorithmic research about the importance evaluation indicators of a complex network, scholars have also explored the application of node importance. Xu et al. [22] proposed an importance evaluation method based on mutual information, which had low computational complexity and was suitable for the node importance assessment of large complex networks. Wang et al. [23] used the mutual information method to evaluate node importance of a weighted directed network. Su and Song [24] applied structural hole theory to evaluate node importance to overcome the defects of the local node evaluation algorithm and the computational complexity of the global measurement algorithm. Based on the water network’s global network topology, Yu and Yang [25] defined the node importance evaluation index from four aspects: local attribute, global attribute, propagation attribute, and network location. They comprehensively evaluated node importance based on the TOPSIS multiattribute decision-making method.
- (2) Research on propagation mechanism based on complex network theory: to aid the decision-making process, Mukul and Rajhans [26] aimed to determine the key influencers in information propagation with the application of network complex. Wang and Chen [27] constructed a risk propagation model of complex products based on the complex network theory to investigate the dynamic propagation process. Using the complex network analysis method, Katerelos and Tsekeris [28] constructed a complex network topology model of microblog public

opinion propagation in mobile Internet and analyzed its structural characteristics and evolution mechanism. In addition, propagation behavior in complex network has similar laws with the disease transmission, applying the infectious disease model such as SI model, SIR model, and SIS model [29] to study the propagation mechanism in networks which has become a classic practice in academic circles.

2.3. Vulnerability Study. Vulnerability research originated from the ecosystem and natural disasters and has been applied to many research fields. The research content mainly involves the definition of vulnerability, a qualitative assessment of vulnerability, an analysis of vulnerability causes, and countermeasures research. Based on the framework of “risk-adaptation-sensitivity,” He and Zhou [30] constructed a vulnerability evaluation index system of farmers’ livelihood. In urban development research, Pei and Guo [31] incorporated the innovation system into the urban vulnerability assessment framework and constructed the urban vulnerability evaluation index system from five dimensions of resources, measuring the urban vulnerability of 11 prefecture-level cities in Shanxi province from 2013 to 2017. In terms of the project system, Zhang and Chen [32] established a System Dynamics model based on sensitivity, adaptability, and exposure to analyze system vulnerability’s driving factors. To understand the degree of PPP project system exposure to the external environment’s adverse impacts, the ability to resist interference and self-regulation recovery, Yuan et al. [33] proposed a vulnerability assessment method for PPP projects. In addition, due to the complex relationship in the network, research on network vulnerability has become necessary. Complex network theory provides a theoretical basis and a powerful tool for network vulnerability assessment. When measuring the nodes’ vulnerability in the nearest neighbor network of smart government, Ma et al. [34] took the node degree value as the vulnerability measurement index. Duan and Zheng [35] designed a vulnerability analysis method for complex networks based on node importance by combining degree value and node betweenness.

In summary, to maintain the objects’ robustness and reliability, vulnerability research in various fields has its practical significance. However, when retrieving “government procurement of elderly care services” and “vulnerability” as keywords, no relevant literature is found. Government procurement of elderly care services has developed into a multiagent and multitask complex system, and it is urgent to study its vulnerability.

2.4. Summary of Literature Review. Through a literature review, it is found that scholars at home and abroad have carried out beneficial explorations on government procurement of elderly care services, complex network theory, and vulnerability research, which provides a theoretical basis for this study. However, there are few studies on the vulnerability of government procurement of elderly care services in existing literature, and it is biased to put the research

focus only on the elderly care service institutions, ignoring the vulnerability research on the complex system which contains governments, the public, and institutions for the aged from the perspective of the complex system. In addition, the current literature on government procurement of elderly care services is mostly qualitative research, concentrating on the performance evaluation of the policy, existing problems, and other empirical research. Moreover, the relevant vulnerability literature also focuses on constructing vulnerability evaluation indicators and the definition of vulnerability driving factors, ignoring the importance of the quantitative measurement of each node's vulnerability. This paper combines qualitative case analysis and quantitative sample statistics to scientifically define the vulnerability influencing government procurement factors of elderly care services. Furthermore, the network compatibility coefficient and the loss of network efficiency are selected to examine the vulnerability of government procurement of elderly care services from the macro and micro levels, respectively.

3. Data Analysis of Vulnerability Influencing Factors

3.1. Case Selection. The first step in analyzing the vulnerability of government procurement of elderly care services with the complex network theory is to construct a network topology diagram, which consists of vulnerability influencing factors. Case analysis and sample statistics are used to obtain the scientific vulnerability influencing factors.

As far as the source of cases is concerned, researchers start with the news and media and consult relevant government websites. Network material of cases is collected through snowballing to compile standardized cases that can be used for further academic research. The results of the case summary are shown in Table 1 by collecting and filing the materials. For example, during the collection of the case "Home-Based Care Services in Jing'an District, Shanghai," the basic information was first extracted from a news report on sohu.com entitled "Elaborating on Several Problems Faced by the Government in Purchasing Home-Based Care Services," and it was kept as the preliminary data of "Home-Based Care Services in Jing'an District, Shanghai." Then researchers searched the website of Jing'an District Government of Shanghai and found reports entitled "Notice on Printing and Distributing the implementation measures of Jing'an District on Supporting the Development of Home-Based Care Services" and "Audit and Investigation Results on the Special Funds for Home-Based Elderly Care by Shanghai Jing'an District Civil Affairs Bureau in 2016-2017." On this basis, the scope was expanded, and the "Notices on Adjusting the Relevant Policies of the City's Community Home-Based Elderly Care Services by the Civil Affairs Bureau" and "Notice of the Civil Affairs Bureau on the Allocation of Subsidy Funds for the Home-Based Elderly Care Service Projects in the First Half of 2017 with Municipal Welfare Lottery Public Welfare Fund-Funded Community" were retrieved from the website of the Shanghai Municipal

Government. With these reports' help, a complete case of "Home-Based Care Services in Jing'an District, Shanghai" has been compiled.

3.2. Variable Identification and Hypothesis Formulation. To break through the traditional practice of case studies, the case materials are coded into statistical data and combined with sample statistics to complete the statistical inference research aim.

3.2.1. Determination of Dependent Variables. The paper aims to define the key vulnerability influencing nodes and the priority of the vulnerability influencing nodes in government procurement of elderly care services. Vulnerability influencing nodes refer to weak links in the complex network, that is, the factors that negatively impact the overall quality or effectiveness of government procurement of elderly care services. Therefore, the effectiveness or quality of government purchasing elderly care services evaluated by governments or the third-party institutions is the dependent variable. Evaluation results provide a "material" basis for the data collection of the dependent variables.

The central government has issued a series of policies requiring the evaluation of procured services, such as "a strict supervision and evaluation mechanism should be established in government procurement" and "the evaluation mechanism composed of buyers, service objects and the third party shall be established." With the promotion of central policies, many local governments began to evaluate various procurement services' effectiveness or quality. Therefore, data on dependent variables are easy to obtain. For example, the case of "Home-Based Elderly Care Services in Shangcheng District, Hangzhou City, Zhejiang Province" was evaluated as 92 points by the third-party evaluation agency, Hangzhou endowment Promotion Association. Another example is the case "Elderly Care Services in Haishu District, Ningbo City, Zhejiang Province," in which the evaluation result is described as "good." It should be noted that some cases' evaluation results are descriptive interval data rather than specific values. With descriptive interval data, the value of 95 is assigned to "excellent," 85 to "good," 75 to "medium," and 65 to "qualified."

3.2.2. Determination of the Independent Variable. The independent variable is the vulnerability influencing factors of government procurement of elderly care services. Through case analysis, quality problems, and weak links in each specific case are identified to decide whether the effectiveness or quality of government procurement of elderly care services is affected by the ratio of the elderly to nursing workers, number of personalized service items, the proportion of professional nursing workers, construction of elderly care service facilities, government purchasing power, the type of procurement target, procurement methods, number of bidding companies, diversity of supervisory bodies, number of volunteers, support of policies and

TABLE 1: Case summary of government procurement of elderly care services.

Number	Case	Financial input	Type of procurement target	Procurement method	Operation cycle
1	Home-based care services in Jing'an district, Shanghai	Government invested 2 million yuan in 2019	Social organizations	Directional entrustment	1 year
2	Government of Zhongmu county, Henan province procured elderly care services	1.83 million yuan	Commercial company (Hanjing Project Management Co., Ltd.)	Open and fair competition	2 years
3	Elderly care service in Guangzhou City, Guangdong province	The provincial government raised 30 million yuan in the welfare lottery fund each year from 2010 to 2012	Social organizations; commercial company	Open and fair competition	3 years
4	Elderly care services in Pukou District, Nanjing City, Jiangsu Province	Since 2013, the government has subsidized 1.2 million yuan in fiscal funds every year	Social organizations	Directional entrustment	1 year
5	Elderly care services in Haishu District, Ningbo City, Zhejiang Province	Since 2004, the government has allocated 1.5 million yuan annually	Nonprofit social organization	Internal designation (established by the government)	1 year
6	Home-based elderly care services in Shangcheng District, Hangzhou City, Zhejiang Province	In 2015, the government invested 25 million yuan in financial funds	Social organizations	Directional entrustment	1 year
7	Procurement of home-based care services by Huaian municipal government in Jiangsu Province	In 2016, the government allocated 3 million yuan	Government-affiliated institutions	Internal designation	1 year
8	Procurement of elderly care services in Xiamen City, Fujian Province	In 2012, the government invested 5 million yuan in early-stage start-up funds and 2 million yuan each year after that	Social organizations	Open and fair competition	3 years
9	Procurement of home-based elderly care services in Hefei City, Anhui Province	The government procured home-based care services worth 600 yuan per month for the elderly	Government-affiliated institutions	Directional entrustment	2 years
10	"Home-based elderly care service card" launched by Taiyuan City, Shanxi Province	Government invested 6 million yuan in 2016	Government-affiliated institutions	Directional entrustment	1 year
⋮	⋮	⋮	⋮	⋮	⋮
66	Elderly care services in Zhenjiang, Jiangsu University	Zhenjiang municipal government invested 60 million yuan in 2017	Commercial company	Directional entrustment	1 year
67	Government purchase of home-based elderly-care services in Urumqi	The city has invested 1.86 million yuan in total	Social organizations	Directional entrustment	1 year
68	Smart elderly care services in Shanghai	Government invested 3.6 million yuan	Commercial company	Directional entrustment	2 years

regulations, the coverage rate of service, starting time of procurement, operation cycle of projects, and the economic conditions of the region.

(1) Ratio of the elderly to nursing workers (f1): the ratio between the elderly and nursing workers should be balanced. In actual cases of government procurement of elderly care services, a small number of nursing workers are taking care of a raft of elderly people in the elderly care service center. The ratio of the elderly to nursing workers has reached 15:1. Obviously, the higher the ratio of the elderly to nursing workers, the less time and lower the quality of service the elderly get. The shortage of nursing workers is closely related to high prejudice and the poor treatment of the industry. Therefore, the first hypothesis of this study is put forward.

Hypothesis 1. The lower the ratio of the elderly to nursing workers, the higher the effectiveness or quality of government procurement of elderly care services.

(2) Number of personalized service items (f2): elderly people of different age groups and different physical conditions have different service needs. With modernization and urbanization, the needs of the elderly have gradually deviated from basic physiology and safety to emotion, respect, and self-realization. Essential service items of elderly care include meal aid, cleaning aid, and medical aid. As for obtaining the variable data, the specific number of service items can be obtained from the procurement documents. For example, Huai'an, Jiangsu Province, actively explored home-based care services procurement and promulgated

“the 13th five-year plan for the development of the elderly, and the construction of the pension system.” Elderly care services include seven items stipulated as daily cooking, meal assistance, cleaning, medical assistance, purchasing assistance, agency, and daily communication.

Hypothesis 2. The more personalized the service items, the higher the effectiveness or quality level of government procurement of elderly care services.

(3) Proportion of professional nursing workers (f3): at present, there are no relevant political restrictions on the qualification of nursing workers in China, and their training is not a priority, which leads to the problem of a “low quality” of nursing workers in elderly care institutions. There are few nursing workers with professional skills in the whole service team. Recently, more attention has been paid to the professional level of nursing workers in government procurement of elderly care services. Some specific requirements for the proportion of professional nursing workers have been released in relevant documents. For example, in the “notice of printing and distributing the implementation opinions on further accelerating the construction of social pension service system in Pukou district” issued by the People’s Government of Pukou District, Nanjing, it is recorded that “the proportion of nursing workers with medium and high professional titles must account for more than 10%.”

Hypothesis 3. The higher the proportion of professional nursing workers, the higher the government’s effectiveness or quality procured pension services.

(4) Construction of elderly care service facilities (f4): the construction of elderly care service facilities is measured by three aspects: the accommodation (area), safety (handrails, nonslip ground, etc.), and the provision of functional facilities (reading room, table tennis room, and opera room). Ostensibly, it is difficult to obtain the measurement data. However, there is a clear record of the institution’s facility construction in the government procurement and bidding enterprise documents. The value of f4 is measured by considering all three aspects of accommodation, safety, and functional equipment, and 3 is assigned to f4.

Hypothesis 4. The more complete the construction of elderly care service facilities, the higher the effectiveness or quality of government procurement of elderly care services.

(5) Government purchasing power (f5): governments’ financial contribution to the procurement project is used to reflect the government’s procurement power. The greater the government’s procurement power, the greater the motivation of elderly care service institutions to improve their services, and the more the elderly will benefit.

Hypothesis 5. The greater the purchasing power, the higher the effectiveness or quality of government procurement of elderly care pension services.

(6) Type of procurement target (f6): in China, there are mainly two forms of government procurement in the elderly care service domain: first, governments procurement from

social forces (enterprises and social organizations) and second, governments procure from government-affiliated institutions. According to classical theory, once an institution connects with governments closely, it will turn inefficient. Therefore, there is a risk of low efficiency and low quality when government-affiliated institutions provide pension services.

The measurement of the variable “type of procurement target” is processed according to the following model. Social force (enterprises and social organizations) is assigned to 1, and government-affiliated institutions are assigned to 2.

Hypothesis 6. From the perspective of the type of procurement target, the effectiveness and quality of elderly care services provided by social forces are higher than the effectiveness and quality of elderly care services provided by public institutions.

(7) Procurement methods (f7): according to the definition of Government Procurement of Public Services, service procurement refers to open and fair competition with a clear service objective. Market competition is introduced into government procurement to encourage potential targets to improve service level. However, in actual cases, there are three procurement methods: open and fair competition, directional entrustment, and internal designation. Among the three procurement methods, the independence between governments and social organizations is gradually reduced, and the risk of quality problems in government procurement of elderly care services is also gradually increasing.

In the empirical test, the variables of “procurement methods” are assigned as follows: open and fair competition = 3, directional entrustment = 2, and internal designation = 1.

Hypothesis 7. In terms of procurement methods, the effectiveness of elderly care services procured in an open and fair competition is higher than directional entrustment. The effectiveness of elderly care services procured with the above two methods is higher than that of internal designation.

(8) Number of bidding companies (f8): in a fair, just, and open environment, multiple bidding companies are conducive to stimulating market vitality. Candidates providing elderly care services will strive to improve their service capabilities to obtain the opportunity to become procurement targets.

Hypothesis 8. The greater the number of bidding companies, the higher the effectiveness or quality of government procurement of elderly care pension services.

(9) Diversity of supervisory bodies (f9): in the government procurement of elderly care services, governments have changed from its original role as a direct service provider to an indirect provider. As a result, governments tend to ignore their responsibilities as “buyers” and “regulators” in many practical cases. In addition, third-party institutions are considered to be the natural supervisory bodies of government procurement of elderly care services

due to their high objectivity, professionalism, and neutrality. Multisubject supervision will improve supervision efficiency and ensure the effectiveness of procurement. The diversity of supervisory bodies is measured by the following method. If the supervisory body only includes the government, 1 is assigned to the independent variable of f_9 . If the supervisory bodies include both government and third-party agencies, 2 is assigned to the independent variable of f_9 .

Hypothesis 9. The higher the diversity of supervisory bodies, the higher the effectiveness or quality of government procurement of elderly care pension services.

(10) Number of volunteers (f_{10}): voluntary service is an important part of the elderly care service system in the new era. In the procurement of elderly care services, professional medical staff, nursing workers, and many volunteers are needed to create a social atmosphere of filial piety and respect for the elderly. The number of volunteers can be obtained from the procurement documents of elderly care services. For example, in the “notice of printing and distributing the implementation opinions on further accelerating the construction of social pension service system in Pukou district” issued by the People’s Government of Pukou District, Nanjing, it is mentioned that “voluntary service for the aged should be extensively carried out, and the number of volunteers serving the elderly needs to reach 2000.”

Hypothesis 10. The more the volunteers, the higher the effectiveness or quality of government procurement of elderly care pension services.

(11) Support for policies and regulations (f_{11}): it is generally believed that policies and regulations are important factors to induce elderly care services’ government procurement effectiveness. The imperfect policies and regulations of procurement standards, procedures, and regulatory systems lead to frequent government corruption, market disorder, and low pension services quality. Data on the support for policies and regulations can be obtained by consulting local government documents related to elderly care services procurement. For example, in the case of “Home-Based Care Services in Jing’an District, Shanghai,” consulting the Shanghai municipal government website, the website of Shanghai municipal government procurement, and some news reports, three documents are obtained. These include, “Implementation plan of deepening the elderly care service in Shanghai (2019–2022),” “Some opinions on improving the basic public services for the elderly in Shanghai,” and “Suggestions on encouraging social forces to participate in the construction of elderly care service system.”

Hypothesis 11. The more the support for policies and regulations, the higher the effectiveness or quality of government procurement of elderly care pension services.

(12) The coverage rate of service (f_{12}). The coverage rate of service is the ratio of the number of elderly people enjoying the policy to the number of elderly people in the area. The purpose of government procurement of elderly- are is to expand pension service resources and popularize pension services. Therefore, a high coverage

rate of service should be the intention of the policy. The acquisition of the variable is not complicated. For example, in the case of “Procurement of home-based care services by the Huaian municipal government in Jiangsu province,” the city issued a document stipulating that the scope of procurement of home-based care services will be expanded to the age of 60 years, based on the original coverage, benefiting 59000 elderly people. According to the Huaian Municipal Bureau of Statistics data, there are 330000 elderly people over 60. Therefore, the coverage rate of the service is 17.8%.

Hypothesis 12. The higher the coverage rate of service, the higher the effectiveness or quality of government procurement of elderly care pension services.

(13) Starting time of procurement (f_{13}): as a policy to improve elderly care service resources’ efficiency, government procurement of elderly care services presents a significant feature of “gradualism.” According to the historical experience, the earlier the starting time of procurement, the longer the exploration time will be. Thus the practice of government procurement of elderly care services will be more mature, and the effect will be better, which can be explained by the “first cause-effect.” Data on the time of procurement is easy to obtain.

3.2.3. Determination of the Control Variable

Hypothesis 13. The earlier the procurement’s starting time, the higher the effectiveness or quality of government procurement of elderly care pension services.

(14) The operation cycle of projects (f_{14}): the operation cycle of projects is not related to the starting time of the procurement. The operation cycle of projects refers to the time from the effective starting date of the procurement to its end. The longer the operation cycle of projects, the greater the risks, and the more difficult the supervision. Therefore, the following hypothesis is formulated.

Hypothesis 14. The longer the operation cycle of projects, the lower the effectiveness or quality of elderly- care pension services’ government procurement.

(15) Economic conditions of the region (f_{15}): it refers to the economic conditions of the area where the elderly care services are procured. Generally speaking, the better the regional economic situation, the stronger the vitality of local social organizations, and the stronger its ability to provide elderly care services. The regions’ economic conditions can be measured by total GDP, obtained from the “China Statistical Yearbook.” According to the ranking of the total GDP of major regions in 2019, the economic conditions of seven regions from Northwest to East China are shown below: northwest: 4,659.2 billion yuan; northeast: 5,543 billion yuan; southwest: 876.3 billion yuan; North China: 1,13672 billion yuan; Central China: 1161100.1 billion yuan; South China: 14.7036 billion yuan; and, East China: 288818 billion yuan.

TABLE 2: Summary of variables and the measurement method.

Variable	Factors	Measurement
Dependent variables	Effectiveness or quality of government purchasing elderly care services (EFFE)	Evaluated by governments or third-party institutions, the score is 0~100
Independent variables	Vulnerability influencing factors	
	Ratio of the elderly to nursing workers (f1)	Ratio of the number of the elderly served to the number of nursing workers
	Number of personalized service items (f2)	Number of services provided
	Proportion of professional nursing workers (f3)	Proportion of nursing workers with middle and senior titles
	Construction of elderly care service facilities (f4)	Considering all three aspects, accommodation, safety, and functional equipment, 3 is assigned to f4
	Government purchasing power (f5)	Governments' financial input
	Type of procurement target (f6)	Social forces (enterprises and social organizations) = 1 and government-affiliated institutions = 2.
	Procurement methods (f7)	Open and fair competition = 3, directional entrustment = 2, internal designation = 1
	Number of bidding companies (f8)	Number of companies participating in bidding
	Diversity of supervisory bodies (f9)	If the supervisory body only includes the government, 1 is assigned to f9. If the supervisory bodies include both government and third-party agencies, 2 is assigned to f9.
	Number of volunteers (f10)	Number of volunteers participating in the project
	Support for policies and regulations (f11)	Number of documents related to the policy
Coverage rate of service (f12)	Proportion of the number of elderly people enjoying the policy to the total number of elderly people in the region	
Control variable	Starting time of procurement (f13)	Start time of procurement project
	Operation cycle of projects (f14)	Time period from the effective start date of the procurement to the end of the procurement
	Economic conditions of the region (f15)	The total GDP of the region obtained from the "China Statistical Yearbook"

TABLE 3: Descriptive statistics of variables.

Variable	Sample size	Mean	Mode	Minimum	Maximum	Standard deviation
f1	68	16.4	15	6	30	5.84
f2	68	4.5	3	3	8	1.57
f3	68	0.12	0.1	0.05	0.2	0.04
f4	68	2.12	3	1	3	0.83
f5	68	185.1	20	0.8	2000	400.4
f6	68	1.3	1	1	2	0.48
f7	68	2.3	3	1	3	0.8
f8	68	2.2	0	0	7	2.3
f9	68	1.5	2	1	2	0.5
f10	68	222.8	100	0	2000	405.4
f11	68	4.2	5	2	10	1.6
f12	68	0.29	0.32	0.1	0.52	0.11
f13	68	2015	2016	2012	2019	1.93
f14	68	1.56	1	1	4	0.82
f15	68	241855.5	288818	46592	1161101	285015.5
E	68	78.4	85	55	95	12.1

Hypothesis 15. The better the region's economic conditions (GDP) where the government procures elderly care services, the higher the effectiveness or quality of government procurement of elderly care pension services.

The specific meaning of each variable and the measurement method is shown in Table 2.

3.3. Results of the Statistical Analysis. After obtaining the data for each variable, researchers clarify the variables'

descriptive statistics and test their correlation. Finally, regression testing on the hypothesis is performed step by step.

3.3.1. Descriptive Statistics of Variables. The statistical results of 68 sample data are summarized in Table 3.

3.3.2. Correlation Test of Variables. The correlation test results between variables are shown in Table 4.

TABLE 4: Correlation test of variables.

Variable	f1	f2	f3	f4	f5	f6	f7	f8	f9	f10	f11	f12	f13	f14	f15	E
f1	1	-0.10	0.15	0.31*	-0.06	-0.14	-0.02	0.03	-0.06	-0.22	-0.06	-0.02	-0.29	0.02	-0.17	0.12
f2	-0.10	1	0.07	-0.31*	0.13	0.03	-0.22	-0.21	0.01	0.23	0.33	0.17	0.04	0.09	0.42	0.03
f3	0.15	0.07	1	0.11	0.18*	0.22	0.03	0.35	0.25	0.12	0.17	0.42	0.20	0.27	0.09	0.17
f4	0.31*	-0.31*	0.11	1	0.34	0.06	0.16	0.25	0.09	0.19	0.22	0.26	0.61	0.33	0.19	0.23
f5	-0.06	0.13	0.18*	0.34	1	0.14	0.18	0.24	0.37	0.12	0.35	0.41	0.19	0.56	0.72	0.37
f6	-0.14	0.03	0.22	0.06	0.14	1	0.33	0.28	0.47	0.65	0.61	0.73	0.48	0.52	0.64	0.58
f7	-0.02	-2.22	0.03	0.16	0.18	0.33	1	0.37	0.58*	0.18	0.29	0.26	0.48	0.69	0.54	0.64
f8	0.03	-0.21	0.35	0.25	0.24	0.28	0.37	1	0.55	0.64	0.62	0.74	0.67	0.38	0.49	0.71
f9	-0.06	0.01	0.25	0.09	0.37	0.47	0.58*	0.55	1	0.38	0.57	0.53	0.26	0.36	0.38	0.74
f10	-0.22	0.23	0.12	0.19	0.12	0.65	0.18	0.64	0.38	1	0.85	0.61	0.69	0.77	0.63	0.84
f11	-0.06	0.33	0.17	0.22	0.35	0.61	0.29	0.62	0.57	0.85	1	0.85	0.17	0.88	0.79	0.83
f12	-0.02	0.17	0.42	0.26	0.41	0.73	0.26	0.74	0.53	0.61	0.85	1	0.69	0.48	0.52	0.54
f13	-0.29	0.04	0.20	0.61	0.19	0.48	0.48	0.67	0.26	0.69	0.17	0.69	1	0.59	0.33	0.41
f14	0.02	0.09	0.27	0.33	0.56	0.52	0.69	0.38	0.36	0.77	0.88	0.48	0.59	1	0.53	0.64
f15	-0.17	0.42	0.09	0.19	0.72	0.64	0.54	0.49	0.38	0.63	0.79	0.52	0.33	0.53	1	0.49
E	0.12	0.03	0.17	0.23	0.37	0.58	0.64	0.71	0.74	0.84	0.83	0.54	0.41	0.64	0.49	1

Note. * $P < 0.05$ and ** $P < 0.01$. The test was double tailed and the correlation coefficient was a Pearson correlation coefficient.

A correlation between variables can be concluded from the results of the testing. The value of the correlation is less than 0.5. It means the possibility of multicollinearity is insignificant, indicating that the variables can be used for a regression test.

3.3.3. *Regression Test.* The result of the stepwise regression test is shown in Table 5.

It can be seen from Table 4 that, after adding the independent variables one by one, the model is significant at the level of 0.05 and the explanatory ability continues to improve. Model 13 shows that it is statistically significant and can explain 34% of the variance of the dependent variable (R -square = 0.345, F = 38.723). The white heteroscedasticity test of Model 13 shows that the p value is 0.79. The original assumption H_0 : the model is homovariance. The original assumption is accepted, and it is considered that Model 13 does not have heteroscedasticity. Then, Model 13 is tested for sequential correlation. The test results show that there is no sequential autocorrelation in Model 13. According to regression results in Model 13, the following analysis is carried out. The regression coefficient of f1, which is the ratio of the elderly to nursing workers, is -0.122. It is significant at the level of 0.001, indicating that the ratio of the elderly to nursing workers and the effectiveness of government procurement of elderly care services are negatively correlated. Therefore, Hypothesis 1 is supported. The elderly's ratio to nursing workers is indeed the vulnerability influencing factor in government procurement of elderly care services. There is no statistical correlation between the operation cycle of projects and the effectiveness of government procurement of pension services. Therefore, Hypothesis 14 is not supported, and the projects' operation cycle will not be identified as a vulnerability influencing factor. In the same way, other hypotheses can be proved. Therefore, the vulnerability influencing factors of government procurement of elderly care services to include the ratio of the elderly to nursing workers (f1), number of

personalized service items (f2), the proportion of professional nursing workers (f3), construction of elderly care service facilities (f4), government purchasing power (f5), type of procurement target (f6), procurement methods (f7), number of bidding companies (f8), diversity of supervisory bodies (f9), number of volunteers (f10), support of policies and regulations (f11), the coverage rate of service (f12), starting time of procurement (f13), and economic conditions of the region (f15).

4. Vulnerability Analysis on Government Procurement of Elderly Care Services

4.1. *Construction of Network Topology Diagram.* To construct the network topology diagram of the vulnerability influencing factors, it is necessary to clarify the correlation between the factors after defining the vulnerability influencing factors of government procurement of elderly care services. Six experts were investigated, including two directors of the home-based pension service center, two in-service teachers studying government purchasing pension services, and two master's and doctoral students of **university engaged in government procurement research. Firstly, each expert's opinions about the correlation between different vulnerability influencing factors are solicited by face-to-face inquiry, and results are sorted and summarized. The correlation between factors will be fed back to experts, soliciting opinions and summarizing again. In this way, collection and feedback are taken as a cycle, repeating this cycle three times. Finally, an agreement on the relationship between the vulnerability influencing factors is reached.

To realize the analysis and visual operation of the complex network of vulnerability influencing factors of government procurement of elderly care services, the vulnerability influencing factors and their relationships are recorded in Notepad and transformed into NET format with txt2pajek software. Finally, the network topology diagram of vulnerability influencing factors is constructed using Pajek and is shown in Figure 1.

TABLE 5: Result of stepwise regression analysis.

Variable	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13
f1	-0.135**	-0.172**	-0.164**	-0.174**	-0.158**	-0.139**	-0.126**	-0.178**	-0.166**	-0.134**	-0.147**	-0.122**	
f2		0.124***	0.136***	0.137***	0.129***	0.135***	0.127***	0.179***	0.158***	0.139***	0.166***	0.142***	
f3			0.129*	0.145*	0.128*	0.133*	0.146*	0.065*	0.124*	0.151*	0.123*	0.132*	
f4				0.162**	0.183**	0.142**	0.119**	0.138**	0.127**	0.133**	0.154**	0.162**	
f5				0.151***	0.142***	0.142***	0.191***	0.114***	0.152***	0.133***	0.127***	0.142***	
f6							-0.163**	-0.116**	-0.127**	-0.136**	-0.162**	-0.119**	-0.121**
f7								0.104**	0.089**	0.052**	0.126**	0.124**	0.167**
f8									0.065***	0.043***	0.024***	0.015***	0.062***
f9									0.062	0.062	0.053*	0.071*	0.043*
f10										0.137***	0.142***	0.163***	0.127*
f11											0.145*	0.127*	0.123*
f12													
f13	-0.038*	-0.028*	-0.016*	-0.046*	-0.031*	-0.042*	-0.022*	-0.018*	-0.027*	-0.016*	-0.075*	-0.062*	-0.042*
f14	0.127*	0.167	0.128	0.121	0.152	0.106	0.103	0.116	0.139	0.126	0.183	0.172	0.152
f15	0.216**	0.133**	0.145**	0.137**	0.126**	0.107**	0.114**	0.126**	0.173**	0.165**	0.153**	0.142**	0.126**
N	68	68	68	68	68	68	68	68	68	68	68	68	68
F	1.106	3.342	7.431	10.011	13.165	15.342	19.230	23.141	27.103	31.122	33.062	35.621	38.723
R ²	0.023	0.054	0.076	0.098	0.128	0.163	0.194	0.211	0.246	0.268	0.293	0.314	0.345

Note. *P < 0.05, **P < 0.01, and ***P < 0.001.

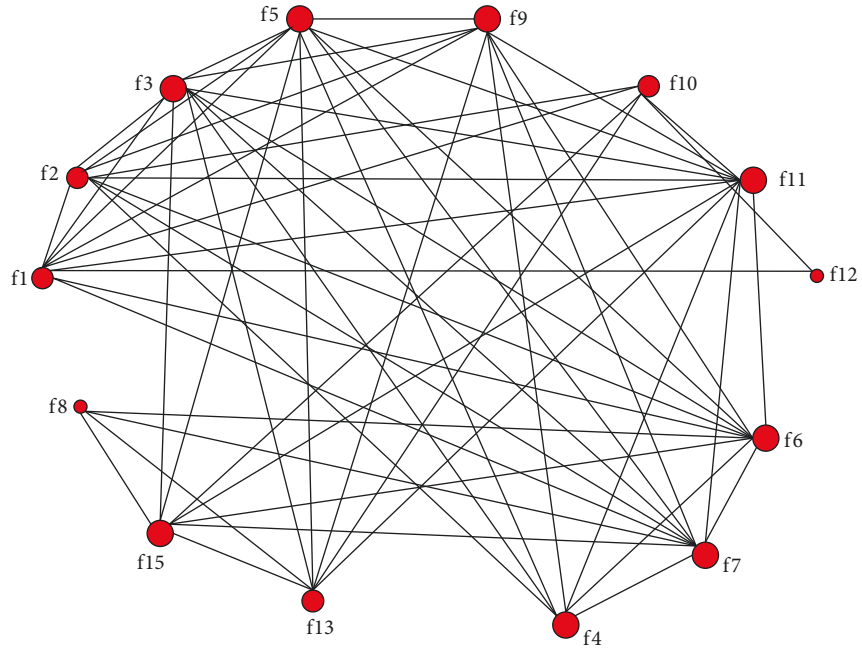


FIGURE 1: Network topology diagram of the vulnerability influencing factors in government procurement of elderly care services.

TABLE 6: Statistical characteristics of Figure 1.

Structural parameters	Number of nodes	Density of network	Average degree	Average shortest path	Diameter
	14	0.615	8	1.406	3

TABLE 7: Degree value of nodes in network topology network of vulnerability influencing factors.

Node	f1	f2	f3	f4	f5	f6	f7	f8	f9	f10	f11	f12	f13	f15
Degree value	9	9	9	7	10	9	10	4	9	6	11	2	7	9

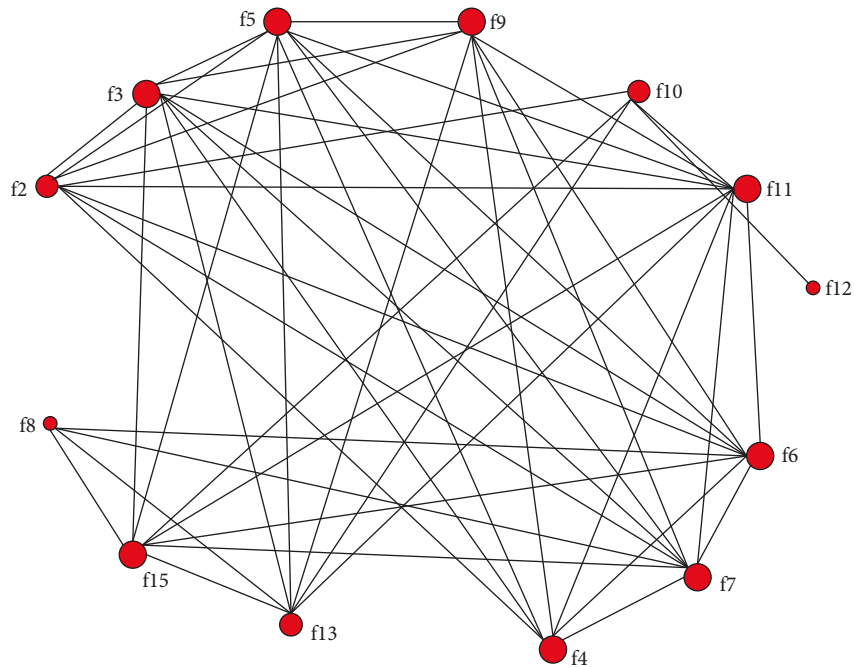


FIGURE 2: Network topology diagram where f_1 fails.

The statistical characteristics of Figure 1 are shown in Table 6.

4.2. Calculation of the Compatibility Coefficient. After obtaining the network topology diagram of vulnerability influencing factors and its basic statistical characteristics, the paper examines the network's vulnerability from the macro level by using the compatibility coefficient to judge the overall vulnerability of government procurement of elderly care services. If the node with a high degree tends to connect with the node with a high degree, it is defined as a homomorphic network; otherwise, it is a heteromorphic network. Newman found that, compared with the heterogeneous network, information in the homomorphic network flows easier, and the network is more stable when the nodes are removed. The definition of the compatibility coefficient is as follows:

$$r = \frac{M^{-1} \sum_i j_i k_i - [M^{-1} \sum_i 1/2(j_i + k_i)]^2}{M^{-1} \sum_i 1/2(j_i^2 + k_i^2) - [M^{-1} \sum_i 1/2(j_i + k_i)]^2}, \quad (1)$$

where j_i and k_i are the degree value of two endpoints of the i -th edge. M is the total number of edges in the network. If $r > 0$, then the network is homomorphic. If $r < 0$, then the network is heteromorphic.

The degree values of 14 nodes in the network topology diagram are shown in Table 7. After calculation, $\sum_i j_i k_i = 4130$, $\sum_i 1/2(j_i + k_i) = 485$, $\sum_i 1/2(j_i^2 + k_i^2) = 4337$, so the compatibility coefficient of the network topology diagram is -0.512 . Therefore, as mentioned above, the network of the vulnerability influencing factors of government procurement of elderly care services is heterogeneous. It means that the network topology diagram of Figure 1 is vulnerable, and when some nodes with a high degree value are deleted, the network presents a greater vulnerability. Nodes with a high degree value are not necessarily connected with high degree value nodes. Therefore, the value of the degree cannot directly reflect the vulnerability of the nodes. It is imperative and necessary to study the vulnerability of nodes further and grasp the key vulnerability factors.

4.3. Calculation of Nodes Vulnerability. Concerning the vulnerability measurement of the complex network, a series of measurement indexes have been proposed in the literature, such as degree value, betweenness, and the largest connected subgraph scale. However, according to system vulnerability's general definition and characteristics, vulnerability refers to the network system's sensitivity when the function is damaged during disasters and emergencies [36]. Therefore, the vulnerability of government procurement of elderly care services is defined as the declining ratio of system efficiency under the threat of the vulnerability influencing factors [37]. The vulnerability of nodes can be evaluated by the loss of network efficiency. Vulnerability of node f_i is

$$V(f_i) = \frac{E(G) - E(G, f_i)}{E(G)}, \quad (2)$$

where $E(G)$ is the average efficiency of the network under the normal conditions, and $E(G, f_i)$ is the average efficiency of the network in which node f_i fails. Usually, the failure of a node is represented by deleting the node and the edges connected to the node. Network efficiency is the most commonly used and effective index to measure network performance, which is defined as

$$E(G) = \frac{1}{n(n-1)} \sum_{i \neq j} \frac{1}{d(i, j)}, \quad (3)$$

where $d(i, j)$ is the shortest path between node i and node j ; n is the number of network nodes. The vulnerability assessment process of government procurement of elderly care services is as follows:

Step 1: calculating the network efficiency $E(G)$ under the normal conditions and the network efficiency $E(G, f_i)$ with node f_i fails by using formula (3).

Step 2: calculating the vulnerability of each node by using formula (2).

Combined with *Pajek*, the new network topology diagram is obtained by deleting each node and its connected edge. The vulnerability of each vulnerable node is calculated according to the above steps.

Vulnerability of node f_1 , which is recorded as $V(f_1)$ is calculated as follows. Firstly, the network efficiency of the initial network, in Figure 1, is 0.418. Secondly, the node f_1 and its connected edges are deleted to obtain a new network topology shown in Figure 2. With the help of formula (3), the network efficiency of the network is calculated where node f_1 is deleted, and the value is 0.406. Thus, $V(f_1) = 0.029$. The vulnerability of the ratio of the elderly to nursing workers (f_1) is 0.029. Following this step, the vulnerability results of the remaining nodes are shown in Figure 3.

4.4. Establishment of Node Vulnerability Priority. After calculating the node vulnerability of government procurement of elderly care services, establishing the vulnerability priority can provide an important reference for promoting government governance. The purpose of establishing node vulnerability priority is to strengthen node vulnerability and complete classification and refinement based on node vulnerability. Nodes with a higher vulnerability priority should be focused on to improve the quality of government procurement of elderly care services and maintain their robustness. Node vulnerability priority is shown in Table 8.

According to the value of node vulnerability of government procurement of elderly care services, the nodes are divided into the three priorities shown in Table 8.

① The first priority includes government purchasing power (f_5) and diversity of supervisory bodies (f_9), and their vulnerability is 0.067. Compared with other nodes, the vulnerability of these two nodes is very high. Managers should pay more attention to government purchasing power and supervisory bodies' diversity, which are the first priority. Managers are supposed to increase government procurement power, expand the

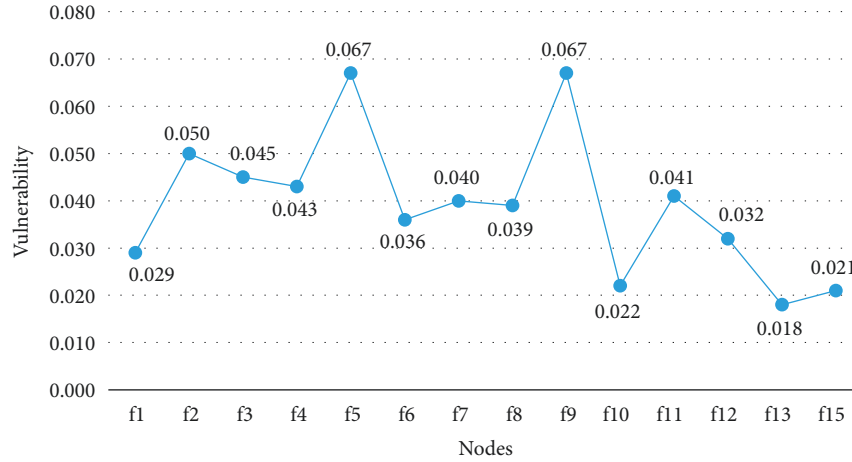


FIGURE 3: Results of node vulnerability.

TABLE 8: Vulnerability value of factors.

Priority	Vulnerability influencing factors	Vulnerability
1	Government purchasing power	0.067
	Diversity of supervisory bodies	0.067
2	Number of personalized service items	0.05
	Proportion of professional nursing workers	0.045
	Construction of elderly care service facilities	0.043
	Procurement methods	0.04
	Support of policies and regulations	0.041
3	Ratio of the elderly to nursing workers	0.029
	Type of procurement target	0.036
	Number of bidding companies	0.068
	Number of volunteers	0.022
	Coverage rate of service	0.032
	Starting time of procurement	0.018
	Economic conditions of the region	0.021

policy coverage, and popularize government procurement of elderly care services to enable the efficient and optimized allocation of elderly care service resources. To ensure the effectiveness and quality of government procurement of elderly care services, a diversified regulatory system with government regulation as the main body, third-party professional institutions as the guarantee, and consumer supervision as the auxiliary should be established.

② The second priority includes the number of personalized service items (f2), the proportion of professional nursing workers (f3), the construction of elderly care service facilities (f4), procurement methods (f7), and support of policies and regulations (f11). These nodes' vulnerability value is between 0.04 and 0.05. The vulnerability influencing factors are the "mainstay" in government procurement of elderly care services. Managers should increase the number of personalized service items according to the needs of the elderly. The proportion of professional nursing workers needs to be optimized, and the professional quality of nursing

workers should be improved. In addition, enhancing the facility construction of elderly care service institutions is favorable to the effectiveness and quality of government procurement of elderly care services. Finally, open and fair competition should be adopted in the procurement process as much as possible.

③ The third priority includes the ratio of the elderly to nursing workers (f1), type of procurement target (f6), number of bidding companies (f8), number of volunteers (f10), the coverage rate of service (f12), starting time of procurement (f13), and economic conditions of the region (f15). These nodes have an insignificant negative impact on the overall quality or effectiveness of government procurement of elderly care services, but they should not be ignored.

5. Conclusion

Government procurement of elderly care services is necessary to alleviate the contradiction between supply and demand of elderly care service resources and it is important

to study this complex system. With the help of case analysis and sample statistics, the factors affecting the vulnerability of the government procurement of elderly care services are determined after verifying a series of hypotheses. Then, based on the interrelationship of the vulnerability influencing factors, *Pajek* is used to construct the network topology diagram of the vulnerability influencing factors, and the basic statistical characteristics of the diagram are obtained. Mining the key vulnerability nodes in the government procurement of elderly care services is an important way to maintain the complex network's robustness and ensure the procurement project's effectiveness. After calculating and analyzing the compatibility coefficient of the network topology and the vulnerability of each node, the nodes' priority is established, which provides effective countermeasures and suggestions for the policy construction of government procurement of pension services. Simultaneously, the paper's research methods apply to vulnerability research of other complex systems with good adaptability. During the research, several shortcomings were discovered. The relationship between the vulnerability influencing factors is determined subjectively. Even through multiple rounds of feedback from experts, there are still problems and risks, which should be improved in future research.

Data Availability

The data that support the findings of this study can be obtained from the corresponding author upon reasonable request.

Conflicts of Interest

The authors have no relevant financial or nonfinancial interests to disclose.

Authors' Contributions

All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by Yuting Zhang and Zhengnan Lu. The first draft of the manuscript was written by Yuting Zhang and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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