

## Research Article

# Anti-Risk Ability of Government Purchasing Elderly Care Services under the Coordination of Complex Network and GERT

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Risk problems of government purchasing elderly care services occur frequently. In order to open the “black box” of decision-making regarding the risks, this study explores the anti-risk ability of government purchasing elderly care services from the perspective of complex network and graphical evaluation review technique (GERT). Firstly, network of government purchasing elderly care services is established, which consists of link level and level of risk factors. Secondly, GERT is employed to analyze the anti-risk ability of the link level of the policy. Then combined with complex network theory, propagation process of risks is simulated at the level of risk factors and anti-risk ability of the complex network consisting of risk factors is explored. Results show that the anti-risk ability of each link in government purchasing elderly care services is obtained, which provides the priority for managers to conduct the risk management. And compared with the anti-risk ability under the random risk attack and deliberate risk attack, the anti-risk ability under the risk attack based on links is obviously lower.

## 1. Introduction

China is rapidly entering the era of accelerating aging. Under the background of “One-child policy” and “421 family structure,” the demand for elderly care services in China has increased sharply. However, there are many deficiencies of governments in producing and supplying elderly care services monopoly. Therefore, it is an inevitable choice for governments to purchase elderly care services and attract multiple subjects to participate in the supply of elderly care services.

Government purchasing elderly care services refer to a new supply mode of elderly care services in which part of elderly care services originally provided directly by governments are transferred to social organizations through contract outsourcing, public-private cooperation, subsidies or vouchers, etc., and governments pay for it according to the quantity and quality of services. For example, Taizhou Municipal Government, Jiangsu Province, China, began to purchase home-based care service projects in 2017, and the project undertaker was Anjitong home-based care service center. By 2019, Taizhou Municipal government has invested about 6.6 million yuan,

which is mainly used for facilities and equipment, emergency rescue, daily care, and other materials of elderly care service center. At present, many regions in China have implemented the policy of government purchasing elderly care services. Introduction of social organizations into elderly care services can not only provide more professional and high-quality elderly care services for the elderly people, but also reduce the financial burden of governments to a certain extent.

However, there are many constraints and risks in government purchasing elderly care services. For example, in June 2020, the false and superficial services of an elderly care service agency which is purchased by government in Dazhou City, Sichuan Province were exposed. The staff in this elderly care service agency pretended to wash feet, do the haircut, and pose for the elderly people. In addition, there are also many elderly care service institutions with weak professional ability, which cannot effectively undertake the elderly care service projects that entrusted and purchased by governments, resulting in many quality problems and risks in elderly care services. Government purchasing elderly care services have a trend in frequent risks. Research on anti-risk ability can open the black

box of “risk prevention decisions” and provide managers with a clear basis for risk prevention decisions. Government purchasing elderly care services have broken the situation that government monopolizes the production of elderly care services. In government purchasing elderly care services, multiple subjects interact and cooperate to supply elderly care services, forming a multicenter structure, which is a complex network. Therefore, it is necessary to explore the anti-risk ability of government purchasing elderly care service network from the perspective of network.

Government purchasing elderly care services have just started in China. Existing researches are almost value judgments of the policy, neglecting the research on risks. Different from the previous studies, this study makes the following contributions:

- (1) Firstly, a network diagram of government purchasing elderly care services is constructed based on complex network and graphical evaluation review technique (GERT) network. The constructed network consists of two levels, which are the link level of government purchasing elderly care service and the level of risk influencing factors. The link level corresponds to the whole process of the policy, which is represented by GERT. The level of risk influencing factors, which is represented by complex network, corresponds to the connection between the risk influencing factors and the corresponding link. Network of government purchasing elderly care service under the cooperation of GERT network and complex networks provides a comprehensive and systematic basis of link level and risk factors’ level for the research of anti-risk ability.
- (2) Secondly, the anti-risk ability of government purchasing elderly care service is studied based on the cooperation of two networks. At the link level of the policy, the GERT network model is used to obtain the anti-risk ability of risk elements in each link. At the level of risk influencing factors, the simulation method is used to simulate the risk propagation process in the network. And with the help of complex network theory, effective scale of network and network efficiency are selected to measure the anti-risk ability of the complex network, so as to realize the risk management research of government purchasing elderly care service under the cooperation of two networks.

The rest of this article is organized as follows: Section 2 is a literature review, which provides the basis of our research. Section 3 provides the model of anti-risk ability based on GERT and complex network. Network of government purchasing elderly care services based on GERT and complex network as well as the further analysis of anti-risk ability are detailed in Section 4. Section 5 concludes the study.

## 2. Literature Review

*2.1. Studies on Government Purchasing Elderly Care Services.* The development of government purchasing elderly care services in China is not yet mature, and the relevant research

is still in its infancy, mainly focusing on policy analysis, empirical research of local practices, and performance evaluation research etc.

Compared with the mature development of government purchasing elderly care services in developed countries [1–3], the policy in China is still in an exploratory period, so the relevant research mostly starts from the macro analysis of policy [4–6]. For example, Ni and Zhang [4] conducted a policy analysis on government purchasing elderly care services in the context of the imbalance between the supply and demand of elderly care services, proposing a series of reform strategies to the policy. In addition, the exploration of the government’s purchase mode [7] and fund management [8] in the field of elderly care service are all within the scope of the policy analysis. With the promotion of the policy, local governments began to implement the policy as a solution to the contradiction between supply and demand of elderly care services. On the basis of empirical investigation, relevant scholars have made a series of summaries on the existing problems and solutions of the policy. Wang [9] studied elderly care services purchased by Hua’an Municipal government and summarized many problems, such as unclear roles and functions of the participants, poor relationship between the two parties, and substandard qualification of elderly-care institutions. Hu and Li [10] took the government purchasing elderly care services in Hunan Province as an example and described the ideal accountability relationship among governments, provider organization, service object, and frontline workers, analyzing the problems existing in the accountability relationship. Finally, as a test method of the implementation effect of the policy, research on performance evaluation has become the focus of the government purchasing elderly care services [11–13]. For example, Shao [11] evaluated the economic and social benefits of government purchasing elderly care services from three main bodies of government, social organizations, and the public.

The abovementioned research mainly discusses issues such as the policy analysis, local experiences, and performance evaluation of government purchasing elderly care services from a micro or macro perspective, but there are relatively few studies on its risks, which is necessary for the implementation of the policy. Based on the perspective of the elderly care service chain, Li et al. [14] summarized the risks of policy deviation, adverse selection, rent-seeking, formalization of evaluation, etc., in the government purchasing elderly care services. Wu [15] deeply explored the risk influencing factors of government purchasing home-based care services through the grounded analysis of 25 in-depth interviews. In fact, there are many research results on risk, not only including the definition of risk factors, but also risk measurement [16, 17], risk propagation [18, 19], risk assessment [20, 21], risk aversion [22], risk bearing [23–25], etc. However, in the field of government purchasing elderly care services, the existing research on risks are all qualitative, which are about determining the risk factors. In addition, the risk research related to elderly care service [26–28] also provides a useful reference for this study. However, the risk research of elderly care services mainly focuses on service institutions, which belongs to the micro level and static

research category. With the development of government purchasing elderly care services, there are more and more interactions among the government, social organizations, and the public. The traditional chain structure has developed into a complex network structure. Under this background, it is more practical to study government purchasing pension services from the perspective of network. To sum up, in view of the lack of qualitative research on the risk of government purchasing elderly care services, this study aims to explore the anti-risk ability of government purchasing elderly care services through quantitative research from the perspective of network.

*2.2. Studies on Complex Network and GERT Network.* Regarding the specific application of complex network theory, three research objects and results are summarized as Table 1.

GERT network is a complex network composed of multiple nodes with different parameters. The parameters of each node are output to the next node with a certain probability, and the parameters in the GERT can obey any kind of distribution in the density function. With the rapid development of GERT network, its related research mainly focuses on the application in specific fields and its method innovation.

GERT is a new generalized stochastic network analysis method. On the one hand, it can model and analyze many real economic and social systems, and is widely used in product recovery review and prediction [19], biological science research [41], disaster deduction [42], cost analysis [6], production planning [43], quality evaluation [23], etc. On the other hand, many scholars have innovated the GERT method. Yu et al. [44] introduced the method of combining C tags into the moment generating function of GERT model, and studied the functional relationship, algorithm, and determination method of model-related parameters. Zhang et al. [19] synthesized credibility theory and GERT network model and established moment generating function of F-GERT and Mason formula. Ruan and Liu [5] combined grey system theory with GERT network technology, established model of grey random network.

*2.3. Summary of Literature Review.* To sum up, on the one hand, the existing research on the risk of government purchasing elderly care services is all qualitative, which defines risk factors. It cannot be scientifically and effectively provided as a reference for the risk management in the field of government purchasing elderly care services. On the other hand, research on the risk of elderly care services can provide some references for this article. However, research on elderly care services is a traditional chain structure, which does not conform to the complex network structure of the policy. Therefore, in summary, this article studies the anti-risk ability of the government purchasing elderly care services quantitatively from the perspective of the dual-network collaboration of complex networks and GERT networks, so as to accurately identify the risks in the government purchasing elderly care services and improve the efficiency of policy implementation.

### 3. Model of Anti-Risk Ability Based on GERT and Complex Network

*3.1. Demonstration of the Applicability and Necessity of GERT and Complex Network.* In order to study the anti-risk ability of government purchasing elderly care services effectively, this study analyzes the government purchasing elderly care services from the perspective of the dual-network coordination of complex network and GERT. However, are complex network and GERT applicable for studying government purchasing elderly care services? Why is it necessary to use complex network and GERT to conduct research on the anti-risk ability of government purchasing elderly care services? In response to the above questions, this chapter discusses and demonstrates the applicability of applying complex network and GERT to government purchasing elderly care services and the necessity of research on the anti-risk ability of government purchasing elderly care services under the dual-network cooperation.

*3.1.1. Demonstration of Applicability.* Analyzing government purchasing elderly care services from the perspective of service chain can help readers have a deep understanding of the policy from the overall level. Government purchasing elderly care services have the following characteristics of complex system:

- (1) Multi-subjectivity: Multi-subjectivity of the policy can be understood from the process of government purchasing elderly care services. Service chain of government purchasing elderly care services is a multilevel network chain, which contains subjects from governments to service demanders. Beginning of the service chain is the service purchaser, which is government. And the terminal of the service chain is service demanders, which are the elderly people. Between the government and the elderly people are service providers and organizations at all levels, which are integrators, supporters, and producers. Producers directly provide elderly care services for the elderly people, including all kinds of elderly people associations, home-care service centers, elderly-care institutions, etc. Integrators are responsible for integrating and allocating resources in the elderly care service chain and coordinating the work of multiple subjects. Supporters mainly provide support for other participants in the service chain of government purchasing elderly care services. From the above discussion, it can be seen that government purchasing elderly care services presents the characteristic of multi-subjectivity.
- (2) Multistage: According to the definition of government purchasing elderly care services, a complete service chain of the policy integrates the resources of planning, demand screening, project determination, division of production, fund allocation, quality control, supervision, and evaluation. From the functional point of view, service chain of government purchasing elderly care services contains demand chain, supply

TABLE 1: Research objects of complex network.

Research objects	Research contents	Authors
Importance of nodes based on complex network theory	Indicators of node importance, such as degree value, betweenness, near centrality, K-shell value, and eigenvector.	Albert, Jeong and Barabási [29]; Freeman [30]; Sabidussi [31]; Kitsak, Gallos and Havlin [10]; Newman [32]
	Algorithms to improve indicators, such as LocalRank algorithm and Cluster Rank algorithm	Chen, Lu and Shang [33]; Chen, Gao, Lu et al. [34]; Wall, Hirsh, Fraser et al. [35]
Propagation mechanism based on complex network theory	Information propagation	Zhou, Wang and Han [9]
	Risk propagation	Wang and Liu [36]
	Public opinion propagation	Gandica et al. [37]; Koulouris, Katerelos and Tsekeris [38]
Game theory based on complex network theory	Application of game theory in complex networks	Nasiri, Bouyer and Nourani [39]; Li, Deng and Xiao [40]

chain, and evaluation chain. In the stage of demand chain, the problem of “what to buy” is mainly solved, that is defining the content of demand according to the age, health level, and economic status of the elderly people. Supply chain mainly solves the problems of “whom to buy from” and “how to buy.” “Whom to buy from” is to determine the supply objects of elderly care service, which are the social organizations, and “how to buy” aims at choosing the way of purchase. Evaluation chain is to ensure the quality and effect of elderly care services by establishing a set of standardized supervision and evaluation system process. From the perspective of service chain, government purchasing elderly care services shows the characteristic of multistage.

- (3) Uncertainty: Uncertainty of government purchasing elderly care services can be understood with the help of the multistage nature of the policy. Government purchasing elderly care services includes demand chain, supply chain, and evaluation chain. Each link of the service chain is not a deterministic event and has a certain probability. Therefore, government purchasing elderly care services is uncertain.

To sum up, government purchasing elderly care services have the characteristics of multi-subjectivity, multistage, and uncertainty, which are the necessary properties for all complex systems. As a network analysis method, GERT network can model and analyze many complex systems in real life, and complex network theory is a powerful tool to study complex systems. In addition, nowadays, scholars begin to explore government purchasing elderly care services from the network perspective [44, 45]. For example, Cui [44] constructed a quality control mechanism for government purchasing home-based elderly care services with complex network game. Therefore, as complex system tools, GERT and complex network are applicable to study government purchasing elderly care services, which is a complex system.

*3.1.2. Demonstration of Necessity.* Through the demonstration of applicability of dual networks, GERT and complex network can be applied to government purchasing elderly care services. However, the question of “why is it

necessary to apply dual networks to government purchasing elderly care services” also needs to be answered. GERT is a random network technology based on critical path method and plan evaluation technology. GERT has obvious advantages in expressing complex and logical relationships, which can reflect the complex situation in the process of government purchasing elderly care services. Its network arc can show the connection of links in government purchasing elderly care services clearly. Moreover, the random parameters of the network arc can also clearly represent the probability and time required to realize each link. Therefore, GERT network is very suitable for quantitative characterization and risk management in government purchasing elderly care services. However, GERT just focuses on the links of government purchasing elderly care services. Only relying on GERT to study the anti-risk ability of government purchasing elderly care services cannot fully consider the effect of various risk influencing factors. In view of this, current research proposes a network structure of government purchasing elderly care services based on GERT and complex network, which combines links and risk influencing factors closely. Specific operation is as follows: Constructing the network of government purchasing elderly care services, which consists of GERT and complex network. GERT is used to represent the links of the policy, and complex network is to show the corresponding risk influencing factors of links. Meanwhile, at the link level, the anti-risk ability of each link is considered by means of GERT, and at the level of risk influencing factors, the complex network theory and simulation method are used to simulate the risk propagation process in the network, so as to realize the aim of researching on the anti-risk ability of government purchasing elderly care services.

Figure 1 shows the simple network structure of government purchasing elderly care service under the cooperation of complex network and GERT.

*3.2. Model of Anti-Risk Ability Based on GERT.* At the link level of government purchasing elderly care services, the direct object of risk impact is the time required to complete each link. Under the influence of risk factors, the required time of each link is random, and the time spent in each link determines the total time required in the whole process. Combined with the basic definition of GERT, the time required in each link is

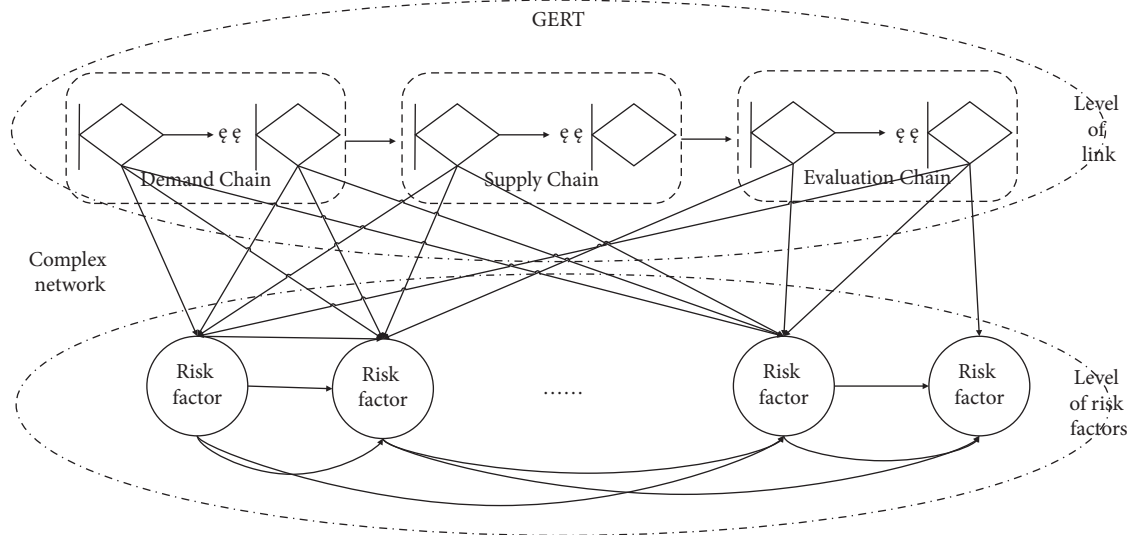


FIGURE 1: Simple network of government purchasing elderly care services based on GERT and complex network.

expressed as risk element. Transmission relationship of each node in GERT network is calculated through the signal flow graph with linear characteristics, so as to explore the anti-risk ability of network that consists of links in government purchasing elderly care services.

### 3.2.1. Basic Parameters of Anti-Risk Ability Model Based on GERT

(1) *Basic Definition.* Diagram of GERT consists of nodes, branch line, and flow, which is recorded as  $D = (V, A, C)$ .  $V = \{v_1, v_2, \dots, v_n\}$  represents the collections of nodes, that is the main links in government purchasing elderly care services, such as project initiation and bidding.  $A = \{a_1, a_2, \dots, a_m\}$  represents the collections of branch lines, that is the transition between links in government purchasing elderly care services. Branch line from node  $v_i$  to node  $v_j$  is recorded as  $a_i = (v_i, v_j)$ . Each branch line is given  $c_{ij}$ , which is described as the flow of branch line  $a_i$ . The parameters of flow in GERT consists of probability  $p_{ij}$  of branch line  $a_i$ , needed time  $T_{ij}$  of completing all links in the branch line, and the probability distribution  $f_{ij}(t)$  of the needed time to complete the links.

#### (2) Basic Parameters.

- (1) Risk element  $x_{ij}$ . Supposing that the required time of completing all links in branch line  $a_i = (v_i, v_j)$  is  $T_{ij}$ , and  $T_{ij}$  is defined as the risk element  $x_{ij}$  of branch line  $a_i = (v_i, v_j)$ .
- (2) Moment generating function  $M_x(\theta)$ . Supposing that the risk element of branch line  $a_i = (v_i, v_j)$  is  $x_{ij}$ , so moment generating function is  $M_{x_{ij}}(\theta) = E(e^{\theta x}) = \sum_{x=0}^{\infty} e^{\theta x} f_{ij}(x)$  when the risk element  $x_{ij}$  is discrete distribution and  $M_{x_{ij}}(\theta) = E(e^{\theta x}) = \int_{-\infty}^{+\infty} e^{\theta x} f_{ij}(x) dx$  when the risk element  $x_{ij}$  is continuous distribution.

- (3) Characteristic transfer function  $w_x(\theta)$ . Combined with the definition of GERT and the research context, the realization probability of the corresponding link of branch line is set as  $p_{ij}$ . With the help of Mason formula, characteristic transfer function  $w_x(\theta)$  of  $a_i$  can be obtained by  $w_{x_{ij}}(\theta) = p_{ij} M_{x_{ij}}(\theta)$ .
- (4) Risk level  $\lambda$  and anti-risk ability  $\pi$ .  $\lambda$  indicates the risk level of realization time between links of government purchasing elderly care services. The higher the risk level of a certain link, the lower is its anti-risk ability.  $E(x)\Delta V(x)$  are the expectation and variance of risk element, respectively. Standard deviation  $\sqrt{V(x)}$  is the absolute measure way of risk level. Therefore, risk level can be expressed as  $\lambda = \sqrt{V(x)}/E(x)$ . And anti-risk ability  $\pi$  is  $\pi = 1 - \lambda$ .

### 3.2.2. Steps for Analyzing Anti-Risk Ability Based on GERT

*Step 1.* Constructing GERT network of government purchasing elderly care services. According to the process of government purchasing elderly care services and the framework of “demand chain-supply chain-evaluation chain,” the nodes and branch lines of GERT can be identified.

*Step 2.* Collecting the time needed for each branch line between links and the realization probability of branch lines. In current research, probability statistics and maximum entropy model are used to determine the realization probability of each branch line. When the relevant data are sound and sufficient, statistical method is used to obtain the probability. And when the data are insufficient to determine the probability, maximum entropy model is established to solve the probability [46].

*Step 3.* According to the formula of  $w_{x_{ij}}(\theta)$ , characteristic transfer function of each branch line can be obtained. Then, in the light of three basic structures of GERT, which are series structure, parallel structure, and hybrid structure, the

characteristic transfer function  $w_E(\theta)$  of the total path from one node to another is calculated.

When branch line of GERT is series structure,

$$w_E(\theta) = w_{x_{ij}}(\theta) \bullet w_{x_{jk}}(\theta) \bullet \dots \bullet w_{x_{tz}}(\theta). \quad (1)$$

When branch line of GERT is parallel structure,

$$w_E(\theta) = \sum_{t=1}^n w_{ij}^t(\theta), \quad (2)$$

where  $t$  is the  $t$ -th path from node  $i$  to node  $j$ , and there are a total of  $n$  roads between the two nodes.

*Step 4.* According to the Mason formula, let  $w_E(\theta) = P_E M_E(\theta)$ , where  $P_E$  and  $M_E(\theta)$  are the realization probability and moment generating function of the total path from one node to another, respectively. In view of the properties of moment generating function,  $M_E(0) = E(e^0) = 1$  when  $\theta = 0$ . So, the formula of  $P_E$  is

$$P_E = \frac{w_E(\theta)}{M_E(\theta)} \Big|_{\theta=0} = \frac{w_E(0)}{M_E(0)} = w_E(0). \quad (3)$$

*Step 5.*  $M_E(\theta)$  can be obtained by  $w_E(\theta) = P_E M_E(\theta)$  as

$$M_E(\theta) = \frac{w_E(\theta)}{P_E} = \frac{w_E(\theta)}{w_E(0)}. \quad (4)$$

*Step 6.* According to the properties of moment generating function, the expected value and variance of risk element of the total path from one node to another can be obtained as follows:

$$E(x) = \frac{dM_E(\theta)}{d\theta} \Big|_{\theta=0}. \quad (5)$$

$$V(x) = \left\{ \frac{d^2 M_E(\theta)}{d\theta^2} - \left[ \frac{dM_E(\theta)}{d\theta} \right]^2 \right\} \Big|_{\theta=0}. \quad (6)$$

*Step 7.* Risk level can be achieved from formulas (3) and (4) as

$$\lambda = \frac{\sqrt{V(x)}}{E(x)}. \quad (7)$$

*Step 8.* Anti-risk ability is expressed as

$$\pi = 1 - \lambda. \quad (8)$$

**3.3. Model of Anti-Risk Ability Based on Complex Network.** The current research uses complex network theory to study the anti-risk ability of the network that consists of risk influencing factors. In complex networks, the basic forms of risk attack are classified as random attack and deliberate

attack. When a node is attacked randomly, the probability of the node being attacked has nothing to do with the structure and function of the node. While under the condition of deliberate attack, risks will choose the node with higher degree value or higher betweenness value to attack first. In addition, this study aims to develop a new form of risk attack that is based on the anti-risk ability of the links in the light of Section of 3.2. Therefore, this study simulates the risk propagation process under the condition of random risk attack, deliberate risk attack based on degree value, deliberate risk attack based on betweenness value, and risk attack based on links' anti-risk ability.

In order to measure the impact of risk influencing factors on the structure and function of the network, the effective scale of the network  $s$  [47] and its change rate  $f_s$  and network efficiency  $E$  [48] and its change rate  $f_E$  are taken as the indicators of measuring anti-risk ability of network. Effective scale of network  $s$  is the number of nodes that contained in the maximum Unicom subgraph. Change rate of effective scale of network  $f_s$  is  $f_s = \Delta s/s$ , where  $\Delta s$  is the change of effective scale after the risk attack. The larger the value of  $f_s$  is, the more serious the risk is and the lower the anti-risk ability of the network is.

Network efficiency  $E$  is the average of the reciprocal of the shortest distance between any two nodes in the network. It indicates the integrity of the network's function.

$$E = \frac{2}{N(N-1)} \sum_{i \neq j} \frac{1}{d_{ij}}, \quad (9)$$

where  $N$  is the number of nodes in network and  $d_{ij}$  is the distance between node  $i$  and  $j$ . What's more, the formula of decline rate of effectiveness of network  $f_E$  is  $f_E = \Delta E/E$ , where  $\Delta E$  is the change of network effectiveness after the risk attack. The larger the value of  $f_E$  is, the more serious the risk is and the lower the anti-risk ability of the network is.

## 4. Research on the Anti-Risk Ability of Government Purchasing Elderly Care Services

**4.1. Constructing the Network of Government Purchasing Elderly Care Services.** Current research studies the anti-risk ability of government purchasing elderly care services from the perspective of GERT and complex network. GERT is employed to represent the link level of government purchasing elderly care services which includes demand chain, supply chain, and evaluation chain. Network of risk influencing factors corresponding to links of government purchasing elderly care services is represented by complex network. Studying the anti-risk ability with the help of dual networks can not only identify the key risk links, but also determine the specific risk influencing factors, so as to evaluate the anti-risk ability of government purchasing elderly care services.

Firstly, key links of government purchasing elderly care services are identified according to the demand chain, supply

TABLE 2: Links in government purchasing elderly care services and corresponding risks.

Nodes of GERT	Meaning of nodes	Corresponding risks
1	Survey of demand	Anchoring range of the beneficiary group is narrow. (r1) Service coverage is low. (r2)
2	Determination of purchase contents	The purchase content is single and the level is low. Medical treatment, hospice care, and other aspects are relatively scarce. (r3)
3	Dependent purchase	Government's administrative monopoly leads to the low vitality of social organizations. (r4)
4	Independent with noncompetitive purchase	Under the purchase way of independent with noncompetitive, social organizations with a certain social reputation reduce the purchase risk to a certain extent; however, they lack the motivation to improve their service quality due to the lack of competition in the market. (r5)
5	Independent with competitive purchase	There is still unfair competition in the acquaintance society. (r6) There is a dependency relationship between governments and social organizations. Once social organizations are "governmental," they tend to be inefficient. (r7)
6	Determination of service providers	There are few nursing workers with professional competence in social organizations. (r8) There are few nursing workers in social organizations where many of the elderly people are accommodated. (r9)
7	Financial investment	The construction of infrastructure in social organizations is not perfect. (r10) The government's capital investment is insufficient, and the support strength is low. r11)
8	In-kind funding	Lack of in-kind funding at all levels of demand, such as medical equipment, rehabilitation facilities, interest class equipment, etc. (r12)
9	Issuance of service voucher	Misuse of service vouchers goes against the original intention. For example, there are service voucher-designated stores raising prices. (r13) The coverage is small, and the object of service voucher is often determined by local residents or house property certificate. (r14)
10	Reduction of venue rent	The government's capital investment is insufficient, and the support strength is low. (r11)
11	Determination of purchase way	Purchase way is single, lacking of multiple and dynamic ways of purchase. (r15) There is the lack of policy and system basis, which aims to supervision and evaluation. The subject of supervision and evaluation is single. (r17)
12	Supervision and evaluation	Supervision and evaluation on the whole process of government purchasing pension services is empty. For example, the selection of early service providers, the use of funds, and the guarantee of service quality all need evaluation and supervision. (r18)

chain, and evaluation chain. In demand chain, beneficiary groups of the policy are anchored, and the demand for elderly care services is determined according to the age, income level, and health status of the elderly people. In supply chain, according to the micro relationship of governments and purchasing objects, purchasing ways can be divided into dependent purchase, independent with non-competitive purchase, and independent with competitive purchase. Under the condition of dependent purchase, purchase objects are usually specially established by governments for the policy. Purchase objects under the condition of independent with noncompetitive purchase are usually social organizations of elderly care services, which exist in the markets before government purchasing elderly care services. Under this circumstance, governments prefer to choose organizations with social reputation to reduce the purchase risk. Social organizations of elderly care services are selected by governments through open bidding and fair competition under the condition of independent with competitive purchase. After determining the service provider, we need to define the purchase way. According to the practical experience of different places, purchase ways can be

summarized as financial assistance, in-kind assistance, issuance of service voucher, reduction of venue rent, etc. To sum up, to complete the whole purchase process, needs of the elderly people should be anchored firstly, then service providers and specific purchase way are supposed to be determined. In order to ensure the quality and effect of government purchasing elderly care services, it is necessary to establish a multiple evaluation mechanism in the evaluation chain that composed of governments, service providers, service objects, and third-party evaluation institutions.

However, only relying on a single GERT network to describe the government purchasing elderly care services cannot reflect the role of risk influencing factors that corresponds to the links. Therefore, the risk influencing factors corresponding to the links are identified and the network consisting of risk influencing factors is constructed. The meaning of links in government purchasing elderly care service and its corresponding risks are shown in Table 2.

In order to construct the network of risk influencing factors, it is necessary to clarify the correlation between the factors. Six experts were investigated, including two directors of

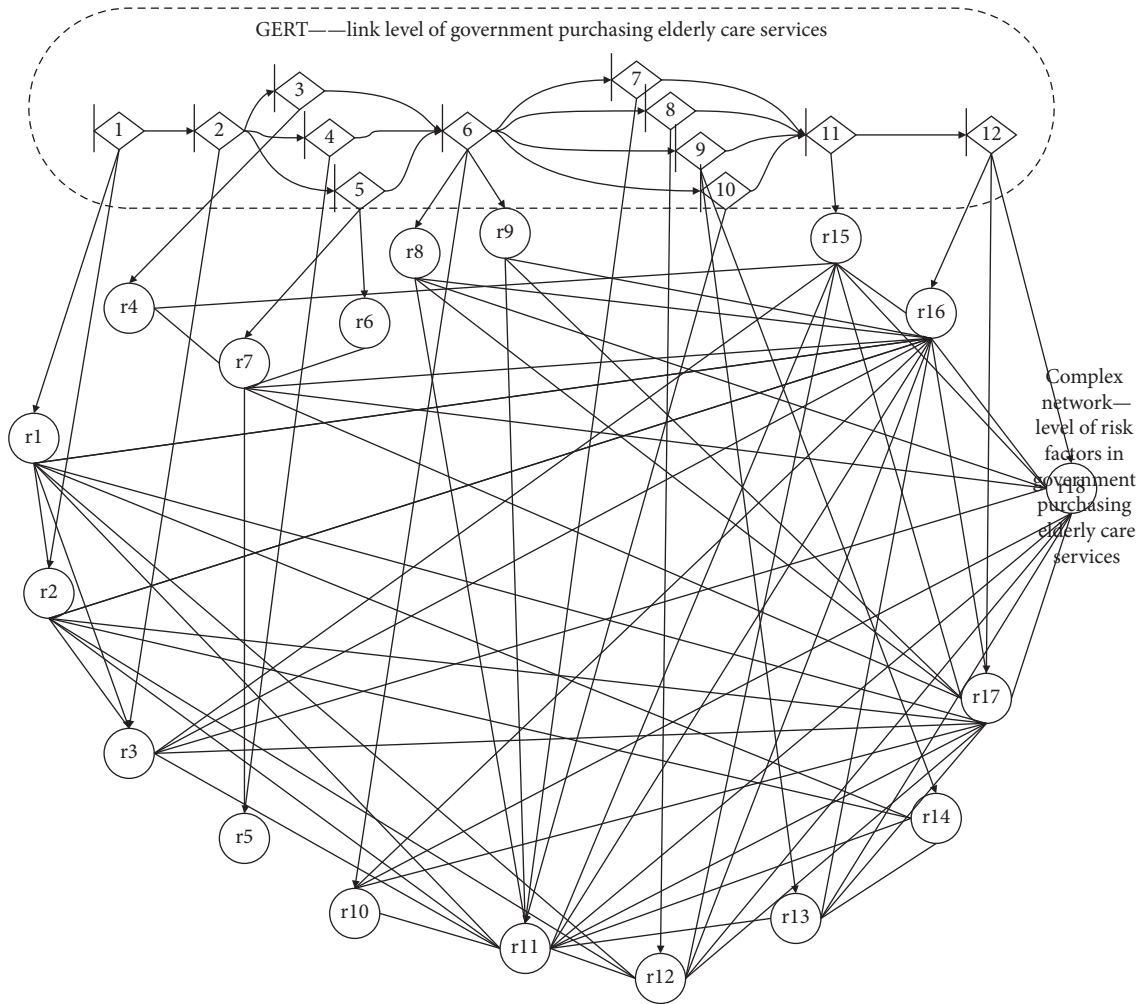


FIGURE 2: Network of government purchasing elderly care services.

pension service center, two in-service teachers studying government purchasing elderly care services, and two master’s and doctoral students of Jiangsu University who are engaged in government purchase research. Firstly, the opinions of each expert about the correlation between different risk influencing factors are solicited by face-to-face inquiry, and results are sorted and summarized. Then the results of the correlation between factors will be fed

back to experts again, 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 risk influencing factors is reached. The adjacency matrix of risk influencing factors is shown in (7). And network of government purchasing elderly care service under the coordination of GERT and complex network is shown in Figure 2.



TABLE 3: Parameters in GERT of link level in government purchasing elderly care services.

Branch line	Time (risk element)	Probability	Probability distribution of risk element	Moment generating function	Characteristic transfer function
(1,2)	1	0.5	Normal distribution (5, 4)	$e^{5\theta+2\theta^2}$	$0.5e^{5\theta+2\theta^2}$
(2,3)	2	0.2	Normal distribution (10, 6)	$e^{10\theta+3\theta^2}$	$0.2e^{10\theta+3\theta^2}$
(2,4)	4	0.5	Normal distribution (9, 10)	$e^{9\theta+5\theta^2}$	$0.5e^{9\theta+5\theta^2}$
(2,5)	2	0.3	Normal distribution (1, 4)	$e^{\theta+2\theta^2}$	$0.3e^{\theta+2\theta^2}$
(3,6)	2	0.2	Normal distribution (1, 4)	$e^{\theta+2\theta^2}$	$0.2e^{\theta+2\theta^2}$
(4,6)	4	0.5	Normal distribution (6, 2)	$e^{6\theta+\theta^2}$	$0.5e^{6\theta+\theta^2}$
(5,6)	2	0.3	Normal distribution (2, 1)	$e^{2\theta+0.5\theta^2}$	$0.3e^{2\theta+0.5\theta^2}$
(6,7)	3	0.4	Normal distribution (5, 10)	$e^{5\theta+5\theta^2}$	$0.4e^{5\theta+5\theta^2}$
(6,8)	2	0.3	Normal distribution (2, 1)	$e^{2\theta+0.5\theta^2}$	$0.3e^{2\theta+0.5\theta^2}$
(6,9)	1	0.1	Normal distribution (8, 10)	$e^{8\theta+5\theta^2}$	$0.1e^{8\theta+5\theta^2}$
(6,10)	4	0.1	Normal distribution (4, 5)	$e^{4\theta+2.5\theta^2}$	$0.1e^{4\theta+2.5\theta^2}$
(7,11)	3	0.4	Normal distribution (1, 1)	$e^{\theta+0.5\theta^2}$	$0.4e^{\theta+0.5\theta^2}$
(8,11)	2	0.3	Normal distribution (1, 1)	$e^{\theta+0.5\theta^2}$	$0.3e^{\theta+0.5\theta^2}$
(9,11)	1	0.1	Normal distribution (2, 4)	$e^{2\theta+2\theta^2}$	$0.1e^{2\theta+2\theta^2}$
(10,11)	4	0.1	Normal distribution (2, 1)	$e^{2\theta+0.5\theta^2}$	$0.1e^{2\theta+0.5\theta^2}$
(11,12)	2	0.5	Normal distribution (1, 1)	$e^{\theta+0.5\theta^2}$	$0.5e^{2\theta+0.5\theta^2}$

$$\begin{pmatrix}
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 \end{pmatrix} \quad (10)$$

beneficial to managers to open the “black box” of decision-making in risk management. In the face of risk threats, exploring the anti-risk ability of the links in government purchasing elderly care services is conducive to improving the governance. Therefore, the current research studies the anti-risk ability of links based on the basic steps of GERT.

Based on the link level of government purchasing elderly care services in Figure 2, parameters of GERT are determined by combining the actual practice of government purchasing elderly care services and maximum entropy model. The results are summarized in Table 3. Assuming that the probability distribution of the realization time of branch lines is normal distribution, the expectation and variance of risk element are obtained through a large number of data.

According to the parameters in Table 2, the risk level between any two nodes can be calculated by using the algorithm proposed in the study. Based on the service chain of government purchasing elderly care services, risk level of the following branch lines is calculated, which are branch line (1,2) “what to buy,” branch line (2,6) “whom to buy from,” branch line (6,11) “how to buy,” and branch line of evaluation (11,12). The calculation of the risk level of branch line (2,6) is taken as an example to verify the effectiveness of the anti-risk ability model based on GERT.

(2,6) is the branch line of “whom to buy from” in government purchasing elderly care services, including the sublimes of dependent purchase, independent with non-competitive purchase, and independent with competitive purchase. There are series structure and parallel structure in three sublimes. Therefore, the transfer function formula of (2,6) is calculated as follows according to formulas (1) and (2):

#### 4.2. Analysis on the Anti-Risk Ability of Government Purchasing Elderly Care Services

4.2.1. Analysis on the Anti-Risk Ability of Link Level Based on GERT. Government purchasing elderly care services is just in its infancy in China. Research on anti-risk ability is

$$w_E(\theta) = w_{x_{23}} \bullet w_{x_{36}} + w_{x_{24}} \bullet w_{x_{46}} + w_{x_{25}} \bullet w_{x_{56}} = 0.04e^{5\theta+11\theta} + 0.25e^{6\theta^2+15\theta} + 0.09e^{2.5\theta^2+3\theta}. \quad (11)$$

So  $P_E = w_E(0) = 0.38$ . Moment generating function of (2,6) is  $M_E(\theta) = w_E(\theta)/P_E = 50w_E(\theta)/19$ . Python software is used to calculate the expectation, variance, risk level, and anti-risk ability of risk elements in branch line (2,6), and they are expressed as follows:

$$E(x) = \frac{dM_E(\theta)}{d\theta} \Big|_{\theta=0} = 11.74,$$

$$V(x) = \left\{ \frac{d^2 M_E(\theta)}{d\theta^2} - \left[ \frac{dM_E(\theta)}{d\theta} \right]^2 \right\} \Big|_{\theta=0} = 5.93, \quad (12)$$

$$\lambda = \frac{\sqrt{V(x)}}{E(x)} = 0.2074.$$

It can be inferred that the anti-risk ability of (2,6) is 79.26%. The anti-risk ability of four main lines, which are (1,2), (2,6), (6,11), and (11,12), and the specific sublines during the main links in government purchasing elderly care services are shown in Table 4. For example, branch line (2,3,6) represents the line from node 2 to node 3 to node 6.

It can be learned from Table 3 that (2,6) in government purchasing elderly care service chain has the lowest anti-risk ability, which means that the process of choosing service providers has the highest level of risk under the influence of external threats. What's more, the anti-risk ability of (11,12) which is the evaluation link is slightly higher than that of the link (2,6). Therefore, in the process of government purchasing elderly care services, managers need to carefully select the service providers of elderly care services and pay attention to the necessity of evaluation. Furthermore, branch line (2,5,6) in the main line (2,6) that represents independent with competitive purchase has the highest level of risk. Independent with competitive purchase is a complex process, which needs to go through many sublinks, such as project approval, bidding, determination of service providers, and each sublink affects the final purchase. Independent competitive purchase is a fair, open, and fair way to choose service providers. In this way, service providers which are social organizations can be motivated to improve their service quality. However, due to the complexity of the process, independent with competitive purchase is also accompanied by a high degree of risk, and its anti-risk ability is relatively low.

**4.2.2. Analysis on the Anti-Risk Ability of Risk Influencing Level Based on Complex Network.** The anti-risk ability of each link in government purchasing elderly care services is obtained based on GERT. Risk influencing factors that caused by each link constitute a complex network. Then complex network theory is applied to study the anti-risk ability of the network composed of risk influencing factors, so as to achieve the purpose of risk management of government purchasing elderly care services.

The performance of the risk attack in government purchasing elderly care services is the failure of risk influencing factors and the connections between factors. From the perspective of risk source, forms of risk attack can be

TABLE 4: Anti-risk ability of link level in government purchasing elderly care services.

Branch line	Anti-Risk ability (%)	Subline	Anti-Risk ability (%)
(1, 2)	86.23		
(2, 6)	79.26	(2, 3, 6)	76.34
		(2, 4, 6)	76.80
		(2, 5, 6)	74.52
		(6, 7, 11)	77.32
(6, 11)	80.41	(6, 8, 11)	78.10
		(6, 9, 11)	78.65
		(6, 10, 11)	80.33
(11, 12)	79.88		

classified as random risk attack and deliberate risk attack. Deliberate risk attack has two specific forms, which are attack based on nodes' degree value and attack based on nodes' betweenness value. In addition, according to the results of previous section, the anti-risk ability of each link in government purchasing elderly care services has been obtained. On this basis, we consider a new form of risk attack which is based on anti-risk ability. And the operation step of risk attack based on anti-risk ability is to fail the risk influencing factors and connected edges that has the lowest anti-risk ability and then fail the risk factors and their edges in turn in the light of the links' anti-risk ability.

Risk attack makes the overall function of the network decline. On the one hand, the integrity of the network is destroyed. On the other hand, the operation efficiency of the network is reduced. Therefore, the current research applies simulation technology to "attack" the complex network of risk influencing factors and takes network efficiency and effective scale of network as evaluating indicator to observe the change of the complex network. To sum up, this study considers the changes of network efficiency and effective scale of network under the random risk attack, risk attack based on degree value, risk attack based on betweenness value, and risk attack based on links' anti-risk ability.

*(1) Simulation of Network Efficiency under Different Risk Attacks.* Figure 3 shows the transformation of network efficiency in complex network of risk factors. The abscissa of the diagram  $f$  represents the proportion of the number of attacked nodes in the total number of nodes, and the ordinate of the diagram is network efficiency. It can be seen from Figure 3 that the network efficiency of the complex network shows a decreasing trend with the increase of the proportion of the attacked nodes. Overall, compared with the network efficiency under random attack, attack based on degree value, and attack based on betweenness value, network efficiency declines fastest under the risk attack based on links' anti-risk ability.

Figure 4 shows the decline rate of network efficiency of complex network. The abscissa is the node of each risk factor, and the ordinate is the decline rate of network efficiency. The broken line represents the decline rate caused by the failure of each node under different risk attack modes. The higher the decline rate of network efficiency is, the lower the anti-risk ability of the network is. As can be seen from

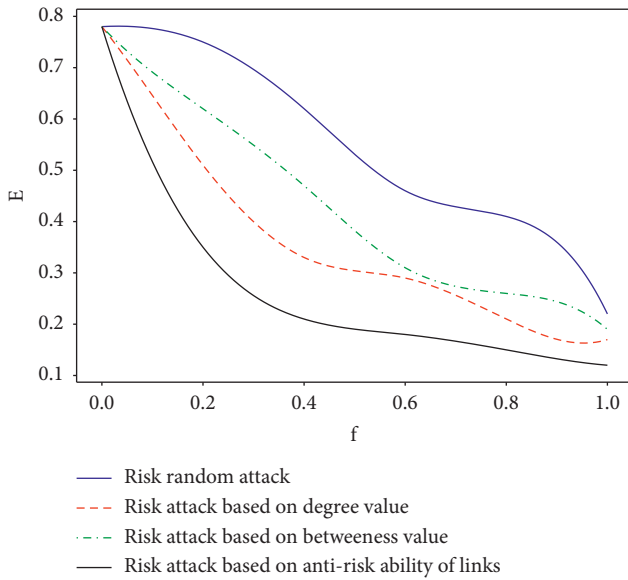


FIGURE 3: Transformation of network efficiency.

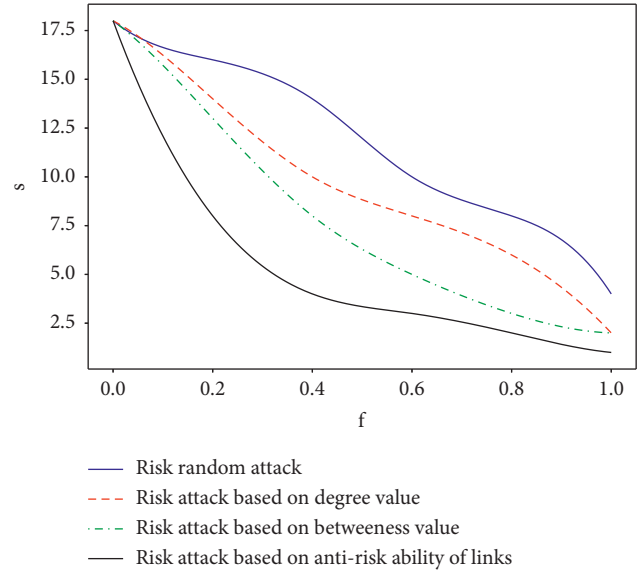


FIGURE 5: Transformation of effective scale of network.

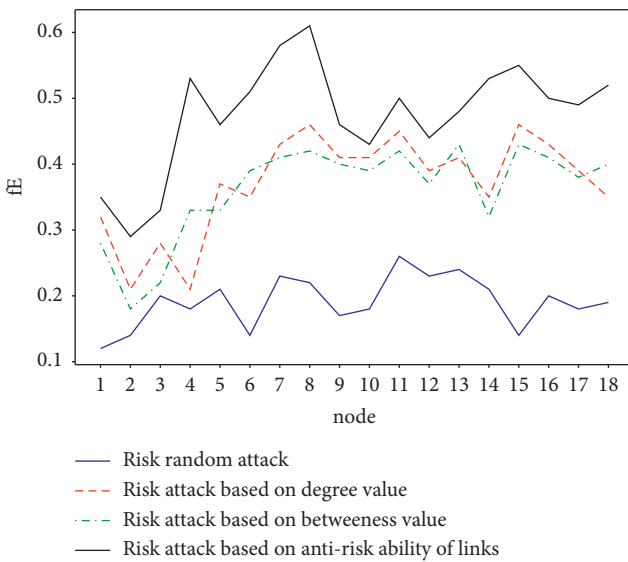


FIGURE 4: Decline rate of network efficiency.

Figure 4, the decline rate of network efficiency under the risk attack based on links' anti-risk ability is higher than the decline rate which is under the risk attack based on random attack, risk attack based on nodes' degree, and risk attack based on nodes' betweenness value, meaning that network composed of risk influencing factors has the lowest anti-risk ability under the risk attack based on links.

(2) *Simulation of Effective Scale of Network under Different Risk Attacks.* Figure 5 shows the transformation of effective scale of network that consists of risk influencing factors under different risk attack modes. Just as the change of network efficiency under different risk attacks, the effective scale of the network also decreases with the increase of the attacked nodes. And the strength of damage on network by

the risk attack based on links' anti-risk ability is higher than that of random risk attack and deliberate risk attack. Figure 6 shows the decline rate of effective scale of network under different risk attack modes, which represents the risk level of network due to failure of each node in the dimension of effective scale. The higher the value is, the lower the anti-risk ability of the network is.

To sum up, the network efficiency and effective scale of network are taken as the indicators of anti-risk ability. And the anti-risk ability of network consisting of risk factors of government purchasing elderly care services are measured under different risk attack modes. From Figures 3 to 6, it can be inferred that the network consisting of risk factors has the lowest anti-risk ability when it is attacked based on the link's anti-risk ability achieved in the previous chapter. Therefore, managers should focus on the risk influencing factors that are in the links with low anti-risk ability. Once the risk influencing factors in the links with low anti-risk ability are attacked, it will bring a greater negative impact in the network efficiency and effective scale of the network.

*4.3. Discussion.* Government purchasing elderly care services are in the ascendant in China and risk events occur frequently. Figuring out the risk links, clarifying the risk influencing factors, and analyzing the anti-risk ability have become the top priority of the implementation of the policy. As a complex system, government purchasing elderly care services have developed into a network model. Therefore, the application of GERT and complex network to the research on the anti-risk ability of government purchasing elderly care services has certain applicability and necessity.

Firstly, the main links and corresponding risk factors of government purchasing elderly care services are identified. Then, network of the policy is constructed with the cooperation of GERT and complex network. GERT is used to represent the links of government purchasing elderly care

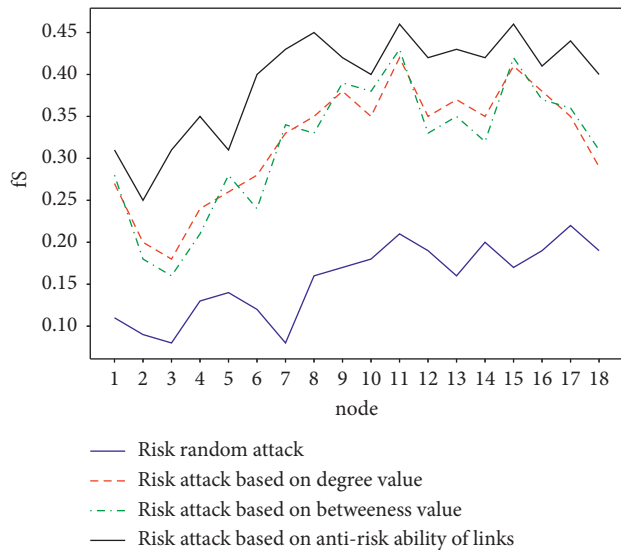


FIGURE 6: Decline rate of effective scale of network.

services, and complex network is applied to represent the risk influencing factors which are corresponding to the relevant links.

Secondly, based on the theory of GERT, the required time to complete each branch line between links is taken as risk element. After obtaining the basic parameters of GERT, the anti-risk ability of the links of government purchasing elderly care services is calculated. Main links that the anti-risk ability sorting from small to large are link (2, 6) “whom to buy from” (dependent purchase, independent with noncompetitive purchase, and independent with competitive purchase), link (11,12) “evaluation,” link (6,11) “how to buy” (financial investment, in-kind funding, issuance of service voucher, and reduction of venue rent), and link (1,2) “what to buy.” In addition, the anti-risk ability of each sublink is also obtained.

Finally, for the complex network consisting of risk influencing factors, the risk forms can be divided into random risk attack, deliberate risk attack, and risk attack based on links’ anti-risk ability which achieved from the previous chapter. Network efficiency and its decline rate and effective scale of the network and corresponding decline rate are selected as indicators to measure the anti-risk ability of complex network of government purchasing elderly care services. Simulation technology is used to simulate the risk attack, so as to obtain the anti-risk ability of the network in the level of risk influencing factors. Results show that compared with the anti-risk ability under the random risk attack and deliberate risk attack, the anti-risk ability based on risk attack under links is obviously lower. Therefore, not only the risk factors with high degree value and high betweenness value need to be paid attention, but also the risk factors with lower anti-risk ability links.

## 5. Conclusion

As a policy tool to deal with the aging of the elderly people, government purchasing elderly care services are an important mean to supply the elderly care services. Studying

the anti-risk ability of government purchasing elderly care services from the perspective of networks is helpful for managers to identify risks and measure the risk level of each link. The article studies the anti-risk ability of the policy at the link level and risk influencing factor level from the perspective of GERT and complex network. The conclusions are as follows:

Firstly, GERT is used to represent the link level of government purchasing elderly care services, and complex network is applied to show the relationship between the risk factors corresponding to the links that represented in GERT. Under the cooperation of two networks, government purchasing elderly care services can be mastered comprehensively and systematically.

Secondly, at the link level, the completion time of each branch line between the links of government purchasing elderly care services is regarded as a risk element from the perspective of elderly care service chain. And the link of “who to buy from” has the lowest level of anti-risk ability. According to “Law of Government Procurement,” the first and the most important step of government purchasing elderly care services is to determine the service providers. The determination of service providers needs to go through complex procedures such as multimode selection and multistage progression. Results of service provider has a decisive impact on the final effect of government purchasing elderly care service. However, the anti-risk ability of the link is the lowest according to the research results.

Thirdly, at the level of risk influencing factors, the anti-risk ability of the network is simulated in four cases, which are random risk attack, risk attack based on nodes’ degree value, risk attack based on nodes’ betweenness value, and risk attack based on links’ anti-risk ability. Results show that managers should focus on risk factors that correspond to links with low anti-risk ability. Once these risk factors are attacked, the effective scale and network efficiency which are the indicators of anti-risk ability will decrease rapidly and bring great negative effects.

In addition, many deficiencies have been found in the process of research. For example, in the construction of complex network of risk influencing factors, the judgment of the relationships between nodes is still subjective. Therefore, how to build a more scientific complex network is a direction worthy of further exploration.

## Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

## Conflicts of Interest

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

## Authors’ Contributions

All the 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. All the authors commented on previous versions of the manuscript as well as read and approved the final manuscript.

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