Journal of Systems Engineering and Electronics
Vol. 32, No. 4, August 2021, pp.907 – 926

Meteorological satellite stakeholder relationship network based on social network analysis

LI Lu, LIU Yupeng*, and HE Kongxin
School of Economics and Management, Harbin Institute of Technology, Weihai 264209, China

Abstract: The meteorological satellite service range is extensive, and science and technology and related industries have become beneficiaries of it. The complex meteorological satellite stakeholder relationship warrants quantitative evaluation. This study investigates the meteorological satellite stakeholder relationship network to provide a new research perspective for meteorological satellites in the field of management. For literature analysis, 16 meteorological satellite stakeholders are identified through keyword screening, classified, and coded. A meteorological satellite stakeholder relationship network model is then constructed through social network analysis (SNA). Ego, local, and overall networks are analyzed from three perspectives to measure the network principle and to form a relationship network coordination degree evaluation system. The improved analytic hierarchy process (AHP)-fuzzy comprehensive evaluation method is then used to determine index weights and evaluate the relationship network coordination process design comprehensively. In empirical analysis, data for the meteorological satellite Fengyun-4 are obtained through questionnaire survey and literature analysis. Ucinet6 is used to generate relationship networks and analyze various stakeholder roles and status, stakeholder relationship network coordination degree, and evaluation results. The results demonstrate that the competent meteorological satellite department, the meteorological administration, the National Meteorological Centre, and the government are in the center of the Fengyun-4 stakeholder relationship network, with coordination degree in an "average" state. Thus, establishing a stakeholder coordination mechanism may strengthen connection and promote the development of meteorological undertakings.

Keywords: meteorological satellite, stakeholder, relationship network, coordination degree.

DOI: 10.23919/JSEE.2021.000078

1. Introduction

Meteorological satellites can monitor changes in cloud maps around the Earth, send weather detection data, and provide meteorological information. In addition, they are used for effectively monitoring ecosystems in areas such as environmental monitoring, disaster prevention, and timely forecasting to reduce national economic loss and protect the safety of people's lives and properties. Meteorological satellites have also promoted the development of related industries and economies, such as science and technology, agriculture and forestry, manufacturing, education, and service industries, and thus they afford large economic benefits. Meteorological satellites are widely used in various fields of national production and life; thus, several scientific and technological fields, related industries, and other groups have become direct or indirect beneficiaries of meteorological satellite services.

However, because of the complexity of current meteorological satellite system engineering and the large number of stakeholders participating in meteorological satellite activities, different goals and motivations exist, resulting in numerous difficulties in analyzing the relationship between meteorological satellite stakeholders. As a key national development project, meteorological satellites are considerably affected by macroeconomic factors, such as the national policy orientation and the social environment, which affect various production fields and related areas. Previous meteorological satellite development required lower social participation projects and engineering; however, with increasing developments in meteorological satellite system engineering, their complexity, comprehensiveness, and dependency have increased. Therefore, it is necessary to promote the development and operation mode of traditional meteorological satellites and clarify the relationships and closeness among many stakeholders and the status and value of each stakeholder in the entire relationship network. Realizing further development of meteorological satellites through coordinated interaction is crucial for obtaining the maximum value of meteorological satellites and achieving national

Manuscript received June 20, 2020.
*Corresponding author.
This work was supported by the National Natural Science Foundation of China (71402040).

economic growth.

At present, domestic research in the field of meteorological satellite management is mainly concentrated in meteorological satellite application services and economic benefit evaluation, and there is a lack of research from the perspective of stakeholder relationships. This paper applies relevant theories of social network analysis (SNA) to the study of meteorological satellite stakeholders, establishes a meteorological satellite stakeholder relationship network, and uses the improved analytic hierarchy process (AHP)-fuzzy comprehensive evaluation method to evaluate the coordination degree of the stakeholder relationship network, which enriches the research content of meteorological satellites in management. From a systematic point of view, this paper studies relevant knowledge of SNA, determines the basic steps of node identification, relationship definition, data collection, network generation, and network feature analysis, gives suggestions, and further broadens the research ideas of meteorological satellite stakeholders. It provides a basic analysis framework for future research directions of the stakeholder relationship network. By proposing different network indicators and network coordination degree evaluation systems, the goal of improving the satisfaction of various stakeholders of meteorological satellites is achieved, and a basis is provided for clarifying the future development direction of meteorological satellites and the formulation of related policies. This study determines the degree of coordination between core stakeholders and the relationship network, so as to establish a reasonable coordination and cooperation mechanism to enable stakeholders to fully carry out their businesses. A coordinated development of different fields of meteorological satellites and the maximum economic benefits of meteorological satellites should be realized, so that they can better serve the society, the country, and the people.

The rest of this paper is organized as follows. Section 2 is a literature review. Section 3 builds a model of the relationship network of meteorological satellite stakeholders and analyzes the measurement principle of the relationship network. An evaluation index system for meteorological satellite stakeholder relationship network coordination degree is established, and the analytic AHP-fuzzy comprehensive evaluation method is selected to improve the evaluation design of this degree. In Section 4, the meteorological satellite Fengyun-4 is selected as the research object for empirical research, and the coordination degree of the relational network is evaluated quantitatively by using a fuzzy comprehensive evaluation method. A network coordination mechanism for the meteorological satellite stakeholder relationship is designed on the basis of the evaluation results, and corresponding suggestions are provided for the development of meteorological satellites. Finally, Section 5 presents the conclusions.

2. Literature review

Research in the management of meteorological satellites mainly focuses on the application service field and the evaluation of economic benefits. In the field of application services, researchers conducted in-depth research and analysis on images and various types of data obtained by meteorological satellites. Guo evaluated the drought conditions of Mekong River from January 1981 to July 2016 by using the satellite-based high-resolution Climate Hazards Group Infrared Precipitation with station data. Guo et al. found that droughts occur more frequently in the south and the north and have a greater impact on vegetation [1]. Arellano-Lara et al. used information based on previous models in combination with satellite imagery and meteorological data to estimate potential storms in Northern Mexico 2 h in advance [2]. Tahir et al. used a numerical weather forecasting model in combination with geostationary meteorological satellites and visible light image data to develop a quantitative precipitation prediction model with reference to a multilayer neural network. This model can better predict 1 h precipitation in tropical flood-prone areas [3]. Lu et al. noted that the data obtained through meteorological satellites can be used to comprehensively monitor a series of processes from occurrences to disappearances in the weather system and, particularly, to provide an objective basis for short-term and near-term forecasting [4]. In terms of economic benefit evaluation, many scholars are paying more and more attention to the economic benefits generated by the use of satellite systems and the promotion of the industry [5−8].

The research content of stakeholders mainly focuses on three directions: concept identification, concept classification, and theoretical research. In terms of concept appraisal, scholars from various countries have expressed different opinions on the research of stakeholders over the years [9−12]. Chen et al. integrated and generalized the definitions of Freeman and Clarkson stakeholders. They defined individuals and groups in the enterprise who make specific investments, bear risks, or are affected by the process of achieving their goals as stakeholders, highlighting the relationship between the stakeholders and the enterprise [13−15].

As a research method to quantitatively analyze the interaction of groups [16], SNA is based on studying the interaction among actors. It uses nodes to represent the research objects and lines to connect these nodes to represent the relations between the research objects [17]. Jiao et al. studied the five relationships of contract, coordination, instruction, information exchange, and performance reward in a private-public partnership (PPP) project; used SNA to establish a PPP project stakeholder relationship network; built decisions from the perspective of the PPP project lifecycle stakeholder relationship network through the stages of decision, implementation, and operation; and quantitatively analyzed the network's characteristics [18]. Xin et al. proposed an original SNA-based model with key success factors for stakeholders and projects as intermediate variables for success. This model clarifies and makes transparent the relationship between various stakeholders and reveals how stakeholders influence the success of a project [19].

The stakeholder coordination mechanism is an approach for studying stakeholder relationships. Tian et al. used the concept of a nonprofit organization incubator and its functions to analyze the relationships among stakeholders such as nonprofit organizations, governments and enterprises, and clarified the coordinating role played by the incubators in improving the relationships among these stakeholders [20]. Chang et al. solved the problem of quantitative measurement of the coordination degree of stakeholder relationships in a project by establishing an internal evaluation index for project stakeholders, an external evaluation index and a coordination measure model, and conducted empirical analyses [21]. Researchers are increasingly studying the coordination mechanism from the relationships among system elements. Martins et al. explored the main coordination mechanisms used to support the governance structure of the Brazilian pork supply chain and proposed a framework for analyzing the coordination of four elements in transactions: price, quantity, quality, and resource allocation [22].

After systematically collecting and sorting out the literature, scholars at home and abroad have conducted a lot of research on the application benefits of meteorological satellites in the management field. However, there is a lack of research on the relationship of various stakeholders involved in the meteorological satellite system engineering. Research on stakeholders mainly focuses on qualitative aspects such as concept identification, classification recognition, and theoretical research. It lacks the use of quantitative methods to analyze the relationship and importance of stakeholders in the organization. Some scholars have introduced SNA for stakeholder analysis, but they have not analyzed in depth whether the individuals, the parts, and the whole of the stakeholder relationship network are in a coordinated state from the perspective of the network. Therefore, by combining the steps of the SNA method, the generation, measurement, analysis, and network coordination degree of the meteorological satellite stakeholder relationship network are comprehensively analyzed.

3. Construction of meteorological satellite stakeholder relation network model and evaluation of coordination degree

3.1 Analysis of meteorological satellite stakeholders

3.1.1 Connotation

The meteorological satellite system engineering is responsible for the development and application of the national government department. The main purpose is to provide meteorological services for human society with fast forecasting, high accuracy, and correct preventive measures. Therefore, it can be regarded as a public organization or a non-profit organization. At present, foreign scholars Nutt, Backoff, and Bryson define the stakeholders of public or non-profit organizations as "any individual, group or organization that can make a claim on the development, resource utilization and output of the organization or is affected by the output" [23,24]. This definition exemplifies the scope of stakeholders in public or non-profit organizations. Therefore, this study defines the connotation of meteorological satellite stakeholders as: any individual, group or organization that can guide and participate in meteorological satellite research and development, manufacturing, application system engineering, or any individual, group, or organization affected by its application. This has laid a good foundation for the selection and definition of stakeholders in the next step.

3.1.2 Definition and classification

Because the direct references for stakeholder research are scarce, in order to more comprehensively complete the identification and definition of meteorological satellite stakeholders, this paper combines the similar characteristics of meteorological satellites and manned space projects, and comprehensively considers relevant domestic and foreign literature on meteorological satellites and manned space projects. The keywords involved in meteorological satellite stakeholders are screened, extracted, and summarized, as shown in Table 1. According to the previous literature review, combined with the connotation of meteorological satellite stakeholders, the following 16 stakeholders can be defined, as shown in Table 2. At the same time, in order to distinguish the differences in attributes of different stakeholders, the stakeholders are divided into six categories: organization management, scientific research and technology, industry participation, target users, market environment, and the public.

Table 1 Summary of key words of meteorological satellite stakeholders

NO.	Author	Stakeholder keywords
1	Sharpe M A, et al. [25]	◎Met Office Space Weather Operations Centre ◎User
2	Huang Q X, et al.[26]	◎The public ◎The government ◎Competent meteorological satellite department
3	Zhang Z P, et al. [27]	◎The government ◎Satellite operator ◎Spacecraft manufacturer ◎Financial institution
4	Green J C, et al.[28]	◎Satellite operator ◎Satellite manufacturer
5	Lu W, et al.[29]	◎Infrared technology ◎Shanghai Institute of Technical Physics, Chinese Academy of Sciences
6	Lakhin O. I.[30]	◎Expert ◎Cargo dispatch ◎Project engineer ◎Manufacturer ◎Application administrator ◎Astronaut ◎International Space Station
7	Dong C H, et al.[31]	◎Meteorological research ◎Agriculture, forestry, fishery and animal husbandry ◎Hydrology ◎Ecological protection ◎Natural disaster monitoring
8	Du D, et al.[32]	◎Weather live report ◎Maritime satellite system ◎Weather channel
9	Cheng X N[33]	◎Meteorological public service ◎Weather forecast ◎Mass media ◎TV viewer ◎Netizen
10	Zhang Q S, et al.[34]	◎WeChat public account ◎The public ◎Flood control and drought relief command department
11	Carr R H, et al.[35]	◎National Weather Service（NWS） ◎National Oceanic and Atmospheric Administration（NOAA） ◎The public ◎Forecast and early warning products
12	Yuan H L, et al. [36]	◎The public ◎New media ◎Public weather service ◎Primary industry ◎NWS
13	Lin R H, et al. [37]	◎Meteorological film and television ◎The public ◎TV media ◎Three dimensional rural issues
14	Chattopadhyay N, et al.[38]	◎Competent meteorological satellite department ◎Meteorological technology ◎Agricultural sector ◎Agricultural Meteorological Consulting ◎Farmer
15	Umehira M, et al.[39]	◎Korea Communications Commission ◎Ministry of Education, Science, and Technology ◎Satellite communications department ◎SMEs and the private sector ◎University
16	Bayissa Y, et al.[40]	◎Drought early warning system ◎Assessing the spatial and temporal pattern of drought ◎School

Table 2 Classification and coding of meteorological satellite stakeholders

Coding	Stakeholders	Category
A1	The government	Organization management
A2	The competent meteorological satellite department	
A3	The meteorological administration	
B1	Science and technology personnel	Scientific research and technology
B2	Scientific research institutes	
B3	Institutions of higher learning	
C1	Mass media	Market environment
C2	Competitors	
D1	Suppliers	Industry participation
D2	Collaborators	
D3	Meteorological satellite manufacturers	
E1	The National Meteorological Centre	Target users
E2	Ministry of Water Resources	
E3	Agriculture, forestry, fishery and animal husbandry	
E4	Environmental protection departments and organizations	
F1	The public	The public

3.2 SNA

After the stakeholders are defined, a relational network model can be constructed by determining the network connotation and network relations. From the ego network, the local network, and the overall network, the measurement principle of different network features is clarified, and the evaluation index system for the coordination degree of the relational network is formed to complete a comprehensive evaluation design.

SNA involves combining a graph with a matrix and studying the network characteristics from different angles. Wellman, an SNA expert, believes that SNA is suitable for studying features that actors in network models comprising complex systems cannot find from the surface [41]. Therefore, SNA is used to clarify and quantify the network relationships of various stakeholders in meteorological satellite system engineering from the ego, local, and overall perspectives to clearly define the status and degree of participation of these stakeholders. In addition, on the basis of the attribute index of SNA, an improved AHP-fuzzy comprehensive evaluation method is used to quantify the coordination degree of meteorological satellite stakeholders and evaluate the coordination degree of the whole relationship network, and accordingly provide corresponding suggestions and strategies for the future development of meteorological satellites.

3.3 Establishment of a network model of meteorological satellite stakeholder relationships based on SNA

This paper defines the meteorological satellite stakeholder relationship network as a network in a specific policy environment for completing the development and application of meteorological satellite products and promote the development of the meteorological public service industry. The sum of formal or informal and relatively stable relationships are established between the government, the competent meteorological satellite department, and related institutions (research institutes, collaborators, suppliers, etc.).

To determine the degree of interconnection among meteorological satellite system engineering stakeholders in the relationship network, four correlation values are set: “3” means strong connection, “2” represents medium connection, “1” represents weak connection, and “0” means no connection. In this study, a questionnaire survey, literature analysis, and expert determination are used to determine whether there is any connection between the stakeholders and the degree of connection.

The relational network is comprised of three parts: nodes, lines, and relational strengths (relational value). Suppose the relational network graph F is composed of sets P and L, denoted as $F=(P, L)$. Here, P represents a node and is a finite non-empty set denoted as $P(F)$. L is a finite set of lines denoted as $L(F)$. Therefore, the network graph of the meteorological satellite stakeholder relationship is directed and its adjacency matrix is asymmetric. Combined with the previous analysis, to facilitate the understanding of the generation of a relational network, one stakeholder in each category is selected as the representative. Table 3 shows the relationship matrix of the six stakeholders.

Table 3 Example of relational matrix

	A1	B1	C1	D1	E1	F1
A1	–	3	2	0	1	0
B1	2	–	3	1	2	2
C1	2	0	–	2	0	0
D1	1	1	3	–	1	1
E1	0	2	2	0	–	0
F1	1	1	0	0	0	–

After the nodes and relationships are determined, a network model for the meteorological satellite stakeholder relationship is established. The relational matrix in Table 3 is input into Ucinet6 (University of California, Irvine, California, United States) and transformed into a visual relational network model, as shown in Fig. 1.

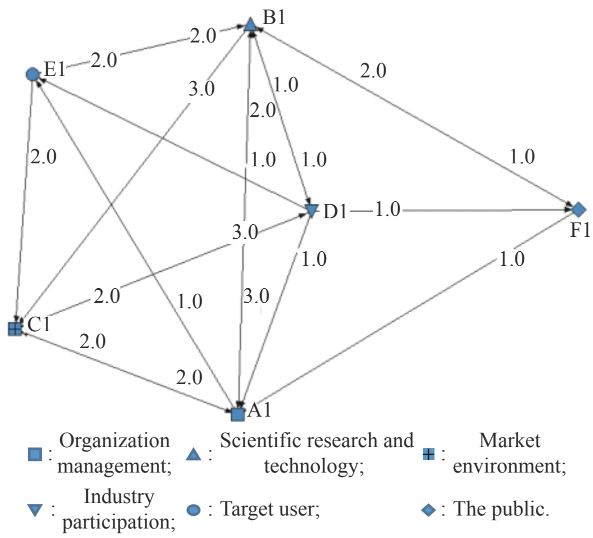

Fig. 1 Example of stakeholder relationship network model

3.4 Characteristic measurement of meteorological satellite stakeholder relationship network

There are three dimensions in the feature analysis of the stakeholder relationship network: the ego network, the condensed subgroup, and the overall network. Through the analysis of these three dimensions, the status and reputation of network stakeholders can be well measured from a global perspective and the value of stakeholders can be determined.

(i) Ego network

i) Indegree and outdegree. The indegree of stakeholder n_i is $d_I(n_i)$. This is the sum of nodes adjacent to n_i. The outdegree $d_O(n_i)$ is the sum of nodes adjacent to n_i.

ii) Degree centrality. $d(n_i)$ represents the number of other stakeholders directly connected to n_i in the network. The degree centrality $C'_D(n_i)$ measures the ability of a stakeholder to directly connect with other stakeholders in the network, and it is calculated as

$$C'_D(n_i) = \frac{d(n_i)}{P-1}. \tag{1}$$

From the definition of $C'_D(n_i)$, its value range is [0,1]. The larger its value is, the greater is the sum of the stakeholder relations and the greater is the centrality of the relationship network. This can strongly influence the direct interaction with different stakeholders while obtaining sufficient information.

iii) Closeness centrality. Use $d(n_i,n_j)$ to represent the minimum distance between stakeholders n_i and $n_j, j \neq i$. The closeness centrality $C'_C(n_i)$ can be calculated as

$$C'_c(n_i) = \frac{P-1}{\sum\limits_{j=1}^{N} d(n_i,n_j)}. \tag{2}$$

The value range of $C'_C(n_i)$ is [0,1]. The greater the proximity to the center, the closer the stakeholder to other nodes in the network, the easier it is to obtain, transmit, and control information, and the more prominent its position is in the network.

iv) Betweenness centrality. g_{jk} represents the number of the shortest paths between stakeholders n_j and n_k. $g_{jk}(n_i)$ represents the number of n_i paths included in the shortest path connecting n_j and n_k. The betweenness centrality of n_i is calculated as

$$C_B(n_i) = \sum_{j<k} \frac{g_{jk}(n_i)}{g_{jk}}. \tag{3}$$

$C_B(n_i)$ represents the sum of the probabilities of all stakeholders except stakeholder n_i. When stakeholder n_i does not pass the shortest path, the minimum value is 0. In the directed graph, when stakeholder n_i is located in the shortest path of all other stakeholders, the maximum value is $(P-1)(P-2)$. Therefore, it is standardized as

$$C'_B(n_i) = C_B(n_i)/[(P-1)(P-2)] = \frac{\sum\limits_{j<k} \frac{g_{jk}(n_i)}{g_{jk}}}{(P-1)(P-2)}. \tag{4}$$

The value range of the normalized $C'_C(n_i)$ is [0,1]. The larger its value, the greater a stakeholder’s role in the organization as a “bridge.” However, from another viewpoint, if only a few stakeholders in the whole network have a high betweenness centrality value, the “transfer station” may also reflect that information, and resources in the organization are monopolized by them, which is not conducive to the development of meteorological satellite system engineering.

(ii) Local network

i) Condensed subgroups (n-cliques) based on accessibility. An agglutination subgroup based on accessibility refers to a small group F_S with a minimum distance of no more than n between any two stakeholders in the relationship network graph F. As shown in (5), for all stakeholders n_i and n_j that belong to F_S,

$$d(n_i,n_j) \leqslant n. \tag{5}$$

ii) Condensed subgroups (k-plex) based on node degree. In F_S, there are g_s stakeholders, and $d(n_i)$ indicates the number of directly connected stakeholders in n_i in F_S. As shown in (6), for all $n_i \in F_S$,

$$d(n_i) \geqslant g_s - k. \tag{6}$$

The E-$Iindex$ is mainly used to measure the size of the faction of the subgroup in the relationship network, as shown in (7):

$$E\text{-}Iindex = \frac{EL-IL}{EL+IL}. \tag{7}$$

The value range of E-$Iindex$ is $[-1,1]$. When $EL=0$, E-$Iindex$ takes the minimum value of -1, implying that all relationships occur within the subgroup, there is no connection with the outside world, and the faction is the largest in the relationship network. When $EL=IL$, $E\text{-}Iindex=0$ takes the maximum value of 1, implying that all relationships occur among the subgroups and the overall relationship network faction is the smallest. When $EL=IL$, $E\text{-}Iindex=0$, it implies that the relationships in the subgroups are randomly assigned.

(iii) Overall network

i) Network density. In a directed relational network, the network density is represented by the ratio of the number of arcs existing between nodes in the relational network to the total number of possible arcs. Therefore, the network density is calculated as

$$\Delta = \frac{L}{P(P-1)}. \tag{8}$$

A larger network density value implies closer communication between stakeholders and a higher frequency of interaction, which is conducive to the diffusion of knowledge, resources, technology, and information. It plays a vital role in the promotion and development of meteorological satellite system engineering.

ii) Network diameter. The network diameter refers to the maximum value of $d(n_i,n_j)$. For all stakeholders n_i and n_j,

$$D = \max d(n_i,n_j). \tag{9}$$

Its value range is $[1, P-1]$. The smaller the network diameter is, the shorter is the path along which the stakeholders need to pass information, which is beneficial to the coordination and interaction of the stakeholders in the relationship network.

iii) Central potential. The higher the central potential is, the more concentrated is the resource aggregation in the relationship network, which corresponds to the stronger ability of stakeholders with higher centrality to control technology, knowledge, information, funds, and other resources. Its value range is [0,1].

$$C = \frac{\sum_{i=1}^{n}(d(n_i)_{\max} - d(n_i))}{\max\left[\sum_{i=1}^{n}(d(n_i)_{\max} - d(n_i))\right]} \tag{10}$$

3.5 Evaluation of coordination degree of meteorological satellite stakeholder relationship network

After measuring the ego, the local, and the overall network characteristics of the meteorological satellite stakeholder relationship network in the previous section, it is understood that each indicator unilaterally characterizes a certain characteristic of the relationship network from the attribute, and that each indicator has different degrees of measuring a certain attribute of the network, resulting in disorder and uncertainty in the evaluation results of the relationship network. In order to make an objective and comprehensive evaluation of the overall stakeholder network, it is necessary to form an evaluation index system for the degree of coordination of the meteorological satellite stakeholder relationship network, and select an improved AHP-fuzzy comprehensive evaluation method to make a corresponding evaluation of the degree of coordination of the meteorological satellite stakeholder relationship network.

3.5.1 Construction of evaluation index system for coordination degree of relationship network

To fully evaluate the coordination degree of the meteorological satellite stakeholder relationship network, the interconnectivity of the nodes, the number of agglomerate subgroups, the size of agglomerate subgroups, and the strength of the network relationship are increased based on the ego, the local, and the overall measurement indicators of the relationship network. The five indicators of network environment friendliness form an evaluation index system for the coordination degree of the meteorological satellite stakeholder relationship network. Table 4 lists the levels, connotations, and quantitative indicators of each indicator.

Table 4 Evaluation index system for the coordination degree of meteorological satellite stakeholder relationship network

Target	Primary indicator	Secondary indicator	Content description	Quantitative indicator
Coordination level of the meteorological satellite stakeholder relationship network (X)	Node centrality (X1)	Node interoperability (X11)	Interconnections among nodes in a relational network	Node exchange rate
		Node relationship (X12)	The degree of direct connection between nodes and other nodes in the relationship network	Degree centrality
		Closeness between nodes (X13)	The distance between a node and other nodes	Closeness centrality
		Node control (X14)	The degree to which nodes in the relational network lie between the other two nodes	Betweenness centrality
	Cohesive subgroups (X2)	Number of agglomerate subgroups (X21)	Number of subgroups in a relational network	The number of cohesive subgroups
		Subgroup with degree (X22)	The closeness of the subgroup's internal and external connections	*E-Iindex*
		Cohesive subgroups scale (X23)	The number of nodes included in each cohesive subgroup in a relational network	Number of subgroup nodes
	Overall network characteristics (X3)	Network density (X31)	The density of interactions between all nodes, and the greater the density, the smoother the communication	Network density
		Network distance (X32)	Length between any two nodes in a relational network	Network diameter
		Degree of resource aggregation (X33)	The degree of concentration of resources, such as technology, knowledge, and information in a relational network	Central potential
		Network relationship strength (X34)	The overall strength of the relationship network	Average relationship strength
		Network environment friendliness (X35)	The quality of the external environment of the network, such as the degree of support for policies	–

3.5.2 Selection of evaluation methods for coordination degree of relationship networks

The comprehensive evaluation of the coordination degree of the relationship network of the meteorological satellite stakeholders mainly includes three crucial characteristics: (i) There is a certain difference in the impact of each indicator on the degree of coordination of the relationship network, and it needs to be assigned a relatively reasonable weight; (ii) The weighting process leads to a certain subjectivity in the evaluation conclusions; (iii) The degree of coordination of the relationship network is difficult to judge with absolute “one or the other” results and conclusions, which has a certain degree of ambiguity. Therefore, in the comprehensive evaluation of the coordination degree of the meteorological satellite stakeholder relationship network, the following three characteristics need to be met to ensure the reliability of the evaluation results: dealing with multiple factors, reducing subjective judgments, and solving ambiguities.

The improved AHP-fuzzy comprehensive evaluation method meets the above three characteristics relatively well. The improved AHP uses a three-scale method to construct a comparison matrix that reduces the number of pairs compared with the traditional nine-scale method. The numerical definition of the importance between the two indicators greatly reduces the impact of human subjectivity on the evaluation results; simultaneously, the weight can be directly obtained by using the optimal transfer matrix without the need to calculate the maximum eigenvalue and consistency check. The calculation process improves efficiency simultaneously. The fuzzy comprehensive evaluation method needs to perform multi-level fuzzy comprehensive operations in the evaluation process, investigate the impact of each index factor on the target layer step by step, and integrate and quantify the opinions of multiple evaluation subjects. Simultaneously, the evaluation level standard is set for the index and the evaluation target, which effectively solves the ambiguity problem due to subjective empowerment and the evaluation target being difficult to define in the evaluation process, and provides scientific, objective, and reasonable evaluation results. Therefore, the improved AHP-fuzzy comprehensive evaluation method is suitable for the comprehensive evaluation of the coordination degree of the stakeholder relationship network of meteorological satellites.

3.5.3 Evaluation process of coordination degree of relation network based on AHP-fuzzy comprehensive evaluation method

(i) Determination of weights based on improved AHP indicators

Step 1 Construct a comparison matrix. The improved AHP uses a three-scale method. Experts compare the relative importance of each level of the index to the upper target layer based on the scales in Table 5. To evaluate the level in accordance with its importance to establish a comparison matrix $\boldsymbol{A}_i = [a_{ij}]$, where $a_{ij} \geqslant 0$, $a_{ii} = 1$.

Table 5 Values and meanings of the three-scale comparison matrix

Number	Scale	Importance level
1	0	Element i is not as important as element j
2	1	Two elements i, j are equally important
3	2	Element i is more important than element j

Step 2 Calculate the importance ranking index q_i:

$$q_i = \sum_{j=1}^{n} a_{ij}. \tag{11}$$

Step 3 Construct the judgment matrix $\boldsymbol{E}_{ij}$:

$$e_{ij} = \begin{cases} \dfrac{q_i - q_j}{q_{\max} - q_{\min}}(k_m - 1) + 1, & q_i \geqslant q_j \\ \left[\dfrac{q_j - q_i}{q_{\max} - q_{\min}}(k_m - 1) + 1\right]^{-1}, & q_i < q_j \end{cases} \tag{12}$$

where $q_{\max} = \max\{q_i\}$, $q_{\min} = \min\{q_i\}$, and $k_m = \dfrac{q_{\max}}{q_{\min}}$.

Step 4 Calculate the transfer matrix $\boldsymbol{F}_{ij}$:

$$f_{ij} = \lg e_{ij},\ \ i = 1, 2, \cdots, N;\ j = 1, 2, \cdots, n. \tag{13}$$

Step 5 Calculate the optimal transfer matrix $\boldsymbol{G}_{ij}$:

$$g_{ij} = \frac{1}{n}\sum_{k=1}^{n}(f_{ik} - f_{jk}). \tag{14}$$

Step 6 Calculate a quasi-optimal uniform matrix $\boldsymbol{E}'_{ij}$:

$$e'_{ij} = 10^{g_{ij}}. \tag{15}$$

Step 7 Solve the normalized matrix $\boldsymbol{T}_{ij}$ of the quasi-optimal uniform matrix $\boldsymbol{E}'_{ij}$:

$$t_{ij} = \frac{e'_{ij}}{\sum\limits_{k=1}^{n} e'_{kj}}. \tag{16}$$

Step 8 Calculate weight size W_i:

$$W_i = \frac{1}{n}\sum_{j=1}^{n} t_{ij}. \tag{17}$$

(ii) Evaluation design based on fuzzy comprehensive evaluation method

i) Determine the set of evaluation factors. The set of factors for evaluating the degree of coordination of the stakeholder relationship network is $\boldsymbol{U} = (\boldsymbol{u}_1, \boldsymbol{u}_2, \cdots, \boldsymbol{u}_N)$, $\boldsymbol{u}_i\,(i = 1, 2, \cdots, N)$ is the first level indicator of the degree of network coordination. This is a first-level indicator of the degree of coordination of the relationship network. For example, $\boldsymbol{u}_2$ indicates condensed subgroup X2. The aggregate factor of the secondary index evaluation can be expressed as $\boldsymbol{u}_i = (u_{i1}, u_{i2}, \cdots, u_{iN})$, $i = 1, 2, \cdots, N$. For example, the number of aggregated subgroups X21 under the aggregated subgroup index X2 is expressed as u_{11}.

Correspondingly, the weight vector of the first-level indicator layer relative to the target layer can be set to $\boldsymbol{W}=\{W_1,W_2,\cdots,W_N\}$, and the weight vector of the second-level indicator layer relative to the first-level indicator layer is set to $\boldsymbol{w}_i=\{w_{i1},w_{i2},\cdots,w_{iN}\}$, $i=1,2,\cdots,N$, where W_i, w_{ij} satisfy the following relationship:

$$0\leqslant W_i\leqslant 1;\ 0\leqslant w_{ij}\leqslant 1;\ \sum_{i=1}^{N}W_i=\sum_{j=1}^{n}w_{ij}=1. \tag{18}$$

ii) Determine evaluation level standard set. The evaluation level standard set refers to the set of evaluation results that may be made by the evaluation object. Set $\boldsymbol{V}=\{v_1,v_2,\cdots,v_h\}$. $v_k(k=1,2,\cdots,h)$ is the standard for each index for the evaluation level k, and evaluation level standards for different evaluation indicators have a certain difference that indictates the range of choice of the evaluation results. The evaluation object can be a qualitative or quantitative index.

iii) Determine membership matrix $\boldsymbol{R}_i$. Suppose that a single-factor evaluation of the secondary index u_{ij} yields a fuzzy matrix $\boldsymbol{R}_{ij}=(r_{ij1},r_{ij2},\cdots,r_{ijh})$ $(i=1,2,\cdots,N;\ j=1,2,\cdots,n; k=1,2,\cdots,h)$ relative to v_k. r_{ijk} indicates that the factor u_{ij} scores on the v_k level standards. A comprehensive evaluation of all secondary indicators u_{ij} under the primary indicator $\boldsymbol{u}_i$ will form a membership matrix $\boldsymbol{R}_i$ with n rows and h columns. For the quantifiable secondary evaluation index, this study uses a semi-trapezoidal distribution function as the membership function. The principle is as follows. Let the actual value set of the evaluation index u_{ij} be $\boldsymbol{Z}=\{z_{11},z_{12},\cdots,z_{ij},\cdots,z_{Nn}\}$, evaluation standard set be $\boldsymbol{V}=\{v_1,v_2,\cdots,v_h\}$, v_k and v_{k+1} be the phase adjacent to the two levels of standards, and $v_{k+1}>v_k$. Then, the membership function of level v_k is

$$\begin{cases} r_{ij1}=\begin{cases}1, & z_{ij}\leqslant v_1\\ \dfrac{v_2-z_{ij}}{v_2-v_1}, & v_1<z_{ij}<v_2\\ 0, & z_{ij}\geqslant v_2\end{cases}\\ r_{ij2}=\begin{cases}1-r_{ij1}, & v_1<z_{ij}\leqslant v_2\\ \dfrac{v_2-z_{ij}}{v_2-v_1}, & v_2<z_{ij}<v_3\\ 0, & z_{ij}\leqslant v_1 \text{ or } z_{ij}\geqslant v_3\end{cases}\\ r_{ijk}=\begin{cases}1-r_{ijk-1}, & v_{k-1}\leqslant z_{ij}\leqslant v_k\\ \dfrac{v_{k+1}-z_{ij}}{v_{k+1}-v_k}, & v_k<z_{ij}<v_{k+1}\\ 0, & z_{ij}\leqslant v_{k-1} \text{ or } z_{ij}\geqslant v_{k+1}\end{cases}\end{cases}. \tag{19}$$

For determining qualitative indicators, such as the degree of membership of the network environment friendliness (X35), multiple experts are invited to make judgments on the basis of the evaluation levels given. And the proportion of the number of experts selected by each evaluation level to the total number of experts is used as the indicator. Therefore, the membership matrix of u_{ij} is $\boldsymbol{R}_{ij}=[r_{ij1},r_{ij2},\cdots,r_{ijh}]$. Therefore, the membership matrix of the first-level evaluation index $\boldsymbol{u}_i$ is

$$\boldsymbol{R}_i=\begin{bmatrix} r_{i11} & r_{i12} & \cdots & r_{i1h}\\ r_{i21} & r_{i22} & \cdots & r_{i2h}\\ \vdots & \vdots & \ddots & \vdots\\ r_{in1} & r_{in2} & \cdots & r_{inh}\end{bmatrix},\ i=1,2,\cdots,N. \tag{20}$$

iv) Comprehensive evaluation. Because of the existence of secondary indicators for the coordination degree of the meteorological satellite stakeholder relationship network, two comprehensive evaluations are required. The comprehensive evaluation of the primary indicators is as follows:

$$\boldsymbol{B}_i=\boldsymbol{w}_i\cdot\boldsymbol{R}_i=(w_{i1},w_{i2},\cdots,w_{in})\cdot \begin{bmatrix} r_{i11} & r_{i12} & \cdots & r_{i1h}\\ r_{i21} & r_{i22} & \cdots & r_{i2h}\\ \vdots & \vdots & \ddots & \vdots\\ r_{in1} & r_{in2} & \cdots & r_{inh}\end{bmatrix}=(b_{i1},b_{i2},\cdots,b_{ih}) \tag{21}$$

where $\boldsymbol{B}_i$ indicates the comprehensive fuzzy calculation result of all secondary evaluation indicators u_{ij} relative to the primary evaluation indicator u_i, $\boldsymbol{w}_i$ represents the weight of u_{ij} relative to $\boldsymbol{u}_i$. $\boldsymbol{B}_i$ is a comprehensive evaluation of the first-level index by the second-level evaluation index. Through $\boldsymbol{B}_i$, a membership matrix of the coordination degree of the meteorological satellite stakeholder relationship network can be formed as

$$\boldsymbol{R}=\begin{bmatrix} b_{11} & b_{12} & \cdots & b_{1h}\\ b_{21} & r_{22} & \cdots & r_{2h}\\ \vdots & \vdots & \ddots & \vdots\\ b_{i1} & b_{i2} & \cdots & b_{ih}\end{bmatrix},\ i=1,2,\cdots,N. \tag{22}$$

Similarly, according to the membership degree matrix $\boldsymbol{R}$ of the coordination degree of the relationship network, a comprehensive evaluation needs to be performed for each level of the indicators. $\boldsymbol{B}$ in (23) is the final fuzzy comprehensive evaluation result of the coordination degree of the meteorological satellite stakeholder relationship network.

$$\boldsymbol{B}=\boldsymbol{W}\cdot\boldsymbol{R}=(w_1,w_2,\cdots,w_N)\cdot(B_1,B_2,\cdots,B_N) \tag{23}$$

To directly judge the coordination degree of the meteorological satellite stakeholder relationship network, the coordination degree of the relationship network is quantitatively calculated by combining the coordination degree evaluation standard set $\boldsymbol{V}=\{v_1,v_2,\cdots,v_h\}$, $v_k(k=1,2,\cdots,h)$.

$$\boldsymbol{Q}=\boldsymbol{B}\times\boldsymbol{V}^{\mathrm{T}} \tag{24}$$

where $\boldsymbol{Q}$ is the value of the coordination degree of the meteorological satellite stakeholder relationship network. Compare $\boldsymbol{Q}$ with its corresponding evaluation level standard $\boldsymbol{V} = \{v_1, v_2, \cdots, v_h\}$ to judge it and determine the degree of coordination of the relationship network.

4. Empirical analysis of stakeholder relationship network for Fengyun-4

The meteorological satellite Fengyun-4 is selected as the research object for empirical analysis.

4.1 Relational network data collection

To better grasp the relationship and intensity among the 16 stakeholders of Fengyun-4, the relationships between stakeholders are determined in three rounds. In the first round, Fengyun-4 stakeholder relationship strength questionnaire is set up and distributed to representatives of different types of stakeholders for filling. As most stakeholders are government and enterprise departments, some difficulties are faced. In the initial stage, the questionnaire contents are explained through email and telephone communication to help the respondents in filling the questionnaire. A total of 30 questionnaires are issued and 18 are collected, with a recovery rate of 60%.

Because of the confidentiality of meteorological satellite system engineering, it is difficult for manufacturers, partners, and other groups to obtain data. The number of questionnaires collected is 0, and competitors are unable to issue questionnaires, resulting in data loss. Therefore, the second round adopts the literature analysis method, which mainly refers to the spatial application benefit stakeholder value network model [42] and combines with the literature collected from stakeholders of construction engineering projects, service-oriented manufacturing projects, and PPP projects to summarize the overall relationship and strength among stakeholders. In the third round, the results of the first two rounds are further sorted out, summarized, and sent to researchers in the field of meteorological satellites to consider and discuss whether any connection exists between various stakeholders of Fengyun-4 and the strength of the connection to form a unified opinion. Finally, the stakeholder relationship matrix of Fengyun-4 meteorological satellites are formed, as shown in Table 6.

Table 6 Stakeholder relationship matrix of Fengyun-4 meteorological satellite

	A1	A2	A3	B1	B2	B3	C1	C2	D1	D2	D3	E1	E2	E3	E4	F1
A1	–	3	3	1	1	1	2	1	0	0	0	2	2	2	1	2
A2	3	–	3	3	3	1	1	1	2	1	3	3	1	1	1	1
A3	3	2	–	2	2	1	2	2	1	1	2	3	2	1	1	2
B1	0	3	1	–	2	1	0	1	0	0	1	2	0	0	0	0
B2	1	3	1	3	–	1	0	1	0	0	2	1	1	1	1	0
B3	1	2	1	1	1	–	0	0	0	0	0	1	1	1	1	1
C1	1	1	2	0	1	0	–	1	0	0	0	2	2	2	2	1
C2	1	2	2	0	1	0	0	–	0	0	0	1	0	0	0	0
D1	0	2	1	0	0	0	1	0	–	2	3	2	0	0	0	0
D2	0	2	1	0	0	0	1	0	1	–	2	2	0	0	0	0
D3	1	3	2	3	3	1	1	0	3	2	–	1	0	0	0	0
E1	3	2	3	2	1	1	1	1	0	1	0	–	3	3	3	2
E2	2	1	3	1	1	0	0	0	0	0	0	3	–	2	2	2
E3	2	1	3	1	1	1	0	0	0	0	0	3	2	–	0	3
E4	2	1	2	1	1	1	0	0	0	0	0	3	1	0	–	2
F1	1	0	1	0	0	0	2	0	0	0	0	1	1	1	1	–

4.2 Stakeholder relationship network analysis of Fengyun-4

4.2.1 Stakeholder relationship network generation

The Fengyun-4 stakeholder relationship matrix is visualized to generate the stakeholder relationship network. To directly determine the role and position of stakeholders of Fengyun-4 in the relationship network, principal component (PC) analysis is conducted on the nodes of the relationship network. See Fig. 2 for details.

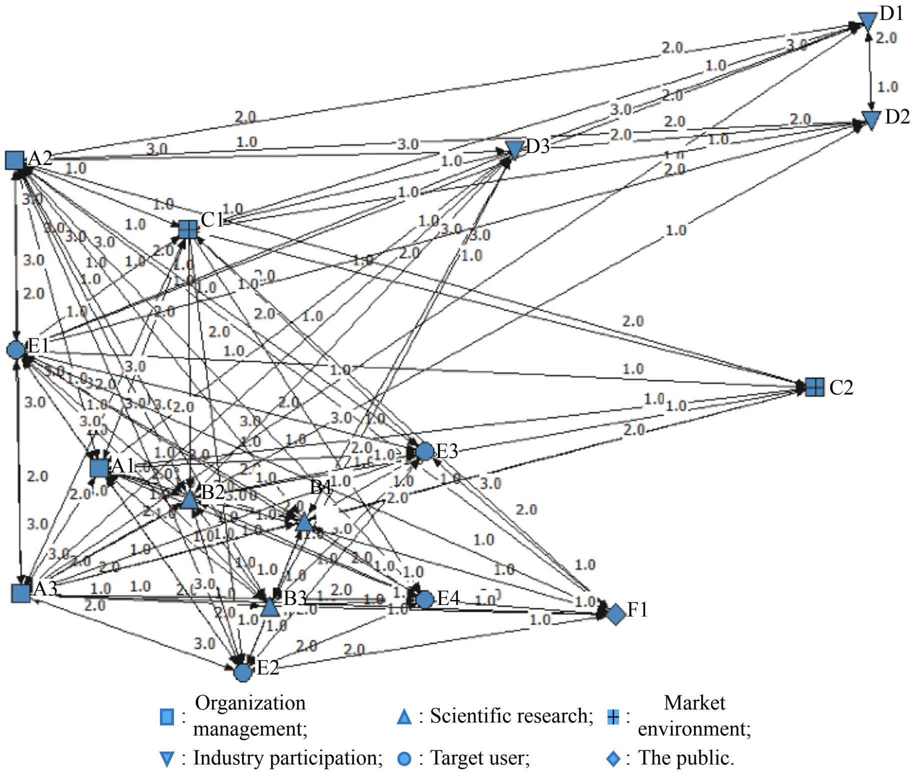

Fig. 2 Fengyun-4 stakeholder relationship network PC diagram

The multidimensional scaling (MDS) of geodesic distances function analysis can also be conducted for the meteorological satellite stakeholder relationship network core-edge structures (Fig. 3).

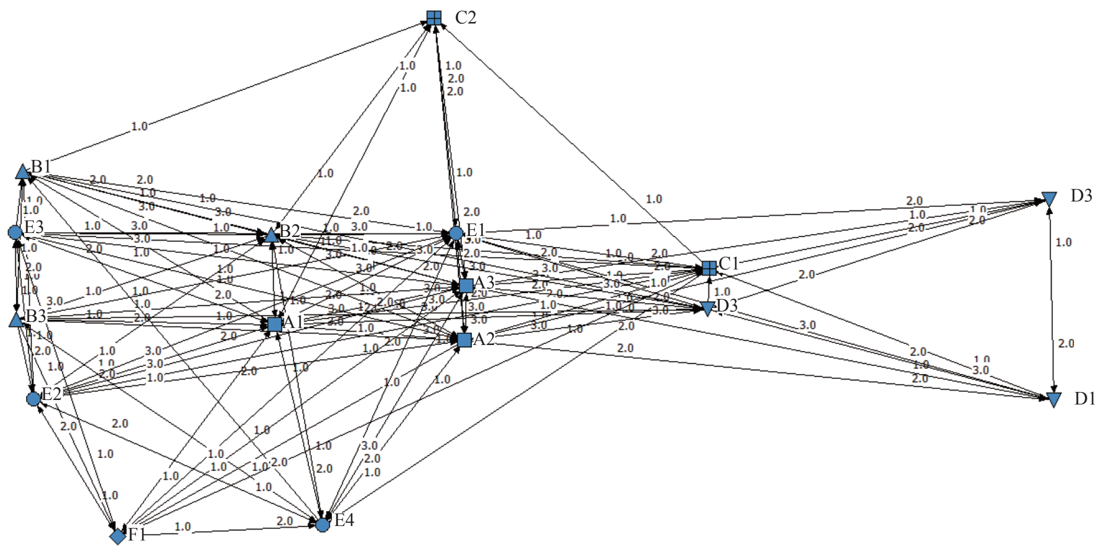

Fig. 3 MDS diagram of Fengyun-4 stakeholder relationship network

In the PC diagram, the importance of each stakeholder of Fengyun-4 in the relational network decreases from left to right. In the MDS diagram, the core stakeholders are located in the middle of the relational network. Fig. 2 and Fig. 3 illustrate that the competent meteorological satellite department (A2), the meteorological administration (A3), the National Meteorological Centre (E1), the government (A1), and scientific research institutes (B2) are at the core of the whole network, gaining high prestige and status in the whole system engineering and assuming important responsibilities for the development of meteorological satellites. Accordingly, the partners (D1) and suppliers (D2) of the industry participation class are distributed at the edge of the whole network, and their positions are roughly similar, reflecting similar functions and functions with less involvement. The results demonstrate that the core-edge structure of the meteorological satellite stakeholder relationship network is obvious.

4.2.2 Ego network analysis

(i) Indegree and outdegree

According to the stakeholder relationship matrix of meteorological satellites, the indegree $d_I(n_i)$ and outdegree $d_O(n_i)$ of each stakeholder are summarized, as listed in Table 7.

Table 7 Stakeholder indegree and outdegree

Vertex degree	A1	A2	A3	B1	B2	B3	C1	C2	D1	D2	D3	E1	E2	E3	E4	F1
Indegree	12	14	15	10	12	9	8	7	4	5	6	15	10	9	9	9
Outdegree	12	15	15	7	11	10	10	5	6	6	10	13	9	9	9	7

Table 7 shows that the government (A1), the competent meteorological satellite department (A2), the meteorological administration (A3), scientific research institutes (B2), and the National Meteorological Centre (E1) have both high input and output values. This indicates that these four stakeholders have a strong ability to output and receive information. In relative terms, suppliers (D1) and partners (D2) in the industry participation category have the least discrepancy.

(ii) Degree centrality

According to the analysis results in Table 8, three stakeholders (the competent meteorological satellite department (A2, 100%), the meteorological administration (A3, 100%), and the National Meteorological Centre (E1, 100%)) have the largest degree centrality. The suppliers (D1, 40%) and the partners (D2, 40%) have the smallest degree centrality, mainly because they are involved in the research and development and the construction stages of meteorological satellite system engineering and the number of directly related stakeholders is small. In the whole relationship network, the average degree centrality of the 16 stakeholders is 72.5%, indicating that direct communication and connections among stakeholders are relatively good, which is conducive to the smooth development of meteorological satellite system engineering.

(iii) Closeness centrality

According to Table 8, the closeness centrality of the competent meteorological satellite administration (A2) and the meteorological administration (A3) is 100%, indicating that they are adjacent to other stakeholders and do not rely on other stakeholders, making it easier to grasp the overall meteorological satellite systems engineering access to information and transmission, and to have the initiative to allocate resources. The closeness centrality of the National Meteorological Centre (E1, 88.235%) and the government (A1, 83.333%) decrease in order, and the overall value is in the upper and middle layers of the entire network. Therefore, the sum of the distances over which these four stakeholders can reach other stakeholders is relatively small, and direct dialogue and communication can basically be established. In addition, the average closeness centrality of the overall network is 75.327%, which is more than three-quarters, indicating that the distance between various stakeholders is not long, which is of great significance for reducing distortion in the process of information transmission and resource sharing.

Table 8 Stakeholder centrality statistics %

Stakeholder	Degree centrality		Closeness centrality		Betweenness centrality	
	Value	Classification	Value	Classification	Value	Classification
A1	86.667	4	83.333	4	2.655	5
A2	100.000	1	100.000	1	9.365	2
A3	100.000	1	100.000	1	10.985	1
B1	73.333	7	65.217	12	1.135	8
B2	80.000	6	78.947	5	2.734	4
B3	73.333	7	75.000	6	0.935	9
C1	86.667	4	75.000	6	2.178	6
C2	46.667	14	60.000	16	0.068	15
D1	40.000	15	62.500	14	0.000	16
D2	40.000	15	62.500	14	0.254	14
D3	66.667	10	75.000	6	1.695	7
E1	100.000	1	88.235	3	6.882	3
E2	73.333	7	71.429	9	0.454	13
E3	66.667	10	71.429	9	0.557	10
E4	66.667	10	71.429	9	0.557	10
F1	60.000	13	65.217	12	0.500	12
Average	72.500	—	75.327	—	2.560	—

(iv) Betweenness centrality

Table 8 shows that the meteorological administration (A3, 10.985%) has the largest betweenness centrality, followed by the competent meteorological satellite department (A2, 9.365%); these play an important role of “bridge intermediary” and have strong control over other stakeholders. The betweenness centrality of the overall relationship network is only 2.56%, indicating that the development of China’s meteorological satellites remains in its infancy. Most stakeholders are not prominent in the network, and their ability to control resources is weak.

Table 8 and Fig. 4 show the node centrality of four stakeholders: the meteorological satellite administration (A2), the meteorological administration (A3), the National Meteorological Centre (E1), and the government (A1). The closeness centrality and betweenness centrality values are relatively large. They play important roles in information transmission and resource allocation in the entire stakeholder relationship network and are at the core of the entire relationship network. Meanwhile, Fig. 4 illustrates that the change tendency of the degree, closeness, and between centralities of the 16 stakeholders are essentially identical.

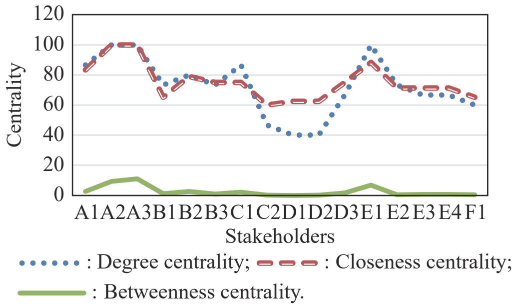

Fig. 4 Comparison of stakeholder degree centrality, near centrality, and betweenness centrality

4.2.3 Local network analysis

(i) Condensed subgroups (n-cliques) based on accessibility.

Table 9 lists the geodesic distances among all stakeholders of the Fengyun-4 stakeholder relationship network. This table indicates that the maximum distance between any two stakeholders is 2. Therefore, when the agglutination subgroup analysis is performed on the basis of accessibility, if $n \geqslant 2$, the 16 stakeholders will be clustered into one category, as shown in Fig. 5. Therefore, the agglutination subgroup analysis based on accessibility has no significance for the local network analysis.

Table 9 Stakeholders' geodesic distance

	A1	A2	A3	B1	B2	B3	C1	C2	D1	D2	D3	E1	E2	E3	E4	F1
A1	0	1	1	1	1	1	1	1	2	2	2	1	1	1	1	1
A2	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
A3	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1
B1	2	1	1	0	1	1	2	1	2	2	1	1	2	2	2	2
B2	1	1	1	1	0	1	2	1	2	2	1	1	1	1	1	2
B3	1	1	1	1	1	0	2	2	2	2	2	1	1	1	1	1
C1	1	1	1	2	1	2	0	1	2	2	2	1	1	1	1	1
C2	1	1	1	2	1	2	2	0	2	2	2	1	2	2	2	2
D1	2	1	1	2	2	2	1	2	0	1	1	1	2	2	2	2
D2	2	1	1	2	2	2	1	2	1	0	1	1	2	2	2	2
D3	1	1	1	1	1	1	1	2	1	1	0	1	2	2	2	2
E1	1	1	1	1	1	1	1	1	2	1	2	0	1	1	1	1
E2	1	1	1	1	1	2	2	2	2	2	2	1	0	1	1	1
E3	1	1	1	1	1	1	2	2	2	2	2	1	1	0	2	1
E4	1	1	1	1	1	1	2	2	2	2	2	1	1	2	0	1
F1	1	2	1	2	2	2	1	2	2	2	2	1	1	1	1	0

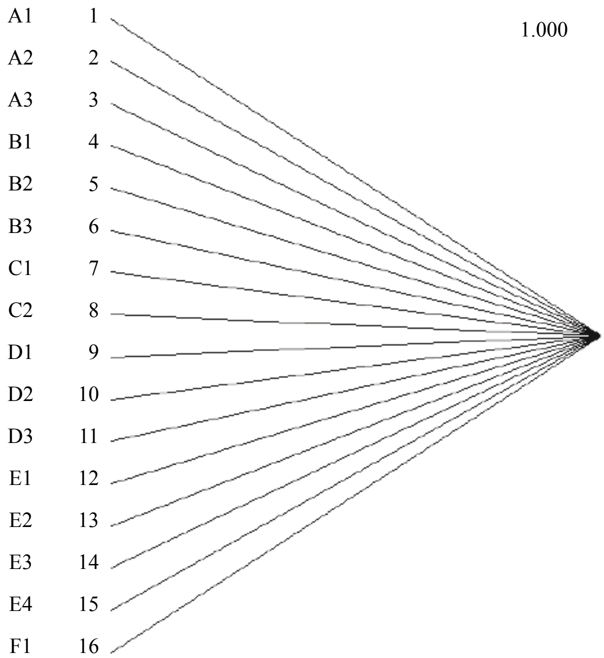

Fig. 5 Results of the agglutination subgroup analysis based on accessibility

(ii) Condensed subgroups (k-plex) based on node degree

The k value needs to be determined carefully. When the k value is too large, the number of cohesive subgroups that meet the node degree requirements is large and the cohesive force is not strong. In this study, through trial and error, $k = 2$, $g_s = 11$ is found to be accurate to reflect the subgroup phenomenon of the meteorological satellite stakeholders. Fig. 6 and Table 10 present the final analysis results.

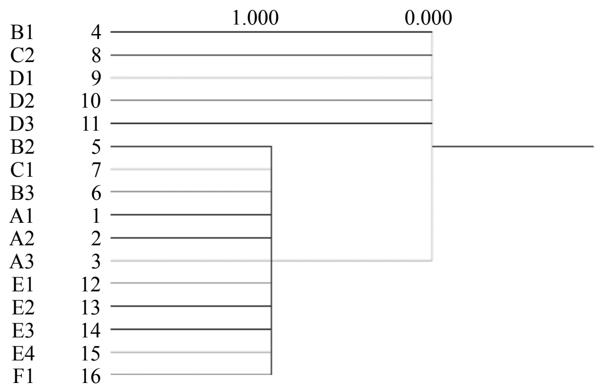

Fig. 6 Analysis results based on k-plex

The k-plex analysis results indicate that meteorological satellite system engineering has a large cohesive subgroup that includes: the government (A1); the competent meteorological satellite department (A2); the meteorological administration (A3); scientific research institutes

(B2); higher education institutions (B3); mass media (C1); the National Meteorological Centre (E1); the Ministry of Water Resources (E2); departments of agriculture, forestry and fishery, and animal husbandry (E3); environmental protection departments and organizations (E4); the public (F1). Table 8 and Fig. 4 demonstrate that these 11 stakeholders have relatively good centrality in the nodes of the meteorological satellite stakeholder relationship network and are relatively important in this network. The 11 stakeholders in this subgroup are derived from five categories and have good coverage and a certain degree of representativeness. This reflects that the stakeholder groups in most different fields are actively participating in the Fengyun-4 system engineering project.

Table 10 Number of *k*-plexes

Coding	Stakeholder
A1	The government
A2	The competent meteorological satellite department
A3	The meteorological administration
B2	Scientific research institutes
B3	Colleges and universities
C1	Mass media
E1	The National Meteorological Centre
E2	Minisitry of Water Resources
E3	Agriculture, forestry, fishery and animal husbandry
E4	Environmental protection departments and organizations
F1	The public

Therefore, in combination with the definition of *E-Iindex* and the stakeholder relationship matrix of meteorological satellites in Table 7, we can calculate the *EL* relationship between the subgroups (with the other five stakeholders) and the internal number of subgroup relationships *IL* (see Table 11).

Table 11 Number of internal and external relationships in subgroups

Relationship	Number
EL	23
IL	97
$EL-IL$	−74
$EL+IL$	120

According to (7),

$$E\text{-}Iindex=\frac{EL-IL}{EL+IL}=\frac{-74}{120}=-0.617 \tag{25}$$

where *E-Iindex* approaches −1, implying that most relationships occur within the subgroup and that the subgroup is denser in the relationship network. Therefore, stakeholders outside the subgroup have low benefits of participation and are relatively disadvantaged.

4.2.4 Overall network analysis

(1) Network density

Table 12 shows that the overall density of the relational network is 0.641 7. The total number of relationships is 154, and the average number of relationships per stakeholder is 9.625. Overall, the communication among stakeholders is at a medium level, relatively beneficial to the entire meteorological satellite system engineering.

Table 12 Overall network characteristic measurement values

Number	Index	Value
1	Network density	0.641 7
2	Total relationship	154
3	Network diameter	2
4	Average distance	1.358
5	Central potential	0.545 1

(ii) Network diameter

As mentioned above, the longest distance between any two stakeholders is 2. Therefore, the diameter of the entire relationship network is 2, and the average distance of each stakeholder is 1.358. The information flow, the instruction transmission, and the knowledge sharing of the relationship network do not need to traverse through too many paths to avoid a wide range of distortions. This is conducive to the efficiency and accuracy of business development.

(iii) Central potential

As shown in Table 12, the corresponding central potential is 0.545 1, which is higher than 50%. This is because the closeness centrality is based on distance. According to the network diameter, the longest distance in the stakeholder relationship network is 2, resulting in relatively high central potential.

4.3 Evaluation of coordination degree of stakeholder relationship network of Fengyun-4

4.3.1 Index weight calculation

The index weight is established by inviting two experts, researchers from Harbin Institute of Technology studying the economic benefits of meteorological satellites, to make a pairwise comparison of the importance levels of each factor according to Table 5 and to examine the relative importance of the primary indicators to the target layer and the secondary indicators to the primary indicators. The weight of the three secondary indicators of the degree of coordination of the relationship network is calculated. Table 13 summarizes the relationship indicators and their weights. The secondary indicators for the target layer are calculated. The factors that have the highest impact on the degree of coordination are the network density X31, network relationship intensity X34, and network environment friendliness X35. The environmental friendliness of the outside world is an important guarantee for the successful development of meteorological satellite system engineering. The second is node control. X14 is consistent with its "bridge mediation" role but may also cause excessive concentration of resources. The subgroup size X23 under the cohesive subgroup makes the least impact.

Table 13 Evaluation index weights of degree of coordination of stakeholder relationship networks

Target	Primary indicator	Secondary indicator	Weight of secondary indicators relative to primary indicator	Secondary indicators relative to target indicator	Sequence
Coordination level of the meteorological satellite stakeholder relationship network X	Node centrality X1 (0.258)	Node interoperability (X11)	0.123	0.032	8
		Node relationship (X12)	0.123	0.032	8
		Closeness between nodes (X13)	0.282	0.073	5
		Node control (X14)	0.472	0.122	4
	Cohesive subgroups X2 (0.105)	Number of agglomerate subgroups (X21)	0.258	0.027	10
		Subgroup with degree (X22)	0.637	0.067	6
		Cohesive subgroups scale (X23)	0.105	0.011	12
	Overall network characteristics X3 (0.637)	Network density (X31)	0.298	0.190	1
		Network distance (X32)	0.037	0.023	11
		Degree of resource aggregation (X33)	0.069	0.044	7
		Network relationship strength (X34)	0.298	0.190	1
		Network environment friendliness (X35)	0.298	0.190	1

4.3.2 Fuzzy comprehensive evaluation

(i) Determination of actual value of the quantitative evaluation index

For the four secondary indicators under node centrality X1, the degree, closeness, and betweenness centrality values are calculated. To measure the overall impact on the coordination degree of the relationship network, the average value is taken as the actual value. Table 8 shows that X12 is 0.725, X13 is 0.753 27, and X14 is 0.025 6. The node interworking rate can be measured by the ratio of the number of interconnected node pairs to the total number of node pairs. According to Table 7, the number of interconnected nodes is 67 and the total number of nodes is 120. Therefore, X11 is 0.558.

Based on the results of the k-plex analysis shown in Fig. 4 to Fig. 6, the number of aggregated subgroups X21 is 1. Because this one aggregated subgroup contains 11 stakeholders, its size, also the number of nodes X23, is 11. The local network analysis indicates the forestry degree of the subgroup, with the *E-Iindex* index value being −0.617.

According to Table 12, the network density X31 under the overall network characteristic X3 is 0.641 7, the network diameter X32 is 2, and the degree of network resource aggregation X33 is the central potential 0.545 1. The network relationship strength is calculated based on the weighted values on each line in the relationship network (the sum of relationship strength divided by the sum of arc numbers). The number of relationships is 154. Therefore, according to Table 8, the total weighted value can be calculated as 258, that is, the total relationship strength between all stakeholders is 258. In turn, the overall average relationship strength X34 is 1.675.

Accordingly, the actual values of each secondary indicator under the centrality degree of Fengyun-4 relationship network's coordination degree node centrality, cluster subgroups, and network characteristics are determined, as summarized in Table 14. Q is the value required for the degree of coordination of the Fengyun-4 stakeholder relationship network.

(ii) Determination of quantitative evaluation index standards

When determining the different evaluation index levels, considering the actual study situation, three evaluation levels (poor, average, and good) are set for each index. These three evaluation levels are served as the evaluation level for the coordination degree of the stakeholder relationship network of Fengyun-4. Based on the actual situation of each indicator of the Fengyun-4 stakeholder relationship network and its value interval, this study combines relevant literature analysis [43–45] and expert evaluation to determine the standard values of each index at different levels. The results are summarized in Table 14. These include the values required for the degree of coordination of the Fengyun-4 stakeholder relationship network.

(iii) Determination of index membership matrix

According to the membership function (19) and the evaluation criteria of the quantitative indicator system in Table 14, the membership of each quantitative secondary indicator of the coordination degree of the meteorological satellite stakeholder relationship network can be determined to consequently determine the membership matrix. The membership of each quantitative index is determined and summarized to form a fuzzy comprehensive evaluation result. To determine the membership of the network environment friendliness (X35) of the weather satellite stakeholders, 10 experts are invited to judge it. None chose "poor," four chose "average," and six chose "good." The comment set is [0,0.4,0.6]. Table 15 shows the fuzzy comprehensive evaluation results of each index.

Table 14 Evaluation criteria for quantitative indicator systems

Quantitative evaluation index	Evaluation level and standard			Actual value
	Poor	Average	Good	
Node interoperability (X11)	0.4	0.6	0.8	0.558
Node relationship (X12)	0.4	0.6	0.8	0.725
Closeness between nodes (X13)	0.4	0.6	0.8	0.753 27
Node control (X14)	0.01	0.05	0.1	0.025 6
Number of agglomerate subgroups (X21)	3	2	1	1
Subgroup with degree (X22)	−1	0	1	−0.617
Cohesive subgroups scale (X23)	12	9	6	11
Network density (X31)	0.4	0.6	0.8	0.641 7
Network distance (X32)	6	4	3	2
Degree of resource aggregation (X33)	0.7	0.5	0.3	0.545 1
Network relationship strength (X34)	0.5	1.5	2.5	1.675
Network environment friendliness (X35)	0.3	0.5	0.7	Q

Table 15 Fuzzy evaluation result of secondary index

Primary indicator	Secondary indicator	Fuzzy evaluation result of secondary indices		
		Poor	Average	Good
Node centrality X1	Node interoperability (X11)	0.210	0.790	0
	Node relationship (X12)	0	0.375	0.625
	Closeness between nodes (X13)	0	0.234	0.766
	Node control (X14)	0.390	0.610	0
Cohesive subgroups X2	Number of agglomerate subgroups (X21)	0	0	1
	Subgroup with degree (X22)	0.617	0.383	0
	Cohesive subgroups scale (X23)	0.667	0.333	0
Overall network characteristics X3	Network density (X31)	0	0.791	0.209
	Network distance (X32)	0	0	1
	Degree of resource aggregation (X33)	0.225	0.775	0
	Network relationship strength (X34)	0	0.825	0.175
	Network environment friendliness (X35)	0	0.400	0.600

According to Table 15, combine the evaluation criteria of the coordination degree of the relationship network in Table 14 and (24), a step-by-step calculation is performed to make a final evaluation of the coordination degree of the meteorological satellite stakeholder relationship network:

$$\boldsymbol{Q} = \boldsymbol{B}\cdot\boldsymbol{V}^{\mathrm{T}} = (0.113, 0.574, 0.313)\cdot(0.3, 0.5, 0.7)^{\mathrm{T}} = 0.54.$$

The coordination degree of the Fengyun-4 stakeholder relationship network is seen to be in an "average" state.

4.4 Coordination mechanism design of meteorological satellite stakeholder relationship network

4.4.1 Analysis of coordination degree of stakeholder relationship network

The coverage of the six stakeholder categories is carefully considered, and the competent meteorological satellite department (A2), scientific and technological personnel (B1), the competitors (C2), the suppliers (D1), the Ministry of Water Resources (E2), and the public (F1) are selected to build a local relationship network (regardless of the relationship strength), as shown in Fig. 7.

Fig. 7 shows that the local stakeholder relationship network diagram is centered on the competent meteorological satellite department (A2), and the other five stakeholders are at marginal positions. A2 is related to D1, A2, and B1, but B1 and D1 are not connected. Therefore, a structural hole is formed between B1 and D1, and there is no direct connection between C2, E2, F1, and D1. The competent meteorological satellite department (A2), at the core location, can obtain information and resources from various stakeholders. Furthermore, it has control over information transmission and resource allocation. It has an absolute advantage in the entire relationship network and controls the entire network. By contrast, the central potential of the local stakeholder relationship network is relatively high, which is detrimental to the coordination degree of the overall relationship network.

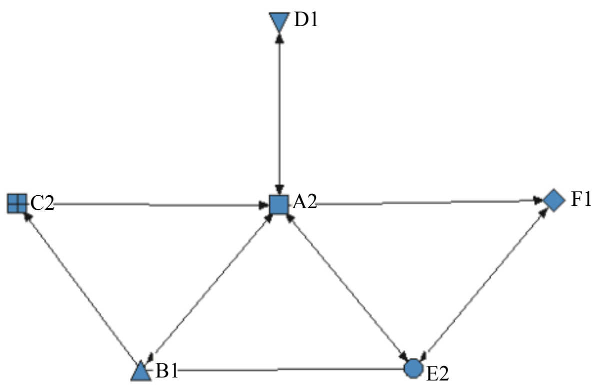

Fig. 7 Local stakeholder relationship network diagram

In response to the above problems, the coordination mechanism of the stakeholder relationship network should be clarified to achieve the following optimization goals:

(i) Enhancing the density of relational networks. Various stakeholders obtain information and resources through business communication and normal communication to make decisions to maintain cooperation in the entire system engineering process. A high-density relationship network makes information transmission and resource sharing smoother, reduces information distortion and resource loss, and makes stakeholder collaboration easier and faster.

(ii) Removing network structure holes. It is necessary to eliminate the "man-in-the-middle" transmission link between stakeholders who have structural holes, establish a direct dialogue, break their monopoly, and remove the structural holes while increasing the density of the relationship network.

(iii) Reducing network center potential. To reduce the centrality of the network and maintain the balance of rights in the entire relationship network, it is necessary to strengthen the links between noncentral point stakeholders and weaken the position of the "central point" in this case, the meteorological satellite authority, thereby its ability to control the network can be reduced.

4.4.2 Stakeholder relationship network coordination mechanism

From the analysis of the degree of coordination of the stakeholder relationship network, irrespective of the method adopted, it is necessary to strengthen the mutual connection of stakeholders in the network. To this end, it is necessary to clarify the coordination and operation mechanism of the relationship network, strengthen the relationship between different categories of stakeholders and internal stakeholders within the same category, make the overall relationship network harmonious, and promote its benefits to expand.

To resolve problems such as the low density of the relationship network and the existence of many structural holes, it is necessary to establish organizational management mechanisms, contract mechanisms, cooperation mechanisms, target coordination mechanisms, publicity and supervision mechanisms, and user participation mechanisms to increase the relationships between stakeholders.

(i) Organizational management mechanisms. Although the organization and management mechanism fully grasps the information and resources, the government, the competent meteorological satellite department, and the meteorological bureau need to make reasonable decisions based on the current development status of the world's meteorological satellites; strive to coordinate the interests and goals of each participant; ensure the legality, fairness, and quality of the participants; establish their links with various stakeholders; provide corresponding policy support; pay attention to the needs; do a good job of management and organization; promote the smooth development of the meteorological satellite system project, thereby serving the people and benefiting society.

(ii) Contract mechanisms. In meteorological satellite system engineering, a considerable number of stakeholders have a formal contractual relationship to ensure normal business transactions. The existence of a legally effective contract mechanism clarifies the responsibilities of various stakeholders and standardizes system engineering. It gives industry participants the opportunity to seek development and enforces certain legal constraints to ensure that all meteorological operations are conducted normally.

(iii) Cooperation mechanisms. It is necessary to fully draw on the experience of developing meteorological satellite industries in the United States, European and other developed countries; understand the application fields and service scopes of competitors' meteorological satellite products; cooperate with the government, national meteorological centers, and scientific research institutions to promote technological innovation and scientific research exchange. On the other hand, each project participant needs to establish a good cooperative atmosphere while fully understanding others' needs and providing the best business support.

(iv) Goal coordination mechanisms. To maximize the benefits of the common goals of different stakeholders and their own goals, the goals must be coordinated. Stakeholders must draw up their own goals for organization managers to improve, adjust, and merge them to form a common goal system, complete the expected goals of the meteorological satellite system project, and form the greatest vision to serve the public and promote the development of meteorological undertakings.

(v) Publicity and supervision mechanisms. The mass media, while deepening the understanding of the public and users about the meteorological satellites, also plays a supervisory role for various participants. The clear exchange of weather satellite funds, selection of partners and suppliers, and success rate of achievement transformation have become the focus of the mass media to ensure the transparency of the development of the meteorological industry.

(vi) User participation mechanisms. Meteorological satellites are national public welfare projects, and users such as the national meteorological center and departments of agriculture, forestry and fishery, and animal husbandry are the direct beneficiaries. Governments and competent meteorological satellite departments should focus on the needs of direct users, and carry out technological innovation according to demand to achieve performance improvement, establish direct channels for direct users and competent departments and technical departments, continuously provide feedbacks and participate in the construction of meteorological services. In addition, the public is an indirect user of meteorological services, and their support continues to provide talent and motivation for the development of meteorological satellites. Meteorological satellite administrations, meteorological bureaus, and other organizations should often conduct activities such as lectures on meteorological knowledge, technology popularization, and sharing; use online resources to conduct online and offline network interactions; and increase the sense of public participation and support.

The design of the coordination mechanism of the meteorological satellite stakeholder relationship network fully demonstrates the roles of the stakeholder organization management mechanisms, contract mechanisms, cooperation mechanisms, target coordination mechanisms, publicity and supervision mechanisms, and user participation mechanisms in the entire relationship network. The coordination mechanisms of the meteorological satellite stakeholder relationship network clearly reflect the links between different categories and associations of stakeholders within the same category. This not only enables different stakeholders to increase their connection with each other on the original basis and thereby increase network density and reduce structural holes and the central potential, but also improves the degree of coordination of the stakeholder relationship network.

5. Conclusions

This article uses social network analysis to build a meteorological satellite stakeholder relationship network, analyzing the characteristics of the relationship network shows that the government (A1), the meteorological satellite department (A2), the meteorological administration (A3), and the National Meteorological Centre (E1) in the ego network are at the center of the entire network and are responsible for information transmission, resource sharing, and other important functions. Based on the analysis results of the k-plex in the local network, it can be observed that in the meteorological satellite stakeholder relationship network, there is a relatively large agglomerated subgroup. The degree of stakeholder participation is high, the overall network density of the meteorological satellite stakeholder relationship network is 0.641 7, the network diameter is 2, and the central potential is 0.545 1, which is relatively advantageous for the entire meteorological satellite system engineering. An evaluation index system for the coordination degree of the relationship network of the meteorological satellite stakeholders is established. Using the improved AHP-fuzzy comprehensive evaluation method to evaluate the degree of coordination, and get the conclusion that the Fengyun-4 meteorological satellite stakeholder relationship network is in an "average" state of coordination. Six types of coordination mechanisms, namely organization management mechanisms, contract mechanisms, cooperation mechanisms, target coordination mechanisms, publicity and supervision mechanisms, and user participation mechanisms are proposed. Thus, the links between different categories and stakeholders in the same category can be strengthened to remove network structure holes, reduce network centrality, and improve coordination degree of the relationship networks. Compared with previous studies that have also used SNA, this paper has formed a systematic stakeholder network analysis system. In addition, in-depth analysis of the coordination state of the stakeholder relational network is conducted, which makes this paper innorative and fills the research gap.

References

[1] GUO H, BAO A M, LIU T, et al. Meteorological drought analysis in the lower Mekong Basin using satellite-based long-term CHIRPS product. Sustainability, 2017, 9(6): 1–21.

[2] ARELLANO-LARA F, ESCALANTESANDOVAL C. Estimation of storm potential by combining satellite images and meteorological data: a case study in northwestern Mexico. Technology and Water Sciences, 2014, 5(5): 39–61.

[3] TAHIR W, AMINUDDIN A K, RAMLI S, et al. Quantitative precipitation forecast using numerical weather prediction and meteorological satellite for Kelantan and Klang river basins. Journal Teknologi, 2017, 79(1): 45–53.

[4] LU N M, ZHENG W, WANG X, et al. Application of meteorological satellites and their products in weather and climate analysis and environmental disaster monitoring. Journal of Marine Meteorology, 2017, 37(1): 20–30. (in Chinese)

[5] ADAMS R M, HOUSTON L L, MCCARL B A, et al. The benefits to Mexican agriculture of an El Nino-southern oscillation (ENSO) early warning. Agricultural & Forest Meteorology, 2003, 115(3/4): 183–194.

[6] KYOUNG A J. A Study on economic assessment of image processing technologies for meteorological satellites. The Journal of Korea Society of Communication and Space Technology, 2012, 7(1): 13-20. (in Korean)

[7] LIU Z M, YAN M, ZHANG W Z. Research on service benefit evaluation of meteorological satellite remote sensing technology in Jilin province. Remote Sensing Technology and Application, 1998, 2: 22–27. (in Chinese)

[8] LIU Y L. Looking at the social and economic benefits of intellectual property rights from the perspective of the satellite navigation industry. China Aerospace, 2015, 9: 35–39. (in Chinese)

[9] FREEMAN R E, REED D L. Stockholders and stakeholders: a new perspective on corporate governance. California Management Review, 1983, 25(3): 88–106.

[10] CLARKSON M B E. A risk-based model of stakeholder theory. Proc. of the Toronto Conference on Stakeholder Theory, 1994, 18−19.

[11] BLAIR M. Ownership and control: rethinking governance for the twenty-first century. Washington D C: The Brooking Institution, 1995.

[12] LEWIS C. Managing conflicts in protected areas. Gland, Switzerland and Cambridge, U·K: International Union for Conservation of Nature, 1995.

[13] FREEMAN R E. Strategic management: a stakeholder approach. Boston: Pitman Publishing Inc, 1984.

[14] CLARKSON M B E. A stakeholder framework for analyzing and evaluating corporate social responsibility. The Academy of Management Review, 1995, 20(1): 92–118.

[15] CHEN H H, JIA S H. An empirical analysis of three-dimensional classification of corporate stakeholders. Economic Research, 2004, 4: 80–90. (in Chinese)

[16] BORGATTI S P, JONES C, EVERETT M G. Network measures of social capital. Connections, 1998, 21(2): 1–36.

[17] FU J L, SUN D Y, XIAO J, et al. A review of terrorist organization network research based on social network analysis theory. Systems Engineering Theory and Practice, 2013, 33(9): 2177–2185. (in Chinese)

[18] JIAO Y Y, FU M H, SHEN Z F. Dynamic analysis of stakeholder relation networks of PPP projects from the perspective of the whole life cycle. Project Management Technology, 2016, 14(8): 32–27. (in Chinese)

[19] XIN L, TAO Y, GUO L. Understanding stakeholders' influence on project success with a new SNA method: a case study of the green retrofit in China. Sustainability, 2017, 9(10): 1–19.

[20] TIAN X Y, ZHANG M X, YE M H. Coordination mechanism of nonprofit organization incubator and stakeholders in China. Proc. of the International Conference on Engineering and Business Management, 2010: 4433−4436.

[21] CHANG H J, ZHAMG T Q, LI G F. Research on evaluation of project stakeholder coordination. Nankai Management Review, 2014, 17(1): 85–94. (in Chinese)

[22] MARTINS F M, TRIENEKENS J, OMTA O. Governance structures and coordination mechanisms in the Brazilian pork chain—diversity of arrangements to support the supply of piglets. International Food and Agribusiness Management Review, 2017, 20(4): 511–531.

[23] NUTT P C, BACKOFF R W. Strategic management of public and third sector organizations: a handbook for leaders. Long Range Planning, 1993, 26(2): 486.

[24] BRYSON J M. Strategic planning for public and non-profit organizations. International Encyclopedia of the Social & Behavioral Sciences, 2015, 28(3): 515–521.

[25] SHARPE M A, MURRAY S A. Verification of space weather forecasts issued by the met office space weather operations centre. Space Weather, 2017, 15(10): 1383–1395.

[26] HUANG Q X, YANG X. Application of defense meteorological satellite program operational line scanner (DMSP/OLS) nighttime light images: a meta-analysis and a systematic literature review. Remote Sensing, 2014, 6(8): 6844–6866.

[27] ZHANG Z P, ZOU Y. The legislative significance of the international association for the unification of private law "Protocol on Specific Issues of Space Assets". Aerospace China, 2012, 2: 50–53. (in Chinese)

[28] GREEN J C, LIKAR J, SHPEITS Y. Impact of space weather on the satellite industry. Space Weather: The International Journal of Research and Application, 2017, 15(6): 804–818.

[29] LU W, HE L, CHEN J X, et al. The development of the infrared technology for meteorological satellites in Shanghai Institute of Technical Physics. Proc. of the Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series,

Defense+Security Volume, 2017: 1017716.

[30] LAKHIN O I. Implementation of multi-agent system for scheduling of flight program, cargo flow and resources of international space station. Mechatronics, Automation, Control, 2016, 17(1): 42–46.

[31] DONG C H, YANG J, LU N M, et al. The main performance and spplication of FY-3A Star (FY-3A). Journal of GEO-Information Science, 2010, 12(4): 458–465. (in Chinese)

[32] DU D, LI M, CHEN C. Application of international maritime satellite system in disaster weather reporting. Radio and Television Technology, 2015, 42(5): 42–44. (in Chinese)

[33] CHENG X N. Analysis of the research elements of effective dissemination of weather forecast programs. Modern Agricultural Science and Technology, 2017, 4: 220–221. (in Chinese)

[34] ZHAO Q S, AN J J, YE J Y, et al. Design and implementation of meteorological service platform based on WeChat public account. Journal of Anhui Agricultural Sciences, 2017, 45(24): 224–227. (in Chinese)

[35] CARR R H, MONTZ B, MAXFIELD K, et al. Effectively communication risk and uncertainly to the public assessing the National Weather Service's flood forecast and warning tools. Bulletin of the American Meteorological Society, 2016, 97(9): 1649.

[36] YUAN H L, SUN M, WANG Y. Assessment of the benefits of the Chinese public weather service. Meteorological Applications, 2016, 23(1): 132–139.

[37] LIN R H, HE X L. Analysis and countermeasures of the status quo of meteorological film and television services for "Three Agricultures". Modern Agriculture, 2012, 8: 58–59. (in Chinese)

[38] CHATTOPADHYAY N, GHOSH K. Agrometeorological advisory to assist the farmers in meeting the challenges of extreme weather events. Mausam, 2016, 67(1): 277–288.

[39] UMEHIRA M, KOBAYASHI K, YASUI Y, et al. Recent Japanese R& D in satellite communications. IEICE Trans. on Communications, 2009, 92-B(11): 3300–3308.

[40] BAYISSA Y, TADESSE T, DEMISSE G, et al. Evaluation of satellite-based rainfall estimates and application to monitor meteorological drought for the Upper Blue Nile Basin, Ethiopia. Remote Sensing, 2017, 9(7): 1–17.

[41] WELLMAN B, BERKOWITZ S D. Social structures: a network approach. Cambridge: Cambridge University Press, 1988.

[42] ZHAO Y, XU G Y, XU X Y, et al. Research on a value network model for the benefit evaluation of space applications. Manned Spaceflight, 2018, 1: 127–135. (in Chinese)

[43] PALETTO A, HAMUNEN K, MEO I D. Social network analysis to support stakeholder analysis in participatory forest planning. Society & Natural Resources, 2015, 28(10): 1108–1125.

[44] BARSING P, DAULTANI Y, VAIDYA O S, et al. Cross-docking centre location in a supply chain network: a social network analysis approach. Global Business Review, 2018, 19(1): 097215091875784.

[45] YAMAKI K. Applying social network analysis to stakeholder analysis in Japan natural resource governance: two endangered species conservation activity cases. Journal of Forest Research, 2017, 22(2): 890.

Biographies

LI Lu was born in 1996. She received her B.S. degree in management from Nanchang University in 2019, Jiangxi, China. She is currently studying for her M.S. degree at the School of Economics and Management, Harbin Institute of Technology, Shandong, China. Her research interests include defense economics and evaluation theories and methods.
E-mail: 13940918983@163.com

LIU Yupeng was born in 1981. He received his Ph.D. degree in management science and engineering from Harbin Institute of Technology in 2010. In 2014, he began to study as a postdoctoral fellow at Dalian University of Technology, Liaoning, China. He is currently an associate professor at Harbin Institute of Technology. His research interests include defense economics and evaluation theories and methods.
E-mail: lucklyp@126.com

HE Kongxin was born in 1993. He received his B.S. degree from Harbin Institute of Technology in 2016, Shandong, China. He obtained his M.S. degree in management from Harbin Institute of Technology in 2018. His research interests include defense economics and evaluation theories and methods.
E-mail: hkx20122213@sina.com