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Article

Exploring Cross-Section Risk Governance Mechanisms for Transportation and Energy Infrastructures in China

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Abstract: This study aims to examine the national risk governance mechanism of critical infrastructure in China from a cross-section perspective. The first research objective is to identify whether horizontal collaboration exists in the risk governance of critical infrastructure. Building on this, the second research objective is to investigate the extent of cross-section collaboration in the transportation and energy domains. The third research objective is to identify the pathways of horizontal collaboration at various levels. The data for this research consists of policy documents retrieved from the official websites of the Ministry of Transport of the People's Republic of China, the National Energy Administration, and the Peking University Legal Information Website. A total of 127 documents were collected using specific search keywords. To analyze data, content analysis is adopted to generate a co-word matrix so that semantic network centrality can be explored. The result indicates that in the transportation domain "engineering" and "road" feature in the top 10 for both standardized degree and degree proportion, while "administration" ranks third highest in share proportion. In the energy infrastructure risk governance keyword network, the fourth highest closeness centrality value is 54.762, associated with keywords such as "administration" and "engineering". These findings suggest that horizontal collaboration is evident at both institutional and personal levels. Moreover, the results imply that the inner collaboration within national risk governance is intricate and interdependent. The study reveals interconnections between different industries and administration levels, contributing a fresh perspective to urban risk governance theory exploration.

Keywords: critical infrastructure; risk; governance; cross section; China

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1. Introduction

Critical infrastructure (CI) refers to the systems or elements that sustain social functioning, health, social security, and financial activities of citizens. These systems typically include electricity, energy, and transportation, which provide essential services to urban societies [1]. China has undergone rapid urbanization, reaching a total urbanization level of 60.6% in 2019, as reported by the National Bureau of Statistics [2]. Transportation infrastructure plays a vital role in facilitating economic activities by enabling the movement of people and goods. It has also contributed to population migration from urban to rural areas, thereby fostering urbanization development [3]. Consequently, the demand for transportation infrastructure continues to rise. Additionally, China boasts the largest and most developed manufacturing system globally, requiring a substantial supply of energy [4]. For a country's strategic competitiveness, energy infrastructure is just as crucial as manufacturing. The increasing population growth in China has led to a rising demand for both transportation and energy infrastructures. However, escalating demands can also lead to broader impacts. Disruptive events can cause the failure of CI systems, resulting in functional breakdowns and substantial national losses [5]. This is because CI services are interconnected, meaning that if one CI fails, other facilities will also be affected, leading to a disruption in daily service supply [6]. This phenomenon, in which disruptive impacts transmit throughout infrastructure systems, is referred to as interdependency. Assessing the vulnerability of CI requires considering interdependency, which can help mitigate the impact of CI failures. Therefore, CI interdependency is a critical factor influencing urban CI protection planning [7]. This research defines a specific type of risk as interdependency-related risk between CIs.

Currently, most research focuses on the interdependency relationships among CIs and their impact on disaster broadcast systems, rather than the resilience processes of CIs [8]. However, the core reason for failure cascades lies in the interdependency-related risk of CIs [9]. Interdependency should receive increased attention alongside infrastructure development to mitigate potential interdependency risks and the cascading effect of service breakdowns. Government administration plays a crucial role in this regard. Effective governance factors and their implementation processes, such as governing road construction, improving water system resilience, and managing electricity systems, are essential for reducing CI risks. These factors encompass organizational components, leadership, and governance levels of both local and central governments [10]. Risk governance for CI systems falls under the responsibility of public work administration [11]. From a perspective of horizontal cooperation, interconnected governance involves various departments and collaborations across national and local levels, as well as institutional and personal levels, which is the central focus of this research.

This paper aims to explore the national governance mechanism of CI systems, with a specific focus on the transportation and energy domains. These domains are selected due to their economic attributes and influence on the manufacturing industry, considering the growing population and urbanization demands in China. The research concentrates on interconnection governance, described as horizontal administration, and its impact on risk cascading in CI systems. The research questions are as follows:

RQ1: Whether there is the existence of interconnection governance behaviors.
RQ2: What levels of cross-section collaboration implemented.
RQ3: How does interconnection governance influence CI systems risk governance.

The theoretical study and mechanism exploration are developed in this paper, based on the research questions. Section 2 provides a comprehensive literature review to establish research keyword strings for data collection, elaborating on the fundamental concepts and theories of infrastructure risk governance. Section 3 introduces the research methodology, employing content analysis to quantify textual data and centrality analysis to identify influential factors and paths in the risk governance semantic network. Section 4 presents the experimental results, followed by a discussion of these findings in Section 5. Finally, Section 6 offers the conclusion, contribution of this research, and directions for future research.

2. Literature Review

The literature review in this paper is organized into four distinct perspectives: Overview of critical infrastructure, Cross-section resilience, Interconnected governance layers, and Risk governance. Section 2.1 provides an introduction to CI, defining its scope and importance. Section 2.2 presents the concept of cross-section resilience as a new perspective within the field. Section 2.3 delves into the intricacies of interconnected governance layers. Finally, Section 2.4 examines the international risk governance process.

2.1. Overview of Critical Infrastructure

The council of the European Union [12] defines CI as a vital object, network, service, physical activities, and information resources essential for a nation, whose failure would have significant impacts on citizen health, safety, security, financial status, and even governance effectiveness. Similarly, in the United States, the Department of Homeland Security

(DHS) defines CI as a complex array of physical assets that encompass social, economic, political, and cultural systems across the country, commonly referred to as Critical Infrastructure and Key Resources (CIKR) [13]. CI is a complex system that encompasses various components such as architecture and facilities, technology devices and energy supply networks, engineering technology, and communication facilities [14]. In China, with the rapid development of urbanization, infrastructure has become a crucial aspect of urban governance [15]. In 2021, the "Critical Information Infrastructure Security Protection Regulations" issued by the State Council of the People's Republic of China defines critical information infrastructure as public communication and information services, energy, transportation, water conservancy, public services, national defense important industries, and fields such as the science and technology industry, as well as other important network facilities and information systems that may seriously endanger national security, national economy, people's livelihoods, and public interests if they are damaged, lose their functions, or leak data [16]. Combining the CI risk governance background, it encompasses a system that provides water, energy, transportation, buildings, services, and facilities [17]. The disruption of CI systems can have significant impacts on operators, communities, and even the entire country in terms of security and finances [18]. Therefore, protecting CI systems from accidents, natural disasters, and terrorist activities has become an urgent task for public administration and enterprises [19]. Recent research on CI protection management commonly focuses on investigating interdependencies among CIs. The failure of one infrastructure facility can affect the operations of others, sometimes even with financial implications at the national level [20]. Moreover, experts have emphasized that the resilience of CI systems is crucial for maintaining the security and sustainability of a complex system. This resilience can be evaluated based on the internal and external dependencies of the CI system [21]. In this paper, there is a consensus that the CI system is an essential element for city operations, and the concept of CI resilience should receive adequate attention.

2.2. Cross-Section Resilience

The emphasis on CI resilience is aimed at reducing system vulnerability, mitigating severe consequences, and enhancing the response capabilities to disruptive incidents. Moreover, studies on the environmental factors influencing CI resilience can contribute to the stability of CI systems [22,23]. Resilience, as defined by Holling [24], refers to the capacity to withstand changes in state variables, motivating variables, and remaining parameters within a system. Therefore, reinforcing resilience is of utmost importance for any CI facility [25]. It is evident from published policies on CI security and recovery, primarily overseen by local government administrations, that ensuring the security and resilience of CIs falls under the jurisdiction of the government.

Addressing potential risks associated with CIs necessitates a focus on the resilience of relevant facilities, cities, and communities. Resilience plays a critical role in security and other systems. Management practitioners can influence CI resilience through their professional skills and performance in maintaining the operational status of facilities (e.g., working conditions, machine functionality, and parameter monitoring). Additionally, the performance of management members is influenced by both the subjective working environment and various factors such as salary changes, mental exhaustion, and psychological pressure. These intangible factors contribute to the resilience of infrastructures during the management process. Experts often evaluate CI resilience and the services provided by CIs in the face of external disruptions by assessing the level of CI performance and its ability to deliver services [26].

Building upon the aforementioned background, resilience is a crucial capability that ensures the consistent and steady operation of CI systems. In this research, the focus is not only on exploring the resilience of CI systems but also on the resilience of government administration in dealing with cross-section emergency incidents involving CI systems. This includes aspects such as cooperation, forecasting, managing cascading failures, and emergency response. Resilience can mitigate the severity of consequences stemming from interdependency risks, help CIs recover their normal functioning, and ensure continuous operation.

2.3. Interconnected Governance Layers

CI systems exhibit complexity due to their interdependencies [27]. Evaluating the vulnerability of CIs requires considering interdependency to mitigate the impact of facility breakdowns. Effective governance of interdependency risks is crucial for national security. Internal governance operates as a multi-level management system involving policy actors from different tiers, territories, and sectors [28]. This research focuses on horizontal administration, facilitating coordination across these boundaries. Interconnected governance across sections can lead to favorable outcomes for the government [29]. The primary area of research in this paper is the cross-section risk governance of CIs. Previous studies have demonstrated that disregarding the clustered nature of the CI system can impose independence failures and cascade them into decision making, repair, recovery processes, and administrative cooperation [30]. Therefore, it is necessary to consider the impact of interdependencies on cross-section risk governance. Interdependence risks significantly affect the ability of CIs to respond to disruptive events, such as extreme hazards. Deepening the understanding of interdependencies between CIs can strengthen governments' emergency management measures for CIs [31].

2.4. Risk Governance

Since 2005, the International Risk Governance Council (IRGC) has developed a risk governance framework aimed at helping policymakers and risk managers understand and apply risk governance principles in their management of risks [32]. Risk governance involves the application of governance principles in decision making related to risks [33]. According to the IRGC, risk governance entails various mechanisms for information gathering, analysis, and dissemination, as well as decision-making processes and regulations involving all stakeholders [34]. Unlike risk management, risk governance is a collective endeavor that requires cooperation between national and local administrations to address and manage risks such as disaster risks and CI risks.

Infrastructure governance encompasses organizational and personnel management, technology, systems, and policies that support the implementation of risk governance activities [35]. This article specifically focuses on risk governance of CIs, combining risk governance theory with CI management theory. Previous studies have highlighted risk governance as the application of core governance principles to risk and related decision-making strategies [36]. Some studies emphasize that the key concept of risk governance is to address issues and respond to challenges arising from knowledge gaps [37]. The IRGC defines risk governance as encompassing the collection, analysis, and transmission of information, as well as the management of decision-making participants, rules, processes, habits, and mechanisms [33]. In the context of this study, the research on CI risk governance focuses on the processing and communication of risk information within national CI systems, as well as the identification of relevant departments' participants, rules, processes, and decision-making mechanisms. Scholars concur that a robust and comprehensive risk governance mechanism is crucial for ensuring cultural diversity, social security, innovation, and social cohesion at the city or country level [38].

Risk governance can be classified into two categories: horizontal governance and vertical governance. This classification is based on the distinction between governance regions and levels [39]. Horizontal governance refers to the interaction among participants and actors at the same administrative level. On the other hand, vertical governance describes cooperation among actors at different management levels, such as districts, cities, and states [40,41]. In this research, our focus is on the interaction between administrations of CIs, thus only considering horizontal risk governance. Furthermore, in the case of researching policy documents, this article discusses risk governance from both a descriptive and regulatory perspective. This allows for the analysis and description of risk governance status, as well as the determination of methods to implement risk governance [42]. To explore the concept of cross-section risk governance, a highly descriptive approach is adopted in this paper.

3. Materials and Methods

The methodology employed in this article is discussed from the perspectives of data collection and data analysis. Figure 1 presents the research framework, which aims to explore the national cross-section risk governance mechanism of CI. The research subtopics are defined based on theoretical support from the literature review, and search keyword strings are designed accordingly for data collection. The data analysis phase utilizes document analysis, content analysis, and network centrality analysis.

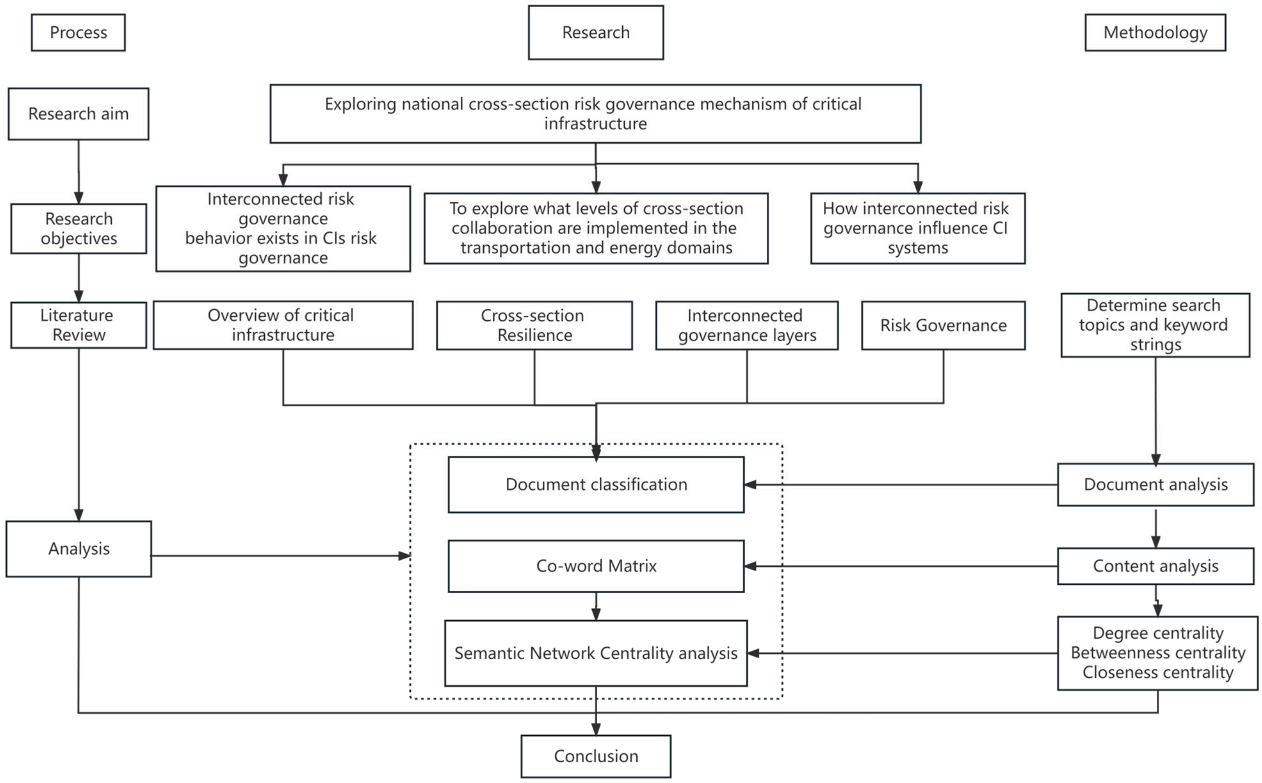

Figure 1. Research framework.

Figure 2 provides a detailed workflow for analyzing documents. Initially, document analysis is employed to classify selected documents, as it effectively handles policy documents by identifying published departments and sorting them according to implementation requirements. Content analysis is then applied to reorganized data sets, converting text information into quantitative data. This involves the generation of a co-word matrix based on a high-frequency matrix during the content analysis phase, facilitating the construction of a semantic network. Subsequently, network node centrality analysis calculates the importance of keywords and explores the correlation between nodes, which form phrases and topics relevant to infrastructure risk governance.

3.1. Data Collection

3.1.1. Identification of Keyword Strings

In order to examine the horizontal risk governance mechanism of national CIs, policy documents were selected as the primary data for this research. The criteria utilized for document selection were based on the major topics associated with the risk governance process. From the literature review, it was identified that the risk governance process consists of four stages: pre-assessment, risk appraisal, acceptability judgement, and risk management. The pre-assessment stage primarily involves the government risk management department, responsible for providing early warnings and screening operational status. The key management domains in this stage can be summarized as collaboration and information, as indicated in Table 1. To appraise identified risks, the risk management department analyzes the causes of risk and its pathways, reflecting the interdependencies involved. In terms of acceptability judgement and risk management phases, professional resilience assessment and management capability are crucial in risk governance. This aspect is related to the division of department functions and clear responsibilities. Hence, the selected research keywords revolve around interdependencies, collaboration, information sharing, and responsibility, as demonstrated in Table 1.

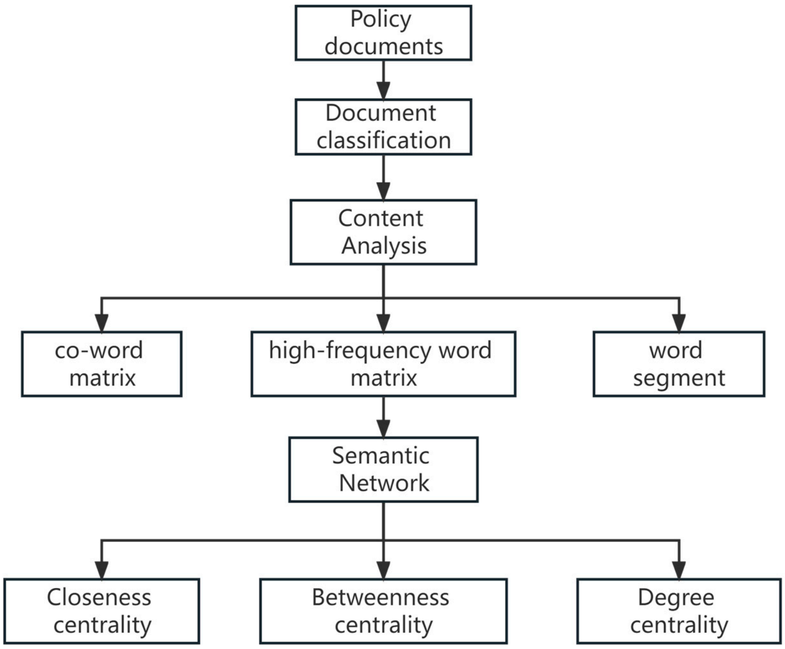

Figure 2. Workflow.

Table 1. Research focus topics which forming the foundation of the document collection.

Domain	Specific Topics
Interdependencies	Hazard identification
Collaboration	Early warning; Judging tolerability and acceptability; Judgement of the seriousness of risk; Option realization; Option identification and generation; Option assessment
Information Sharing	Screening, determination of scientific conventions; Risk description; Risk profile; Feedback from risk management practice
Responsibility	Cause and consequences analysis; Need for risk reduction; Monitoring and control

In practice, the main keyword strings are determined to facilitate data collection. These keyword strings consist of the high-frequency words within the four major risk governance domains mentioned in Table 1. Within each topic, there are numerous documents. Therefore, the phrase with the highest frequency was chosen as the keyword string. The document formats related to these four major risk governance topics include analysis, reports, and assessments. Taking into account the research objectives, the designed keyword strings encompass risk and vulnerability analysis, incident reports, capacity assessments, risk and capability assessments, result analysis, interdependence analysis, and needs assessments. These keyword strings are presented in Table 2.

Table 2. Main keyword strings that are used to identify relevant documents on actor websites.

	Main Keyword String		Supporting/Contextual Keywords
1	Risk and vulnerability analysis	AND	Risk OR Safety Analysis OR Risk Evaluation OR Administration Analysis OR Major policy decisions OR Electric Power Safety OR Emergency OR Social OR System OR Organization Risk OR Risk Report
2	Incident report		
3	Capacity assessment		
4	Risk and capability assessment		
	Broader keyword search		
5	Result analysis, Interdependence analysis; needs assessment		

The policy documents were collected from reputable sources such as the Peking University Legal Information Website and official government websites like the Ministry of Transport of the People's Republic of China and the National Energy Administration. The research team utilized the website search engine to input keywords, resulting in a total of 153 documents published between 2007 and 2022. The types of documents include policy documents, professional technical guides, and **b**asic **c**riteria for **r**isk **i**dentification, **a**ssessment, and **c**ontrol. To ensure a thorough exploration of risk governance across different systems, it is essential to classify the documents. Manual screening of the data using scientific methods enhances the accuracy and professionalism of the research, particularly given the focus on CI systems. Further details on the specific criteria and methods utilized for document categorization will be discussed in the subsequent section.

3.1.2. Documents Classification

In qualitative research, document analysis is a commonly used methodology that is often combined with other analysis methods. Many studies have employed document analysis to collect and explore relevant information through content analysis [43]. Document analysis allows for a comprehensive examination of various perspectives on a single phenomenon, event, organization, or project [44]. Different types of documents can help experts discover, develop, and gain a deeper understanding of insights relevant to the research [45]. Document analysis is commonly adopted when documents serve as the sole source of data and possess unique forms, making it suitable for exploratory research, which aligns with the focus of this article.

From an academic standpoint, document analysis is a method employed to classify policy documents. Policy documents represent the expression of government policies and actions, providing an objective basis for exploring the core values inherent in these policies [46]. In terms of government policy tools, there are three types commonly used for policy management: supply-driven policy, environmental policy, and demand-pull policy. Supply-driven policies involve direct provisions from the government, such as funds and infrastructure facilities. Environmental policies elucidate development measurements and goals, while demand-pull policies are established to foster collaboration between the government and subcontractors, primarily aimed at safeguarding collaboration security and preventing information risks [47]. An alternative system categorizes policies as mandatory tools, hybrid tools, and voluntary tools, advocating for the marketization and socialization of policy tools to facilitate public affairs governance [48]. Considering the research objective, document analysis adopts the latter classification system.

After reorganizing the relevant data, the author collected mandatory policies published by national or provincial administrations, which serve as legal regulations for the specific industry and corresponding departments. The attributes and categories of governance tools discussed in this paper are closely linked to the state management system and current national conditions in China. A total of 127 documents were collected from the official websites of energy, transportation, and communication administrations. To facilitate data classification and explore their internal connections, all these documents were coded in an Excel document, and the classification results are presented in Table 3.

Table 3. Relevant actors, sectors classification, type of documents and the inclusion of actors and the total number of documents in CI systems.

Actor	Sector	Type of Document	Document
Ministry of Transport	TP	Central department working documents	29
Ministry of Water Resources (MWR)	TP	Central department working documents	2
Ministry of Housing and Urban-Rural Development	TP	Central department working documents	3
Bureau of Water Transport, Ministry of Transport	TP	Central department working documents	1
Department of Safety and Quality Supervision and Management, Ministry of Transport	TP	Central department working documents	1
Local Department of Transportation	TP	Local documents	8
Local People's government	TP	Local documents	2
State Electricity Regulatory Commission	EN	Central department working documents	33
National Energy Administration	EN	Central department working documents	25
Ministry of Water Resources (MWR)	EN	Central department working documents	5
National Development and Reform Commission (NDRC)	EN	Documents of NDRC	4
Ministry of Housing and Urban-Rural Development	EN	Central department working documents	1
State Council	EN	Central department working documents	1
General Office of the State Council	EN	Central department working documents	1
State Economic and Trade Commission	EN	Central department working documents	1
State Administration of Work Safety	EN	Central department working documents	1
Work Safety Committee of the State Council	EN	Central department working documents	1
Local Office of Supervision of National Energy Administration	EN	Local documents	2
Local Development and Reform Commission	EN	Local documents	2
National Development and Reform Commission (NDRC)	TC	Central department working documents	1
Ministry of Industry and Information Technology	TC	Central department working documents	1
Local Economic and Information Technology Committee	TC	Local documents	1
General Administration of Customs	TC	Central department working documents	1

3.2. Data Analysis

3.2.1. Content Analysis

To analyze textual data, various text analysis methods are utilized in academic research. These methods, in order of increasing automation, include thematic analysis, content analysis, dictionary-based methods (dictionary analysis), text vectorization (Bag-of-words), supervised learning such as SVM, bayes, and regression, unsupervised learning, and natural language processing [49]. Content analysis is widely employed in the social science field due to its ability to provide an objective, systematic, and quantitative description of specific forms of communication. It allows for an investigation into the focus, internal tendencies, and changing patterns of communication content over time, providing insights into social reality from a content-based perspective [50]. Given that the selected data in this study consists of textual data published by the government, content analysis is a feasible approach for analysis.

Content analysis encompasses several steps, including text input, word segmentation, removal of symbols and nonsensical stop words, stemming, and the construction of a document word frequency matrix using a specific encoding method. Through this process, textual data is compressed into phrase frequencies, transforming qualitative text data into quantitative frequencies [50]. These indices can provide answers to more quantitatively oriented research questions. In this study, the frequency matrix is manually converted into a co-word matrix.

In accordance with the principles and processes of content analysis, ROST Content Mining version 6 is employed to conduct the analysis. Developed by a computer science research team at Wuhan University, ROST Content Mining software caters to the needs of humanistic and social science research. The software offers features such as network analysis, website analysis, browsing analysis, word segmentation, word frequency statistics, cluster analysis, and other text analysis capabilities [51].

Before conducting the main experiment, a preliminary study is conducted to test the feasibility of content analysis for this research and enhance the accuracy of the keyword library. This pilot study involves examining 10 documents obtained from the National Energy Administration and Ministry of Transportation websites. Through content analysis of these documents, keywords with high frequency are identified and used to update the keyword library in the ROST CM6 software v.6. This updated library includes not only common words but also the names of national governing administrations and specialized terms, enhancing the precision of keyword analysis.

In the formal experiment, the content analysis process is divided into four main steps. Firstly, all collected files are converted to a compatible format recognizable by the software. Secondly, word segmentation is performed to establish the content keyword database. Subsequently, word frequency statistics are conducted. Finally, a co-word matrix is generated, in which high-weighted keywords are represented, forming the co-word network.

3.2.2. Node Importance Analysis

In the field of graph theory and network analysis, centrality serves as an indicator for assessing the influence of nodes within a network [52]. In social network analysis, a key objective is to identify individuals in a group who hold greater influence compared to others, helping to comprehend their roles within the network [53]. This is often measured through degree centrality, as defined by Equation (1). Furthermore, to facilitate comparison of the degree centrality across all nodes, standardized centrality is calculated using Equation (2). The findings from these calculations are presented and discussed in Section 4.

$$C_d(v_i) = \sum\nolimits_{i=1, i \neq j}^{n} d_{ij} \tag{1}$$

where d_{ij} is the distance between node v_i and v_j; $C_d(v_i)$ is the degree centrality of node v_j.

$$C_d^{'}(v_i) = \frac{C_d(v_i)}{n-1} \tag{2}$$

where $C_d^{'}(v_i)$ represents the standardized centrality of node v_i; n is the total number of nodes.

The degree of centrality is a useful measure for determining the connections of adjacent nodes within a network. However, when considering the importance of non-adjacent nodes that rely on other nodes within the network, the indicator known as betweenness centrality becomes relevant. Equation (3) provides the calculation formula for betweenness centrality.

$$C_b(v_i) = \sum\nolimits_{s \neq v \neq t}^{n} \frac{\sigma_{st}(v_i)}{\sigma_{st}} \tag{3}$$

where $C_b(v_i)$ is the betweenness centrality of node v_i; σ_{st} is the total number of the shortest paths from node s to t; $\sigma_{st}(v_i)$ is the total number of the shortest paths connecting node s and t through node v_i.

Additionally, closeness is a metric used to quantify the path length between two nodes in a network. Closeness centrality measures the average shortest distance from a node to all other nodes in the network. In essence, nodes with a higher closeness centrality are those that are closer to other nodes [54]. The principles and equations for measuring network centrality are described in Equations (4) and (5):

$$d_i = \frac{1}{N-1} \sum\nolimits_{j=1}^{N} d_{ij} \tag{4}$$

$$C_c(v_i) = \frac{1}{d_i} \tag{5}$$

where d_{ij} is the distance between node v_i and v_j; d_i is the average distance of node v_i to all other nodes in network; $C_c(v_i)$ is the inverse of its average distance.

Based on the previous content analysis and the generation of the co-word matrix, a semantic network can be constructed. Each keyword that is selected from the co-word matrix represents a node within the risk governance network. Node importance is determined through calculations that assess the influence of the node on the entire network, as well as its relationship with other nodes. Considering the specific characteristics of the research objects in this study, degree centrality and betweenness centrality are applied in the transportation domain due to its interdependent and complex nature. On the other hand, degree centrality and closeness centrality are adopted to analyze energy-related document content, given the characteristics of association and resource distribution.

The graphical representation allows for the depiction of the relationships between words. By utilizing a semantic network structure diagram, one can intuitively analyze the hierarchical relationship and degree of closeness among high-frequency words. This approach falls under the umbrella of network analysis, commonly employed in social science research. The mathematical calculations are carried out using Ucinet software v.6, while Netdraw software v.2.118 is utilized for data visualization.

4. Results

4.1. Transportation Content Analysis

In the transportation domain, a total of 46 documents were analyzed. The results of the document analysis are shown in Table 4, which lists the publishing administrations and the number of documents. The results highlight the presence of multiple documents published by the Ministry of Housing and Urban-Rural Development, indicating an administrative link between the construction industry and the transportation sector. Furthermore, the collection of six documents from provincial departments of transportation, two from provincial governments, and three from the Ministry of Housing and Urban-Rural Development signifies the collaborative efforts among various government administration departments.

Table 4. Actors appearing in transportation CI risk governance documents.

Actor	Number
Ministry of Transport	29
MWR (Ministry of Water Resources)	2
Ministry of Housing and Urban-Rural Development	3
Ministry of Transport Water Transport Bureau	1
Department of Safety and Quality Supervision and Management, Ministry of Transport	1
Guizhou Provincial Department of Transportation	2
Henan Provincial Department of Transportation	2
Inner Mongolia Autonomous Region Transportation Department	1
Fujian Provincial Department of Transportation	1
Hunan Provincial Department of Transportation	1
Jiangsu Provincial Department of Transportation	1
Ganze Tibetan Autonomous Prefecture People's Government	1
People's Government of Guiping City	1
Total	46

Furthermore, a content analysis of transportation documents generated a co-word matrix. Due to software constraints, the original matrix contained the first 150 keywords. Based on the original results, the author deleted irrelevant words and finally selected 27 keywords to retain. The optimized matrix was transformed into a weight diagram, as shown in Figure 3. Figure 3 reveals that the refined keyword set from the original co-word matrix includes terms such as "security", "assessment", "administration", "engineering", "major", "potential risk", "road", "employee", "transportation", and "construction". These keywords exhibit a high correlation value of over 100 when combined with another keyword to form a phrase.

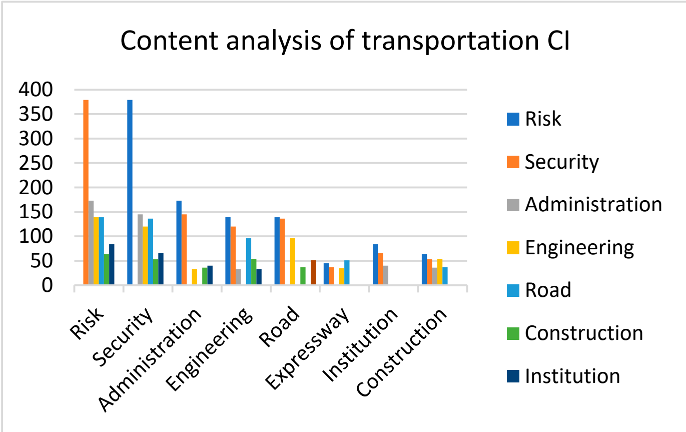

Figure 3. Content analysis of transportation CI documents.

According to the result of co-word analysis, the term "employee" is connected with 3 elements, which are risk, assessment, and administration. Each combination holds a value of approximately 50, indicating that the importance of "employee risk", "assessment", and "administration" is evenly distributed. Furthermore, Figure 3 illustrates the significant relation of "construction" to multiple elements. Specifically, "engineering construction" has a weighting of 54, while "road construction" emerges as a crucial branch within transportation construction. This is evident in the "road" column, as the value for "road engineering" is 96. This phenomenon suggests that infrastructure risk governance is highly connected with engineering construction and road engineering. Risk assessment and security control pertaining to road engineering play a pivotal role in the overall risk governance of national transportation infrastructure.

Both engineering and construction keywords are closely associated with administration. In addition, administration exhibits strong connections with risk, security, and assessment. This suggests that institution administration exerts a significant influence on "risk", "security", and "engineering" as a subdiscipline of administration. Consequently, cross-actor collaboration among administration employees does exist and it is meaningful for ensuring effective infrastructure risk governance in the transportation domain.

4.2. Energy Content Analysis

After data collection, there were 77 energy infrastructure risk governance documents. The results of the document analysis are shown in Table 5, which lists the publishing administrations and the number of documents. The analysis reveals that the State Electricity Regulatory Commission is the primary publisher of most energy infrastructure risk governance documents, highlighting the significant role of electricity in the energy system. Additionally, three documents were published by provincial governments, while one document originated from the Ministry of Housing and Urban-Rural Development administration. This observation underscores the interconnectedness between the construction industry, administration management, and policies pertaining to energy infrastructure risk governance.

The original co-word matrix was constructed using content analysis. However, due to the large number of segmented keywords (over 150), irrelevant keywords were removed, resulting in a refined matrix with 24 retained keywords. Each element in the vector represents the frequency of occurrence, ranging from 73 to 959. A high value in the vector indicates that the keyword appears frequently in policy documents. Figure 4 presents a diagram that visually represents the information contained in the matrix, emphasizing meaningful concepts and findings.

Table 5. Actors appearing in energy CI risk governance documents.

Actor	Number
National Energy Administration	25
State Electricity Regulatory Commission	33
National Development and Reform Commission (NDRC)	4
Jiangsu Regulatory Office of the National Energy Administration	1
Shandong Regulatory Office of the National Energy Administration	1
State Council	1
Hebei Provincial Development and Reform Commission	2
MWR (Ministry of Water Resources)	5
Ministry of Housing and Urban-Rural Development	1
State Administration of Work Safety	1
State Economic and Trade Commission	1
General Office of the State Council	1
Work Safety Committee of the State Council	1
Total	77

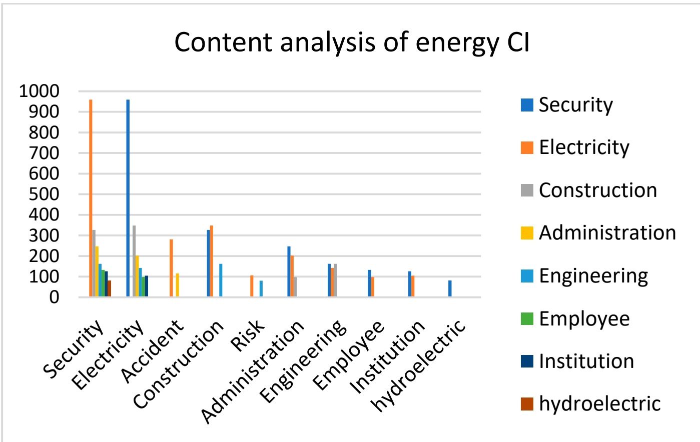

Figure 4. Content analysis of energy CI documents.

Figure 4 depicts two prominently high columns representing electricity and security, indicating that the value of "electricity security" is close to 1000. The analysis of other elements within the energy system reveals that "construction", "administration", "engineering", "employees", and "institution" also play significant roles in infrastructure risk governance. Hydroelectricity, as a subset of the energy industry, also has an impact on energy system security. The grey column represents construction, while the light blue column represents engineering. From the diagram, it is evident that construction has a profound influence on electricity, security, and administration. The correlation between construction and electricity appears to be the strongest, with a value exceeding 300. Engineering, on the other hand, shows an impact on construction and risk, with vector values of 162 and 80, respectively. In summary, engineering construction has a substantial influence on energy infrastructure systems, particularly in the context of electricity engineering.

Additionally, the yellow column in the diagram represents a significant proportion of keywords related to "administration". By analyzing high-frequency keywords, two keywords, "employee" and "institution", emerged and are associated with "administration". Notably, "employee" has higher values of 133 on security and 98 on electricity, which are noticeably higher than the impact value associated with institution. Therefore, "employee" is considered an important factor at the administration level, which also answers the first research question (RQ1) in this study.

4.3. Transportation Node Importance Analysis

Taking into consideration the collected documents and the characteristics of the transportation industry, density cohesion, degree centrality, and betweenness centrality are utilized to analyze the relevant data. Network density is a measure of the strength of connections among nodes in the network as a whole. A higher density value indicates a greater number of established connections among the nodes. The results of density cohesion are presented in Table 6, providing insights into the density of the transportation governance document network. This analysis sheds light on the overall attributes of the network, revealing that the network of transportation governance documents is tightly connected and conducive for further analysis.

Table 6. Transportation Density Cohesion Analysis.

	Avg Value	Std Dev
Transportation	70.0366	53.2160

4.3.1. Degree Centrality Analysis

In the centrality analysis, each institution within the transportation domain is treated as a node. Consequently, the network of transportation CIs risk governance is composed of these nodes and the edges that link them. Given the interdependence of transportation infrastructure and the mutual influence of systems and facilities, the network is considered undirected. Table 7 presents the measurement of degree centrality.

Table 7. Transportation Degree Centrality Analysis.

Keyword	Degree	NrmDegree (%)	Share
Risk	2305.000	23.392	0.201
Security	2081.000	21.118	0.181
Administration	941.000	9.549	0.082
Assessment	922.000	9.357	0.080
Engineering	618.000	6.272	0.054
Road	565.000	5.734	0.049
Major	544.000	5.521	0.047
Operation	386.000	3.917	0.034
Construction	326.000	3.308	0.028
Potential Risk	325.000	3.298	0.028
Transportation	315.000	3.197	0.027
Institution	300.000	3.044	0.026
Establish	218.000	2.212	0.019
Accident	210.000	2.131	0.018
Expressway	208.000	2.111	0.018
Employee	200.000	2.030	0.017
Precaution	141.000	1.431	0.012
Working	132.000	1.340	0.011
Analysis	119.000	1.208	0.010
Event	102.000	1.035	0.009
Ministry of Transport	97.000	0.984	0.008
Criterion	97.000	0.984	0.008
Emphasis	94.000	0.954	0.008
Technology	92.000	0.934	0.008
Harbor	74.000	0.751	0.006
Manager	39.000	0.396	0.003
Nature	35.000	0.355	0.003
Network Centralization = 20.60%			
Heterogeneity = 10.01%. Normalized = 6.55%			

The Degree column in Table 7 represents the total number of connections a node has with other nodes. The standardized centrality values are listed in the nrmDegree column, while the Share column displays the proportion of centrality for each node. Figure 5 visually represents these results, with each circle representing a keyword in the matrix. The size of each circle corresponds to the degree of the word.

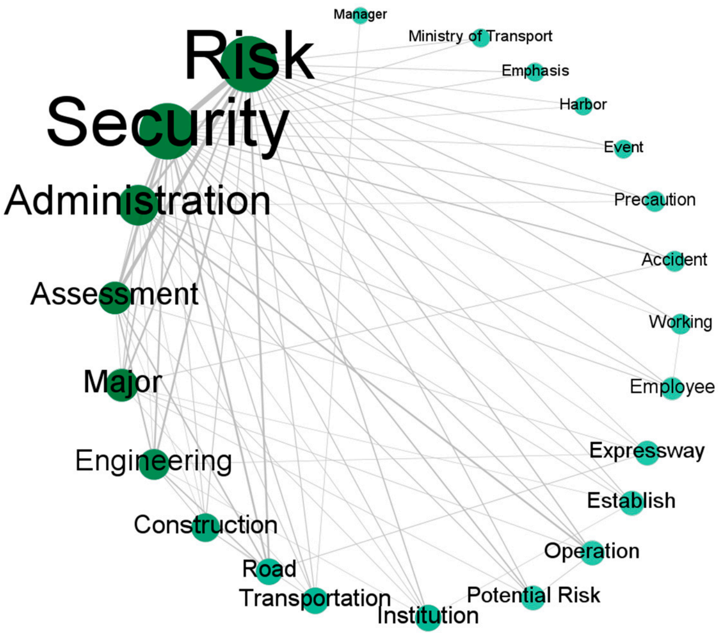

Figure 5. Transportation degree centrality visualization.

Based on the analysis of degree centrality, administration exhibits a significantly high value of 0.21. Furthermore, "engineering" has a degree centrality value of 0.06, while "road" has a value of 0.057. "Operation" and "construction" have degree centrality weights of 0.039 and 0.033, respectively.

To compare their relative importance, the Share calculation data reveals a sequence of proportions that is consistent with the degree centrality results. The range of keyword shares spans from 0.003 to 0.201. For institutions with relatively high degree centrality values, their share proportions are 0.026. Moreover, "operation" exhibits a share proportion of 0.049, surpassing both "construction" and "transportation". When considering the NrmDegree and Share results together, "engineering" and "road" rank among the top 10 in terms of both standardized degree and degree proportion. This emphasizes the significance of road engineering in the context of transportation system risk governance. Finally, "administration" attains a value of 0.083, which ranks third in terms of the highest share proportion.

4.3.2. Betweenness Centrality Analysis

Betweenness centrality measures the influence of nodes on the pathway between two other nodes. These intermediary nodes play a significant role in influencing the nodes at either end of the edges in terms of their interdependent impact. Therefore, the concept of betweenness centrality suggests that if a member appears on multiple shortest paths of other members, it can be considered a central member with greater mediation centrality [55]. The betweenness centrality measurements are presented in Table 8.

The betweenness centrality measurements are presented in Table 8, specifically listed in the Betweenness column. In order to provide a more intuitive representation of the data, a normalized version of betweenness centrality is shown in the nBetweenness column. Normalization allows the values of nBetweenness to range from 0 to 1. When the value is close to 0, it indicates that the node has minimal control over other nodes within the network and is positioned at the periphery. Conversely, when the value is close to 1, it suggests that the node has significant control over other nodes. Additionally, the betweenness of each node is visually displayed in Figure 6.

Table 8. Transportation Betweenness Centrality Analysis.

Keyword	Betweenness	nBetweenness
Transportation	6.000	0.923
Administration	5.333	0.821
Major	4.333	0.667
Engineering	2.000	0.308
Employee	2.000	0.308
Institution	1.333	0.205
Security	0.000	0.000
Risk	0.000	0.000
Road	0.000	0.000
Potential Risk	0.000	0.000
Working	0.000	0.000
Assessment	0.000	0.000
Analysis	0.000	0.000
Construction	0.000	0.000
Event	0.000	0.000
Accident	0.000	0.000
Criterion	0.000	0.000
Operation	0.000	0.000
Harbor	0.000	0.000
Technology	0.000	0.000
Establish	0.000	0.000
Emphasis	0.000	0.000
Manager	0.000	0.000
Nature	0.000	0.000
Ministry of Transport	0.000	0.000
Precaution	0.000	0.000
Expressway	0.000	0.000
Network Centralization Index = 0.83%		

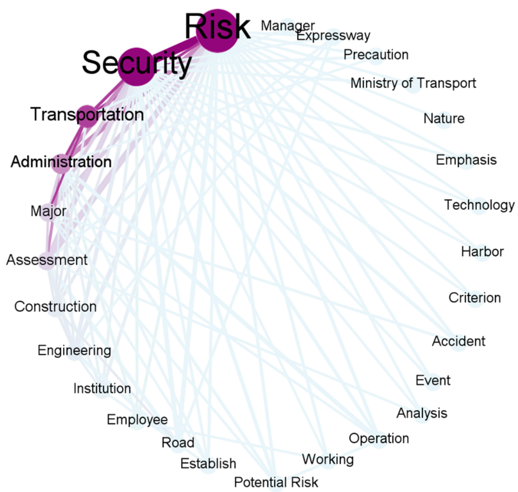

Figure 6. Transportation betweenness centrality visualization.

Based on the normalization of betweenness centrality, only six nodes demonstrate significant betweenness centrality in the network: transportation, administration, major, engineering, employee, and institution. Notably, the importance of "transportation administration" is highlighted by the betweenness centrality values of 0.923 and 0.821, indicating its prominence as an intermediary in the network. Additionally, "engineering" and "employee" exhibit a betweenness centrality of 0.308, surpassing the betweenness centrality of Institution. This observation suggests that although employees may not have direct connections with other elements, their influence greatly impacts cooperation and communication effectiveness in transportation system risk governance.

4.4. Energy Node Importance Analysis

According to the density analysis, the average density value of governance documents in the Energy domain is 145.7, with a standard deviation of 129.1. Higher density values indicate a greater number of established connections among the nodes. The findings of the density cohesion analysis are presented in Table 9, providing insights into the density of the network within the energy domain risk governance. This analysis reveals the overall characteristics of the network, which is compact and suitable for further analysis. In addition to density cohesion, the subsequent text explores more detailed analysis, such as centrality measurements.

Table 9. Transportation Density Cohesion Analysis.

	Avg Value	Std Dev
Energy	145.7037	129.0971

4.4.1. Degree Centrality Analysis

For the energy domain, a total of 77 documents were analyzed. Through the application of ROST CM6, a network of keywords extracted from these governance documents was formed. To conduct network centrality analysis, the author utilized Ucinet software. Initially, degree centrality was employed to assess the connections and significance of nodes in the network. The findings of the degree centrality analysis are presented in Table 10, and a graphical representation of the results is depicted in Figure 7.

Table 10. Energy Degree Centrality Analysis.

	Degree	NrmDegree	Share
Security	4073	18.466	0.259
Electricity	3794	17.201	0.241
Construction	1108	5.023	0.07
Accident	935	4.239	0.059
Administration	662	3.001	0.042
Engineering	546	2.475	0.035
Potential Risk	511	2.317	0.032
Risk	459	2.081	0.029
Criterion	439	1.99	0.028
Technology	372	1.687	0.024
Power Grid	310	1.405	0.02
Event	274	1.242	0.017
Precaution	262	1.188	0.017
Employee	231	1.047	0.015
Institution	231	1.047	0.015
Safety Monitoring	214	0.97	0.014
Reinforcement	199	0.902	0.013
Energy	195	0.884	0.012
Nationwide	177	0.802	0.011
Assessment	170	0.771	0.011
Government	167	0.757	0.011
National Energy Administration	165	0.748	0.01
Society	160	0.725	0.01
hydroelectric	82	0.372	0.005
Network Centralization = 16.90%			
Heterogeneity = 14.23%. Normalized = 10.50%			

Based on the results of the degree centrality analysis presented in Table 10, it is evident that electricity security is a crucial aspect in the risk governance of the energy domain, with a high degree centrality ranking among the top two keywords. Additionally, "construction" and "engineering" are among the top ten words, with degree centrality values of 7% and 3.5%, respectively. Considering the statistical information from the documents, it can be inferred that "construction" and "engineering" have significant influence on energy security, which explains their high degree centrality values. Furthermore, "administration" emerges as a term with high degree centrality in both the transportation and energy domains, highlighting its importance in risk governance. Moreover, the inclusion of "criterion" and "technology" in the top ten keywords with respective degree centrality shares of 2.8% and 2.4% underscores the significance of establishing criteria for regulating responsibilities and rewards in energy risk governance.

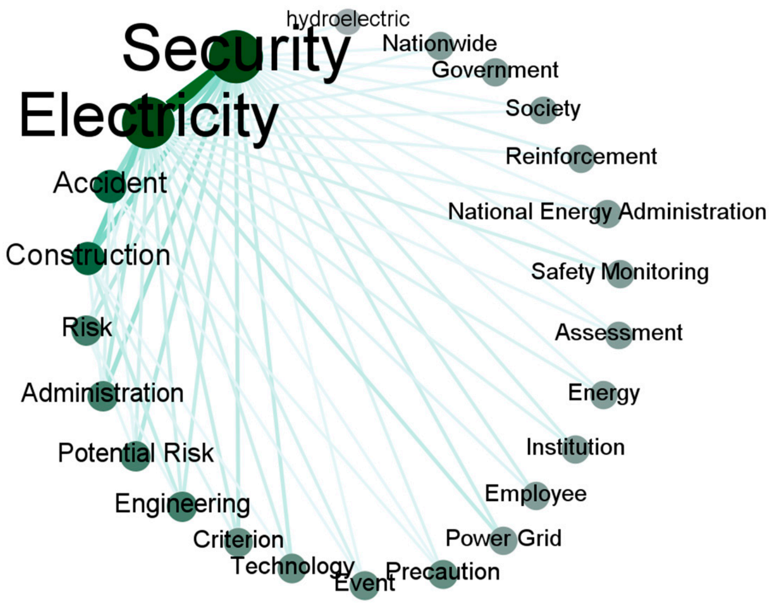

Figure 7. Energy degree centrality visualization.

Another noteworthy finding is that both "employees" and "institution" have the same degree centrality value. This observation, coupled with the presence of the keyword "administration", emphasizes the influence of employees on the level of risk governance and underscores the indispensable role of institutional administration in this context.

4.4.2. Closeness Centrality Analysis

The results of the closeness analysis are presented in Table 11. The Farness column indicates the average distance of each node, which is calculated as the inverse of the closeness centrality. The nCloseness column displays the standardized closeness values. In addition, the impact of every element in the closeness perspective is visualized in Figure 8.

Considering the characteristics of closeness centrality and the range of closeness values, keywords with a value exceeding 53 are being considered. When comparing "electricity" with "hydroelectric", it is evident that "electricity" has a shorter average distance to other nodes, despite "hydroelectric" having little influence on energy infrastructure risk governance. Within the energy infrastructure risk governance network, both "accident" and "construction" display the same closeness centrality value of 57.3, which is the third highest value in Table 11. Following closely is a closeness centrality value of 54.762, corresponding to the keywords "administration" and "engineering".

Based on the analysis of the top ten keywords with high closeness values, it is evident that security and electricity exhibit the highest closeness in the network, aligning with the intended design of the network. Additionally, the keyword "criterion" ranks ninth in terms of closeness, indicating its strong influence on the other elements within the energy infrastructure domain.

Table 11. Energy Closeness Centrality Analysis.

	Farness	nCloseness
Security	23	100
Electricity	24	95.833
Accident	40	57.5
Construction	40	57.5
Risk	42	54.762
Administration	42	54.762
Potential Risk	42	54.762
Engineering	42	54.762
Criterion	43	53.488
Technology	43	53.488
Event	43	53.488
Precaution	43	53.488
Power Grid	44	52.273
Employee	44	52.273
Institution	44	52.273
Energy	44	52.273
Assessment	44	52.273
Safety Monitoring	44	52.273
National Energy Administration	44	52.273
Government	44	52.273
Reinforcement	44	52.273
Society	44	52.273
Nationwide	44	52.273
hydroelectric	45	51.111
Network Centralization = 91.61%		

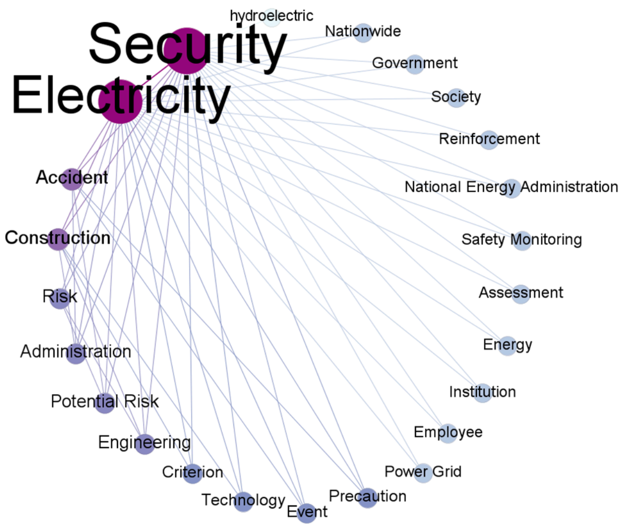

Figure 8. Energy closeness centrality visualization.

5. Discussion

Based on the findings of the content analysis and network centrality calculation, the existence of interconnection governance behaviors (RQ1) is confirmed, thus indicating the presence of horizontal risk governance in both the transportation and energy sectors. Figure 9 demonstrates the identified levels of cross-section risk governance and collaboration paths.

Regarding the administrative aspect, the second research question (RQ2) is explored, revealing that institutional cross-section risk governance occurs in the transportation domain, while personal cross-section risk governance is observed in the energy domain. The importance of horizontal institutional collaboration is highlighted, with collaboration primarily occurring among the construction, urban development, and transportation departments. Conversely, in the energy sector, the risk governance of energy CIs is primarily influenced by cross-actor behaviors, particularly among professional employees.

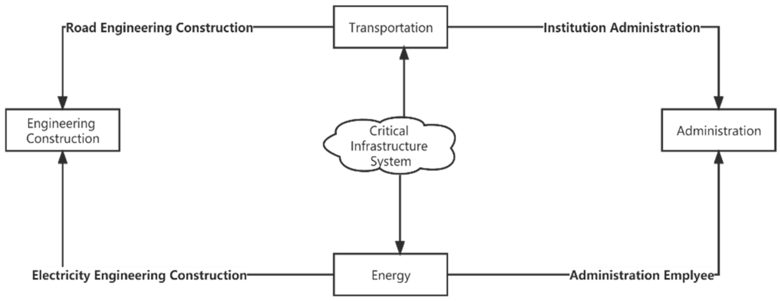

Figure 9. Findings about CI risk governance in transportation and energy domains.

The third research question (RQ3) can be addressed from an engineering construction perspective. The construction industry is identified as significantly influencing the governance of infrastructure risks in both energy and transportation systems, exemplifying its cross-sectional governance role at the industrial level. The findings indicate that cross-section risk governance has an impact on transportation and energy domains through collaboration in engineering construction projects. This is due to the fact that the construction process entails numerous risks, necessitating consideration of factors such as contract management, collaboration among individuals, worker safety, and economic disputes in the risk assessment.

In the transportation domain, both institutional and personal administration play a crucial role in the risk governance semantic network. Furthermore, institutional collaboration significantly impacts transportation, as indicated by its high degree centrality and betweenness centrality. This significance can be attributed to the complexity and difficulty involved in transportation projects, which require the involvement of multiple institutions in the construction and operation of transportation infrastructure. Additionally, since the transportation system encompasses various components such as railways, expressways, and roads, the operational status of each road can influence other elements in the traffic network. Thus, collaboration among administration entities is essential.

Based on the policy documents collected, the Ministry of Transport, Ministry of Water Resources (MWR), and the Ministry of Housing and Urban-Rural Development are among the administration institutions involved in transportation governance. In the context of China's rapid urbanization, metropolitan regions play a crucial role in national development. Due to their geographical features, these regions often encounter cross-boundary challenges, particularly in the transportation domain [56]. Transportation facilities serve as connectors between different regions, facilitating the movement of goods and resources. Consequently, transportation planning is closely linked to urban development projects. Moreover, the issue of traffic congestion poses a significant challenge in metropolitan regions, necessitating cross-sectional collaboration to address this phenomenon. The presence of institutional horizontal risk governance in the transportation industry can help tackle the issues faced by megacities during the urbanization process, including traffic congestion, limited urban land area, and carbon emissions.

From an industry perspective, the results indicate that road construction plays a significant role in infrastructure risk control. This finding further reinforces the connection between the construction industry and the governance of transportation infrastructure risks. Road construction projects are typically long-term endeavors that involve considerations of citizen demands, national transportation planning, as well as geographical and environmental conditions. Consequently, the quality and timely completion of road projects have a substantial impact on the traffic throughput and transportation efficiency of the entire transportation system. These factors, in turn, greatly influence the governance of transportation risks.

In the energy CI systems, the results reveal that employees play a crucial role in risk governance. In China, energy companies are state-owned enterprises, which means that the objectives of the energy industry extend beyond mere profit-making and are subject to political constraints. Given the significance of energy production and consumption to national economic and social development, the operational status and revenue of energy enterprises are of vital importance. Tackling challenges such as energy conservation, the use of renewable energy sources, fuel desulfurization, and waste disposal requires the involvement of cross-boundary organizations.

Employees in the energy industry possess specialized education and training, with backgrounds in disciplines such as electricity engineering, carbon emission reduction, and water pollution prevention [57]. Collaboration within the energy domain focuses on addressing internal issues related to energy production and consumption. This necessitates the collaboration of employees from various departments, each with their own unique professional skills, to address challenges such as machine examination, meeting environmental protection targets, and ensuring a reliable energy supply. By implementing personal horizontal risk governance, potential risks within the energy domain can be minimized, thereby f ensuring a consistent energy supply.

Apart from addressing the risks associated with the operation and maintenance of professional energy facilities, it is vital to recognize the significance of engineering risks and construction administration in energy CI risk governance. In particular, electricity engineering plays a significant role in risk governance as an integral part of the construction process. Supported by the findings of content analysis and centrality analysis, electricity engineering has a substantial impact on infrastructure risk administration, infrastructure security, and accident control.

Power stations serve as an illustrative example of the complexities involved in energy CIs. These facilities are large and intricate structures that require strict adherence to material requirements, including high temperature resistance. Furthermore, they must perform specific functions such as coal desulfurization. These considerations highlight the critical role that engineering construction plays in the development and integrity of energy infrastructure.

6. Conclusions

Within this section, the study concludes with a systematic review of previous findings and their implications and limitations. The objective of this research is to investigate the governance mechanism of CI risk from a cross-sectional perspective, considering the unique social, economic, and political context of China. The experimental results yield the following conclusions: Firstly, engineering construction significantly impacts the safety of both transportation and energy infrastructure. Therefore, it is vital to strengthen collaboration among relevant departments and the Ministry of Housing and Urban-Rural Development at different levels of administration. Secondly, the governance of energy infrastructure systems should prioritize electrical engineering risk control and collaboration between administrators and employees. Lastly, the transportation infrastructure system has potential risks from the perspective of road construction engineering and the corresponding institutional administration.

In the transportation domain, the content analysis and degree centrality analysis results indicate a strong influence of the administration institution. Key related keywords associated with the administration institution, with high centrality values, include administration employee, administration risk, administration assessment, and administration security. This finding corroborates the central role of administration cooperation in cross-section risk governance, aligning with the objective of this research. Moreover, the analysis of the experiment results suggests that both institutions and employees have an impact in the transportation domain. However, it is evident that collaboration among institutions has a more pronounced influence on risk governance compared to the impact of individual employees.

Furthermore, the governance of CI risks is significantly influenced by road construction, engineering security, and administration. Transportation infrastructure primarily consists of roads and railways. Based on current governance documents, road construction projects play a critical role in the development of transportation systems. From a risk governance standpoint, ensuring the security of road engineering construction is of utmost importance due to the complexity of construction processes. Construction safety is vital not only for preventing personal injuries but also for mitigating financial losses, both of which impact the control of risks in transportation infrastructure. Thus, the assessment of risks and the administration of security in engineering construction, particularly in road engineering, exhibit a strong mutual correlation, as supported by the findings of content analysis and node centrality results.

In the energy domain, electricity plays a pivotal role as the primary component of the energy system. Consequently, the majority of potential risk issues are directly related to electricity, aligning with the findings of the assessment of electrical engineering importance. Furthermore, administration exerts significant influence over the entire energy infrastructure system, manifested through the actions of administrative employees. Based on the analysis of the importance of administrative employees, collaboration among employees from different departments and levels emerges as crucial for accident prevention and risk governance.

The findings of this study have implications for improving CI risk governance practices from the perspectives of policymakers, industry professionals, and other stakeholders. For policymakers, the centrality analysis reflects the importance of horizontal collaboration. These findings provide a more intuitive understanding of the cooperative relationship between different departments involved in managing infrastructure systems. This understanding can be used by the government to consider collaboration when dividing governance functions and assigning powers and responsibilities. A reasonable division of responsibility among departments can facilitate effective cross-section administration and enhance the effectiveness of risk governance.

Furthermore, industry professionals can use these findings to identify risk transmission pathways from construction projects to CI systems. This identification can promote collaboration between different industries. In particular, for road and electricity construction projects, it is crucial for professionals to be aware of the potential influence on CI risk. This awareness can help prevent risks to CIs in advance.

Finally, from a national development strategy perspective, there is limited research on risk governance in developing countries. This study contributes to the field by conducting a horizontal exploration of the risk governance mechanism of infrastructure in developing countries. It supplements the existing risk governance mechanisms and provides valuable insights for policymakers, industry professionals, and other stakeholders.

However, a concern regarding the findings is the limited access to data. The data collected in this study mainly consisted of policy documents, while a significant portion of administration collaboration and decision making occurs through verbal consultations or internal meetings. Therefore, the inclusion of interview records and meeting minutes would enhance the comprehensiveness of the data collection process.

Additionally, the study is constrained by the analysis methods employed. Centrality analysis, although a traditional method for investigating networks, may have limitations. Utilizing artificial intelligence algorithms, such as natural language processing, could allow for a more comprehensive interpretation of semantic correlation relationships.

Furthermore, the generalizability of the findings to other contexts, such as the telecommunication industry and other infrastructure systems, is a major limitation. While this study primarily focuses on the inter-collaboration between two infrastructure industries, which are crucial components of CI systems, it is essential to recognize that CI networks are complex and can be classified according to various perspectives, such as functions and locations. Therefore, future research should emphasize the integrity of CI systems, considering both their overall system integrity and spatial heterogeneity.

Moreover, the existing literature reveals a gap between investigations into infrastructure resilience and a comprehensive understanding of horizontal risk governance mechanisms. Consequently, future studies on infrastructure risk governance should consider multiple subsystems and elucidate the paths and methods of cooperation among these subsystems and the infrastructure system as a whole. This broader approach could lead to significant advancements in the field of infrastructure risk governance and contribute to improvements in national resilience.

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