World Journal of Innovation and Modern Technology, Vol. 8, Issue 1, (Jan)
ISSN 2682-5910 **2025**
DOI: 10.53469/wjimt.2025.08(01).06

Analysis of the Course System of Hydraulic Engineering Management Based on Complex Networks

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Abstract: ***The current research introduces the theory of complex networks into the study of the curriculum system of water conservancy engineering management. By visualizing and analyzing the network characteristics such as node degree, betweenness centrality, and PageRank value of the professional course system, this study not only clarifies the status of key courses but also provides a solid theoretical basis for the structure and importance of the curriculum system. Moreover, through an in-depth exploration of network resilience analysis, this research offers profound theoretical insights into the stability of the curriculum system of water conservancy engineering management, thereby helping to develop more robust course systems that ensure uninterrupted information transfer and knowledge exchange within the field. This study not only provides valuable guidance for optimizing courses but also promotes interdisciplinary collaboration, enhances education quality, and provides solid support for educational policies and decisions, as well as theoretical foundations for optimizing the teaching system structure of the water conservancy engineering management field.***

Keywords: Water conservancy engineering management; Complex networks; Network characteristics; Resilience.

1. INTRODUCTION

In the current global environment facing challenges such as climate change, water scarcity, and environmental sustainability, water resources management is an important guarantee for the sustained development of regional society, economy, and ecological environment [1]. Hydraulic engineering plays a crucial role in this field, ensuring the supply and distribution of water resources, as well as covering key aspects such as flood control, disaster prevention, ecological protection, and sustainable development [2]. The design and management of the curriculum system are particularly crucial in order to cultivate professionals in hydraulic engineering management with extensive knowledge and comprehensive capabilities. The curriculum system of hydraulic engineering management mainly involves hydraulic engineering and management science, with a wide coverage [3]. This curriculum system not only requires technical knowledge but also spans across management, environmental science, and social science to adapt to the complex and changing challenges of water resources management. However, constructing and optimizing this curriculum system remains an unresolved issue.

The theory of complex networks is an interdisciplinary field that studies the structure and interactions of networks and has achieved significant achievements in many areas, including social networks, biological networks, and information networks [4,5]. Dai Jianyong et al. explored the optimal risk transmission path of natural gas pipeline networks to improve pipeline safety monitoring and maintenance [6]. Wu Qitao et al. addressed the problem of mining node sets in express logistics networks, constructed the DW-KPP-Pos model based on the positive effect model of key nodes, and designed a heuristic algorithm to improve the computational efficiency of the model [7]. Du Yang et al. focused on the spatial configuration problem of underground space in urban high-speed railway station areas and built a network model of underground space in high-speed railway station areas based on the theory of complex networks [8]. Tian Wen et al. combined the actual operation of the air route network with the construction of a cascading failure model for the air route network and a cascading failure process based on different attack methods. They proposed the vulnerability index of the air route network and a vulnerability analysis method combined with the cascading failure model from the perspective of the loss of operating capacity of the air route points [9]. Similarly, scholars have also used complex networks in course analysis. Xu Hui et al. used complex networks to deal with the training programs of engineering management majors in 10 universities, and generated network analysis of engineering management major courses and analysis of core competencies of engineering management majors [10]. Yang Zhifei et al. used the principles of complex networks to model and study graduate courses. The simulation results show that the graduate course group network under complex network modeling meets the course selection requirements of the training program, reflecting the academic inclination of individual courses; the analysis of course importance reflects the emotional factors of student course selection and the influence of network structure on course importance [11]. Song Bo and Yang Junming analyzed the interrelationship between postal courses using the theory of complex networks, studied the important role of new generation information technology courses in the course system, and conducted practical exploration of course construction for logistics talent training [12]. Yang Bo and Li Yuanbiao used complex network methods to analyze and visualize course data collected from 106 universities on the Internet, respectively constructing a course co-occurrence network and a network of relationships between offering institutions [13]. Therefore, the methods used in this study have a certain applicability. However, its application in the field of water conservancy engineering management is relatively limited, especially in the analysis of course systems. This study aims to fill this research gap by introducing the theory of complex networks into the analysis of the course system of water conservancy engineering management majors, in order to explore the potential structure and relationships within.

This research primarily employs the complex network theory to delve into the structure and interactions of the curriculum system in water conservancy engineering management by analyzing network characteristics such as node degree [14], betweenness [15], PageRank [16], and conducting network robustness analysis [17] to evaluate the stability and robustness of the curriculum system. Through these analyses, it not only enhances the understanding of the curriculum system in water conservancy engineering management, reveals the connections and information flow patterns between courses, but also aids in identifying and strengthening key courses, promoting the academic development of the discipline, enhancing educational quality, and offering strong theoretical guidance for optimizing and improving the curriculum. The findings of this study also provide robust support for the formulation of educational policies and decision-making in the field of water resources management, helping to meet industry needs and challenges.

2. WEB-BASED MODELLING OF WATER RESOURCES ENGINEERING MANAGEMENT COURSES

In contemporary society, water conservancy engineering management profession is an area of great importance that concerns national infrastructure and social economic growth, which encompasses a broad and intricate body of knowledge [18]. To gain a deeper understanding of the inherent connections and influences among courses within the water conservancy engineering management profession, network modeling is introduced as an effective method to reveal the correlations and dependencies existing among these courses. This study models each course offered in the engineering management major at the School of Water Resources and Hydropower Engineering at North China University of Water Resources and Electric Power as a network node. The relationships between the knowledge points contained in each course and the sequence of their study are employed as the basis to determine the edge relationship between each pair of courses, thus establishing a course network for the water conservancy engineering management profession. The engineering management program consists of 33 courses (as indicated in Table 1) and 423 edges.

Table 1: Courses in Water Resources Engineering Management

No.	Course
1	advanced mathematics
2	Linear Algebra
3	Probability Theory and Mathematical Statistics
4	University Physics
5	Engineering Mechanics
6	Hydraulics
7	Hydrostructures
8	Geotechnics
9	Operations Research
10	Applied Statistics
11	Geology of Hydraulic Engineering
12	Introduction to Engineering Graphics
13	Surveying
14	Engineering Materials
15	Accounting
16	Financial Management
17	Engineering Economics
18	Hydraulic Engineering Construction
19	Virtual Design and Construction
20	Introduction to Hydraulic and Hydroelectric Engineering Migration

21	Resettlement Planning for Water Conservancy and Hydropower Projects
22	Engineering Project Management
23	Project Investment and Financing
24	Project Bidding and Contract Management
25	Project Management Information System
26	BIM Technology and Application
27	Engineering Project Risk Management
28	Python Programming
29	Engineering Project Quality and Safety Management
30	Engineering Ethics
31	Hydraulic Reinforced Concrete Structures
32	Engineering Costing
33	Intelligent Water Conservancy

Complex networks are typically described using graph theory as $G = (V, E)$, where $V = \{v_1, v_2, \cdots, v_n\}$ represents the set of nodes in the network, and $|V| = N$ indicates that there are N nodes in the network, while $E = \{e_1, e_2 \cdots, e_n\}$ represents the set of edges in the network, and $|E| = M$ indicates that there are M edges in the network. Node connection relationships in the network can be stored using an adjacency matrix, represented by $A = \left(a_{ij}\right)_{n\times n}$, where a_{ij} denotes the value at the i -th row and j -th column of matrix A. If $a_{ij} = 1$, then nodes v_i and v_j are connected, whereas if $a_{ij} = 0$, they are not connected. Based on the interrelationships between courses in Table 1, an adjacency matrix was constructed, and the network model was drawn as shown in Figure 1. Each course name is labeled on its respective node, with node filling based on node degree via a gradient color scheme. Nodes with higher degrees are represented with darker colors.

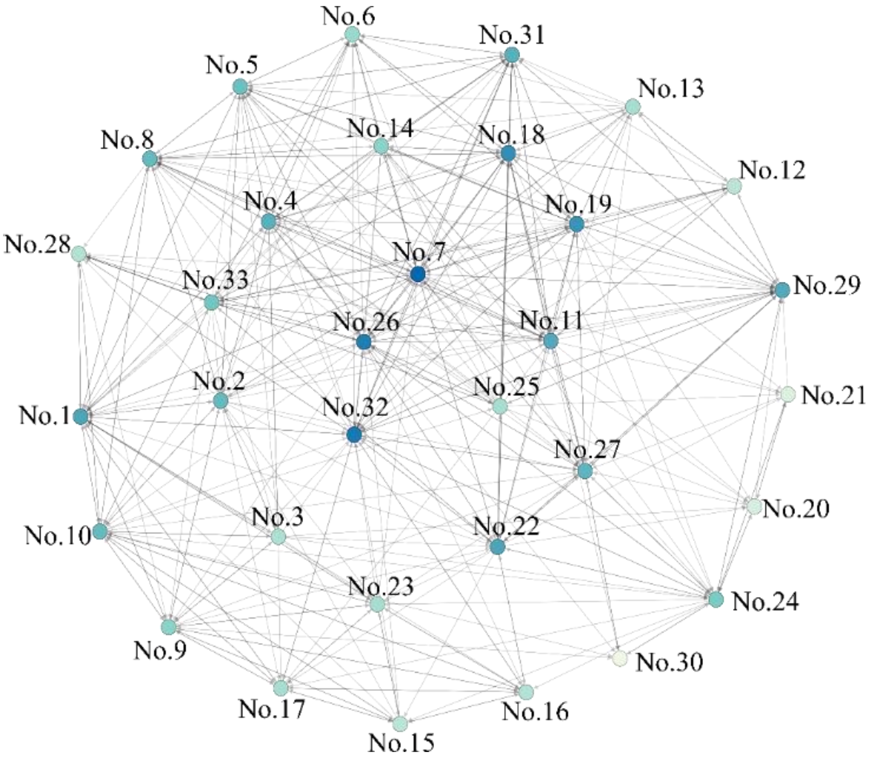


Figure 1: Curriculum network for water engineering management

3. NETWORK TOPOLOGY ANALYSIS AND DISCUSSION

Degree, betweenness centrality, and PageRank value can be used to analyze the structural characteristics of a network [19]. In this study, we used these parameters to analyze the course network of Water Resources Engineering Management. Using Matlab software, we calculated the characteristic parameters of the network and performed a feature analysis of the actual course system network based on the network parameters.

3.1 Network Node Characteristics

In network theory, the degree of a node represents the number of edges directly connected to it [20]. Generally, this concept can be explained as the degree or quantity of direct connections between a node and other nodes in the network, thus reflecting the position and influence of the node in the network structure. In the curriculum system network, the degree of each node essentially presents the strength of the course's relationship within the entire course relationship network. This measurement further reflects the degree of course citation, interaction, and information dissemination in the knowledge system. Highly connected nodes reveal their status as key courses, spanning multiple fields of knowledge, while carrying significant academic influence. Furthermore, the degree of a node also characterizes the degree of cross-coverage of the course in multiple fields. Such interdisciplinary nature signifies the course's disciplinary comprehensiveness, emphasizing its unique value in interdisciplinary learning, research, and practice. This interdisciplinary nature highlights the course's ability to address complex problems across disciplines and its ability to bridge different fields. In the professional course relationship network, the specific expression of degree is given by:

$$k_i = \sum_{j=1}^{n} a_{ij} (i \neq j) \tag{1}$$

In the formula, a_{ij} represents the numerical value in the i -th row and j -th column of the adjacency matrix A for professional course relationships.

In a network, the betweenness centrality of a node refers to the statistical measure of the proportion of all shortest paths that pass through the node. In the professional course relationship network, the betweenness centrality of a node reflects the degree of its crucial role in internal information transmission within the network. In such a network, nodes with higher betweenness centrality act as important bridges and key transmitters, connecting different courses, knowledge domains, and essential aspects of academic communication. This implies that these nodes greatly facilitate the flow of information within the network and establish connections between disciplines. Nodes with higher betweenness centrality may actively contribute to knowledge integration, interdisciplinary collaboration, and academic interaction, strengthening both intra- and inter-disciplinary communication and cooperation, promoting comprehensive academic understanding. The expression of betweenness centrality in the professional course relationship network is as follows:

$$C_B(i) = \sum_{S \neq i \neq t} \frac{n_{s,t}(t)}{n_{s,t}} \tag{2}$$

In the equation, $n_{s,t}$ represents the shortest path from node$s$to$t$, while $n_{s,t}(i)$ represents the count of shortest paths passing through node$i$.

In a network, the PageRank value of a node typically indicates its importance within the whole network and is closely related to the influence it receives from other nodes. If a node is connected to many other nodes, it is likely to be an important node, and its PageRank value will accordingly increase. In the professional course relationship network, the PageRank value of a node symbolizes its importance and influence. This concept is closely associated with the connections from other nodes in the network. In such a network, courses with high PageRank values often represent core concepts, foundational knowledge, or interdisciplinary junctions within the system. These courses may be referenced, linked, or cited by other courses, indicating their relevance and authority within the disciplinary framework. Courses with high PageRank values typically play crucial roles in learning pathways, guiding students to progressively delve deeper and potentially serving as entry points to the discipline. Moreover, courses with high PageRank values may also represent disciplinary centers that attract broad academic attention. In the professional course relationship network, the specific formula for expressing PageRank is:

$$PR(i) = \frac{1-d}{N} + d \sum_{j=1}^{N} \frac{PR(i)}{L_j} W_{jt} \tag{3}$$

In the given formula, $PR(i)$ signifies the PageRank value of the i -th node, L_j denotes the outdegree of node j, w_{ji} represents the edge weight from node j to node i, and d signifies the damping factor, typically chosen as 0.85.

Based on the above network node characteristic formulae, the network of water resources engineering management courses was calculated and the values were normalised to obtain the data shown in Figure 2.

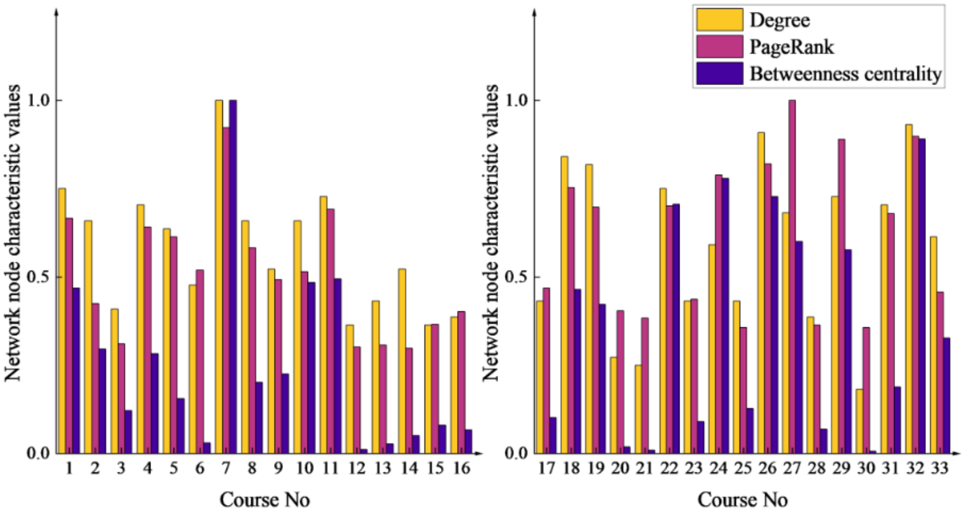


Figure 2: Nodal characteristic values of engineering management programme network

Based on the data analysis in Figure 2, hydraulic structures play a significant role in the field of water resources engineering management from the perspectives of degree and betweenness centrality. They are core components of water resources management and have wide-ranging impacts and applications. Firstly, hydraulic structures include dams, reservoirs, channels, and drainage systems, among others, serving as essential infrastructures for ensuring water supply security, agricultural irrigation, industrial water use, power generation, and the normal operation of urban drainage systems. Studying relevant knowledge about hydraulic structures helps students understand and master the principles underlying the design, construction, and maintenance of these facilities. Secondly, the design and management of hydraulic structures are closely related to disaster prevention and mitigation. Incorrect design or management may lead to natural disasters such as floods, flash floods, and geological hazards, posing severe threats to society and the environment. Therefore, students need to understand how to prevent and respond to these disasters in order to reduce potential risks, ensuring the safety and stability of hydraulic structures. Lastly, the management of hydraulic structures also needs to consider factors related to sustainable development. Faced with the challenges of global climate change and limited water resources, students need to learn how to incorporate ecological, environmental, and social sustainability factors into the design and management of hydraulic structures, ensuring long-term sustainable water resources management. The hydraulic structures course covers various key areas, including water resources management, engineering project management, disaster prevention and mitigation, and sustainable development, providing students with extensive knowledge and skills and offering reliable solutions for water resources management in society. From the perspective of PageRank value, engineering project risk management holds an important position in the field of water resources engineering management. The close connection between this course and other courses is derived from its multidisciplinary nature and practical application requirements. Water resources engineering management encompasses elements from various fields, such as engineering, management, and statistics, and risk management methods provide a framework for the comprehensive application of this knowledge in water resources engineering projects. The significance of this discipline also lies in its crucial role in project lifecycle management and support for project decision-making, including planning, design, construction, and maintenance stages. Through the risk management course, students can integrate various knowledge and skills to better manage the complex risks in water resources engineering projects, ensuring the successful completion of projects.

3.2 Network Destruction Resilience

In a network, the network efficiency of a node refers to the efficiency of information transmission between this node and other nodes. In infrastructure networks, a higher network efficiency of a node implies a stronger ability of this node for information transmission and exchange in the network. In professional course relationship networks, the network efficiency still reflects the efficiency of information transmission among nodes. Network efficiency reflects the academic transmission capability and information exchange efficiency of nodes in the course relationship network. A high network efficiency of a node means that the course has good performance in helping students quickly acquire knowledge and build discipline systems. These nodes are important channels for knowledge transmission, helping students to effectively master core concepts and basic knowledge, promoting links between disciplines, and providing a comprehensive perspective. At the same time, nodes with higher network efficiency play a key role in interdisciplinary cooperation, resource sharing, and academic discussions, promoting communication and cooperation among students and enhancing the vitality of academic communities. In professional course relationship networks, the specific expression formula for network efficiency is expressed as:

$$E = \frac{1}{n(n-1)} \sum_{i,j \in n, i \neq j} \frac{1}{d_{ij}} \tag{4}$$

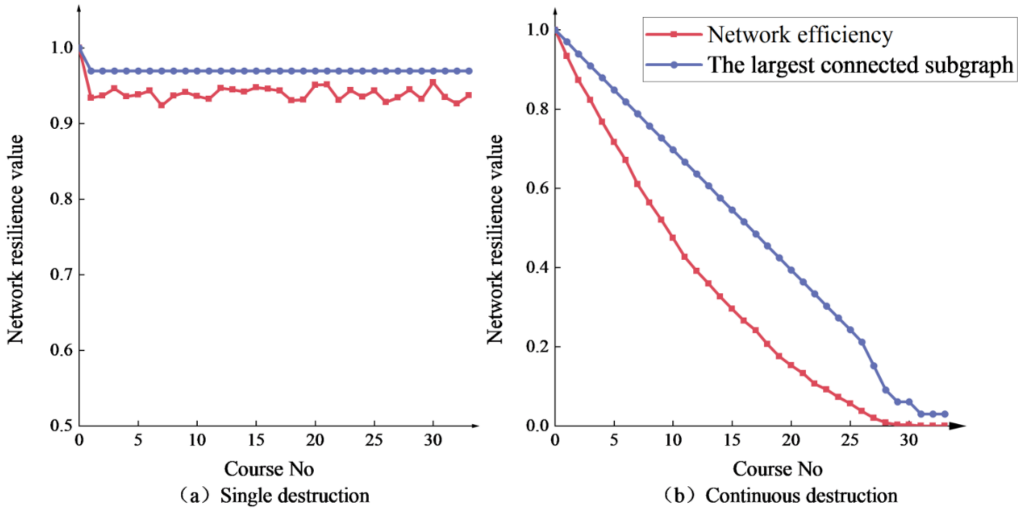
Where n is the number of nodes in the network and d_{ij} denotes the shortest path between two nodes.

In a network, the largest connected subgraph refers to the situation where the network nodes or edges are attacked, leading to the network being divided into two or more subnetworks. The largest connected subgraph is the subgraph with the most nodes among all subgraphs. In a professional course relationship network, the largest connected subgraph represents the largest subgraph composed of interrelated courses in a course or discipline relationship network. This means that in this subgraph, each course is directly or indirectly connected to at least one other course, forming a closely connected academic field or collection of knowledge. In this case, the largest connected subgraph can help identify the relationships between professional courses, enabling students and educators to better understand the connections between different courses. In professional course relationship networks, the specific expression formula for the largest connected subgraph is expressed as:

$$M = n^{'} \tag{5}$$

Where $n^{'}$ is the number of nodes in the maximum connected subgraph of the professional programme relationship network after a disruption.

Based on the formula for network node survivability mentioned above, a destructive simulation was conducted on the water resources engineering management professional course network, as shown in Figure 3. Single destruction refers to the operation of destroying the nodes in the network, but the network will be restored after the next destruction; continuous destruction refers to the operation of destroying the nodes in the network, but the network will not be restored after the next destruction.



（a）Single destruction

（b）Continuous destruction

Figure 3: Network destruction resistance values for engineering management courses

Based on the data analysis in Figure 3, it can be observed that the water resources engineering management professional course network demonstrates high network efficiency and a high maximum connected subgraph, reflecting the outstanding performance of the close interconnection between course networks and the interaction of information between disciplines. Firstly, the water resources engineering management profession itself is interdisciplinary in nature. It encompasses multiple disciplines such as engineering, management, environmental science, and water resources management, thus including courses from various related disciplines in the course network. This interdisciplinary nature promotes the integration of knowledge across different disciplines, requiring students to engage in multiple disciplinary fields, naturally leading to increased connections between courses in the course network. Secondly, water resources engineering management emphasizes practical application. Water engineering projects are typically complex and demand the comprehensive application of knowledge and skills from multiple disciplines. As a result, course design tends to emphasize practical cases, project management, decision analysis, and other practical application areas, facilitating more frequent and close interaction of information between different courses. Furthermore, modern education increasingly emphasizes interdisciplinary education and comprehensive projects, fostering integration and communication between disciplines. The development of online learning platforms and educational technology also facilitates students' participation in courses from multiple disciplines, thereby enhancing network efficiency. Consequently, the superiority of network efficiency and the maximum connected subgraph of the water resources engineering management professional course network reflects the interdisciplinary nature, practical application orientation, and advancements in educational methods within this field.

4. CONCLUSION

This paper introduces the theory of complex networks and applies it to the field of water resources engineering management, providing new analytical tools and methods for this discipline. The introduction of this method enables a more in-depth study of the internal relationships and information flow patterns between courses within the water resources engineering management curriculum. By analyzing network properties such as node degree, betweenness, and PageRank value, it offers a solid theoretical foundation for the structure and significance of the water resources engineering management curriculum, contributing to the clarification of the roles of key courses and facilitating the academic development and enhancement of educational quality in this field. Moreover, network resilience analysis provides profound theoretical insights into the stability of the water resources engineering management curriculum, assisting in the formulation of a more robust curriculum system to ensure that information transmission and knowledge exchange within the discipline will not be easily interrupted when facing various challenges.

The analysis results presented in this paper have had a positive impact on the practical operation of water resources engineering management. Firstly, these results can be used to guide course optimization, thus enhancing students' academic experience. Secondly, these research findings are conducive to promoting interdisciplinary collaboration, encouraging teachers and students to engage in closer cooperation across different fields of study, providing them with a more comprehensive education. Moreover, through the analysis of network properties, we can identify potential areas for course improvement and development, which is helpful for improving educational quality and ensuring that students receive training that is in line with actual needs and industry standards. Lastly, these research findings also offer solid support for educational policies and decision-making in the field of water resources engineering management. Decision-makers can utilize these analysis results to formulate more informed course planning and development strategies that meet the demands of the field.

In summary, this paper examines the curriculum system of water resources engineering management based on complex network theory. It not only extends the application domain of complex network theory in theory but also offers beneficial guidance for enhancing education quality, promoting interdisciplinary collaboration, and making decisions. It holds significant practical implications for the development and practice of water resources engineering management.

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