Design and Application of the Jing-Jin-Ji Coordinated Innovation Development Map System: Postprint

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Abstract

[Purpose / Significance] Promoting collaborative innovation is the strategic choice and fundamental driving force for the orderly alleviation of Beijing's non-capital functions and the coordinated development of the Beijing-Tianjin-Hebei region. [Method / Process] Based on the strategic needs of the Beijing-Tianjin-Hebei coordinated development, this study proposes the design basis, concept, and overall framework of a GIS-based collaborative innovation development map system, and conducts case analysis focusing on the analysis of innovation resource stock and spatial distribution, interconnections among innovation entities, and information integration and display of innovation spatial patterns. [Result / Conclusion] The results indicate that the system can effectively process spatial and attribute data of innovation resources, intuitively display the spatial distribution of innovation resources and the development trends of collaborative innovation in the Beijing-Tianjin-Hebei region, plays an auxiliary role in revealing the spatial distribution characteristics of resources and analyzing existing problems, and provides support for evaluating the level and efficiency of collaborative innovation development in the Beijing-Tianjin-Hebei region.

Full Text

Preamble

The Design and Application of Map System for Collaborative Innovation and Development of Jing-Jin-Ji Region

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Abstract

[Purpose/significance] Collaborative innovation is the strategic choice and fundamental driving force to orderly relieve Beijing's non-capital functions and promote coordinated development of the Jing-Jin-Ji region. [Method/process] According to the strategic needs of collaborative development in the Jing-Jin-Ji region, this paper proposes the design rationale, conceptual framework, and overall architecture of a GIS-based collaborative innovation development map system. Case studies are presented focusing on the analysis of innovation resource stock and spatial distribution, correlation analysis among innovation subjects, and information integration and display of innovation spatial patterns. [Result/conclusion] The results demonstrate that the system can effectively process spatial and attribute data of innovation resources, intuitively display the spatial distribution of innovation resources and the development trend of collaborative innovation in the Jing-Jin-Ji region. It serves as an auxiliary tool for revealing spatial distribution characteristics of resources and analyzing existing problems, providing support for evaluating the level and efficiency of collaborative innovation development in the region.

Keywords: Jing-Jin-Ji region; innovation resources; collaborative innovation; map system; case study
Classification Number: G322; P208

1 Introduction

The 21st century has witnessed the quiet arrival of the fourth industrial revolution based on cyber-physical systems, with countries worldwide leveraging big data and artificial intelligence as crucial tools to seize the commanding heights of new-round competition. In response to this technological revolution, China has positioned independent innovation at the core of its national development strategy. The 18th National Congress of the Communist Party proposed "implementing an innovation-driven development strategy," while the 19th Congress affirmed that "innovation is the primary driving force for development" [1]. Concurrently, China attaches great importance to the construction of regional collaborative innovation communities, using the enhancement of scientific and technological innovation capabilities in strategic regions such as Jing-Jin-Ji and the Yangtze River Economic Belt as new momentum. By forging regional collaborative innovation communities, China aims to coordinate and guide integrated regional development, propelling advantageous regions like Beijing and Shanghai to become globally influential centers for scientific and technological innovation.

The Jing-Jin-Ji region represents a key focus of national strategic planning, where collaborative innovation has become a practical pathway for rapidly enhancing innovation-driven capabilities and a concrete measure for advancing coordinated development among the three jurisdictions [2]. Since the promulgation of the "Jing-Jin-Ji Coordinated Development Plan Outline," extensive collaboration has been undertaken across multiple levels—regional, industrial, and micro-agent—with accelerating coordination. Over the past five years, Beijing, Tianjin, and Hebei have promoted the flow of innovation elements and interaction among innovation subjects through establishing branch institutions, co-building collaborative innovation platforms and parks, jointly issuing policies, and optimizing industrial and innovation layouts. These efforts have strengthened inter-city division of labor and cooperation, yielding remarkable results. However, relevant data on collaborative innovation remain scattered across online and offline sources and constantly change, making integration and utilization difficult. Therefore, employing information collection and processing technology to regularly track, collect, and categorize these fundamental data reflecting collaborative innovation status, and presenting them through appropriate visualization methods, holds significant importance for assessing the current state and predicting development trends of Jing-Jin-Ji collaborative innovation.

With continuous advances in computer technology, visualization has been increasingly applied to cartography. Geographic Information System (GIS) map visualization technology can process large volumes of spatial data, vividly displaying spatial characteristics and providing profound and unexpected spatial insights, thus gaining growing favor. Currently, map visualization is widely used in social, economic, natural, and environmental fields, though applications in science and technology remain limited and exploratory. Researchers such as Geng Xiaobo [3], Hu Haiying [4], and Li Mei [5] have conducted studies on map visualization of scientific and technological resources, while Fan Chuanhao [6] constructed a dynamic evaluation and visualization analysis model for urban collaborative innovation levels, presenting results through map visualization from static and dynamic perspectives. In practice, platforms like the Jing-Jin-Ji Science and Technology Resources Digital Map Platform, Zhejiang Science and Technology Innovation Cloud Service Platform, Shanghai Industrial Map, Dongguan Innovation Map, Ningbo Innovation Cloud Service Platform, and Gansu Scientific and Technological Innovation Capability Digital Map display the spatial distribution of innovation subjects, carriers, and service resources through mapping. However, no specialized map system for regional collaborative innovation has been reported. Building upon theoretical research on regional collaborative innovation and integrating Jing-Jin-Ji collaborative innovation measures, approaches, and implementation paths, this study employs Internet information collection and processing technology and GIS to develop the Jing-Jin-Ji Collaborative Innovation Development Map System, providing information and intelligence support for decision-makers and researchers to timely grasp collaborative innovation trends, formulate relevant policies, and conduct evaluation research.

2 Design Basis and Framework Concepts

The Jing-Jin-Ji Collaborative Innovation Development Map System represents an application of map visualization technology in the collaborative innovation domain, whose overall design should follow relevant research and practical achievements. From a research perspective, after German physicist Hermann Haken first proposed the "synergy" concept in the 1970s, synergy theory gradually intersected and integrated with innovation theory and regional innovation systems, guiding and leading regional collaborative innovation practices. International research on collaborative innovation started earlier, focusing primarily on micro-level (enterprise) empirical studies to reveal its connotation, motivations, elements, and models. Domestic research concentrates on definitions and connotations, mechanisms, collaborative innovation networks, models, and efficiency evaluation. Existing studies indicate that the collaborative game process among differentiated agents constitutes the essence of regional collaborative innovation, with the flow of innovation elements and the agglomeration and diffusion of knowledge and innovation being key factors [7]. Gong Yi et al. [8] constructed a four-level system for urban agglomeration collaborative innovation from two dimensions ("local space" and "flow space") and two levels ("industry" and "innovation"), comprising the environment layer, resource and element layer, industrial division/linkage layer, and collaborative innovation network layer, where the "flow space" characteristic manifests as the flow of various innovation elements within the urban agglomeration. Gao Jianxin [9] argued that regional collaborative innovation is constrained by key macro-environmental factors such as innovation policies and regional economic development levels. Based on existing research and the spatial agglomeration characteristics of innovation, we contend that innovation resource element coordination, innovation subject and carrier coordination, industrial innovation space coordination, and innovation policy coordination can effectively indicate the developmental status of a region's collaborative innovation level.

From a practical perspective, Jing-Jin-Ji currently employs several measures to promote regional collaborative innovation: (1) Governments optimize the innovation environment through strategic goal layout and policy alignment, integrate key industrial functional zones and node regions, and construct the overall regional innovation system architecture; (2) Under government guidance and support, markets promote regional industrial collaborative innovation and innovation resource sharing through industrial technology alliances, collaborative innovation platforms, and Internet-based virtual R&D organizations; (3) Enterprises, universities, and other subjects accelerate innovation achievement transformation through project or outcome cooperation and establishment of branch institutions or subordinate colleges. Based on these research and practical achievements, the Jing-Jin-Ji Collaborative Innovation Development Map System designs its content framework from five dimensions: resource element coordination, subject coordination, industry coordination, layout coordination, and policy coordination, systematically displaying the status and effectiveness of Jing-Jin-Ji collaborative innovation development in recent years and providing fundamental support for scientifically evaluating its collaborative innovation level and efficiency.

3 Overall System Framework Design

3.1 Technical Framework

The map system adopts a Service-Oriented Architecture (SOA) and .NET system design concept, utilizing Web Services to achieve integration in a loosely coupled heterogeneous environment. Through geographic information service standards and specifications, unified management is realized, facilitating geographic information data invocation and extension, and enabling business integration and interoperability in wide-area network environments (such as the Internet). The map system comprises four layers: infrastructure, data, system service, and application. The infrastructure layer manages and supports various system nodes through a server management platform. The data layer stores and processes basic spatial data, scientific and technological institution data, innovation policy data, park spatial data, industrial data, interaction data, and key area data using relational databases. Simultaneously, it establishes standardized database structures to enable interconnection among different sub-databases. The system service layer performs data management, map visualization display, and management services based on Web middleware, SuperMap iServer, iObjects, iDesktop, and other software, integrating functions and unified data sharing through a unified platform. The application layer conducts applications around five core content modules—resource element coordination, subject coordination, industry coordination, layout coordination, and policy coordination—providing intelligence support for government decision-making. The specific technical framework is shown in Figure 1 [Figure 1: see original paper].

3.2 Database and System Function Design

The database constitutes the foundation and crucial support of the entire system, enabling storage and utilization of Jing-Jin-Ji collaborative innovation data and providing basic data flows and storage for operation results for scientific decision-making and services. Based on understanding of collaborative innovation connotations and government decision-making needs, and considering spatial visualization expression, Jing-Jin-Ji collaborative innovation data are categorized into: innovation resource element data, subject interaction data, industrial data, key area data, and jointly issued policy data. Data collection methods include self-collection and purchase, with data sources comprising government official websites, various statistical yearbooks, news reports, and survey data. According to collaborative innovation data structures, database tables and structures, field designs, and standards are formulated.

From a system composition perspective, the system comprises a data management subsystem, map visualization display subsystem, and operation and maintenance subsystem, integrating support for five core content modules. The specific structure is shown in Figure 2 [Figure 2: see original paper].

3.2.1 Resource Element Coordination The endowment of innovation resources such as human, financial, material, and information resources forms the foundation of regional collaborative innovation. Understanding regional resource endowments holds significant importance for the formation and development of regional collaborative innovation. The map system achieves positioning of innovation subjects including enterprises (national high-tech enterprises, Zhongguancun high-tech enterprises, unicorn enterprises, etc.), universities, and research institutes through address matching technology. Through database association, it integrates relevant talents, achievements, projects, and infrastructure resources using institutions as carriers, and presents them through visualization methods such as point distribution maps, heat maps, and statistical charts. This enables the display of spatial distribution and regional statistics of Jing-Jin-Ji innovation resource elements, providing a fundamental basis for intuitively showing resource distribution dynamics, identifying existing problems, and evaluating current status.

3.2.2 Subject Coordination Subject coordination constitutes the core content of the map system, comprising branch institutions (Zhongguancun enterprises, universities, etc.), collaborative innovation platforms (including co-built R&D institutions, co-built laboratories, co-built alliances, co-built parks), project and outcome cooperation, and technology transfer and technology markets. The map system tracks and obtains relevant information through Internet collection technology, comprehensively employing thematic map methods such as relationship diagrams, graded symbol maps, segmented color maps, composite statistical maps, and heat maps to visualize Jing-Jin-Ji collaborative innovation status. This enables comprehensive and intuitive understanding of collaborative innovation effectiveness and development trends, providing scientific foundations for revealing stage characteristics and problems and evaluating Jing-Jin-Ji collaborative innovation efficiency.

3.2.3 Industry Coordination Industry coordination focuses on key development industries such as artificial intelligence, next-generation information technology, energy conservation and environmental protection, and new materials. Aiming at map visualization of industrial resources and basic information, it integrates information on institutions, talents, and achievements in relevant industrial fields for users, enabling them to quickly locate relevant industrial and technological resources and facilitating examination of technology frontiers.

3.2.4 Layout Coordination Innovation resource spatial layout represents the concrete spatial manifestation of Beijing's and Jing-Jin-Ji's industrial functional positioning and constitutes an important foundation for optimizing innovation resource allocation and achieving high-quality development. Therefore, the layout coordination module covers the "Three Cities and One District" including Zhongguancun Science City, Huairou Science City, Future Science City, and Beijing Economic-Technological Development Area, as well as the Jing-Jin-

Ji "2+4+46" industrial cooperation platform and Jing-Jin-Ji industrial development axes and other important functional zones and key nodes. It integrates and displays their basic information on maps for analysis, enabling spatial attribute queries and facilitating users to quickly locate and browse basic information on target areas.

3.2.5 Policy Coordination Policy coordination represents the key to current Jing-Jin-Ji collaborative development. In recent years, national and local governments have intensively issued relevant policy measures across various fields, achieving phased results in Jing-Jin-Ji policy integration. The policy coordination module organizes and analyzes jointly issued policy information across various fields, providing users with query, classification statistics, and publishing institution association display functions for convenient policy review.

4 Application Case Analysis

Based on the Jing-Jin-Ji Collaborative Innovation Development Map System, this section selects the three content modules of resource element coordination, subject coordination, and layout coordination for case analysis, demonstrating that the system can analyze the current status of Jing-Jin-Ji innovation resource stock and spatial distribution, subject correlations, and provide intelligence support for scientific decision-making.

4.1 Innovation Resource Stock and Spatial Distribution Analysis

Regional innovation element allocation efficiency depends on its own factor endowments and combination patterns. Innovation resource endowments constitute the factor foundation for regional innovation activities and represent one factor affecting regional innovation performance. Their spatial distribution heterogeneity manifests as the stock characteristics of innovation resources in specific regions during certain periods and the dynamic evolution process of interregional factor allocation optimization and integration [7], with spatial layout being an important factor affecting innovation resource spatiotemporal allocation [10]. Research indicates that cooperation among innovation subjects is influenced by spatial distance, with closer subjects more likely to form cooperative and interactive relationships [11]. Therefore, clarifying the stock and gaps of innovation resources among Beijing, Tianjin, and Hebei and analyzing spatial distribution characteristics and problems facilitates assessing innovation resource distribution patterns and helps science and technology managers and researchers grasp innovation development trends from a regional perspective. The map system yields several conclusions:

(1) The Jing-Jin-Ji region possesses abundant innovation resource stock. Beijing and Tianjin exhibit high spatial agglomeration of innovation resources, highlighting regional distribution imbalances. Based on data released by the Ministry of Education, Ministry of Science and Tech-

nology, and other government official websites, statistics show that by 2018, the Jing-Jin-Ji region had over 300 higher education institutions, more than 2,000 research institutes, 35,000 national high-tech enterprises, over 600,000 technology-based enterprises, and 84 national technology business incubators with a total valuation of $337.8 billion. Specifically, Beijing's innovation resources concentrate in the southeast of Haidian District and adjacent areas such as Xicheng, Dongcheng, and Chaoyang Districts. Tianjin's resources concentrate in urban areas and Binhai New Area, while Hebei's resources concentrate in Shijiazhuang's urban area. Thus, integrating the three regions' innovation resources and addressing resource imbalance constitutes the key to Jing-Jin-Ji collaborative innovation.

(2) Jing-Jin-Ji innovation resources are in a stage of rapid evolution from point agglomeration to block agglomeration. Taking national high-tech enterprises as an example, analysis of micro-agent spatial distribution reveals that under the combined effects of agglomeration and selection effects, these enterprises exhibit distinct spatial distribution characteristics of "large agglomeration, small dispersion," as shown in Figure 3 [Figure 3: see original paper]. Enterprise resources form large agglomerations centered on Beijing and Tianjin, with multiple dispersed points in Hebei's central cities, while also showing certain randomness.

4.2 Innovation Subject Correlation Analysis

Regional collaborative innovation requires factor flow and inter-subject interaction, with interaction among innovation subjects being the primary driving force for regional collaborative innovation. Tracking and monitoring interaction data among innovation subjects represents an important indicator reflecting Jing-Jin-Ji regional collaborative innovation status. The "Subject Coordination" module excavates and presents spatial connections, interaction status, radiation scope, and detailed information through map visualization means, revealing collaborative relationships among subjects. Analysis yields the following conclusions:

(1) Zhongguancun serves as an explorer and leader in accelerating Jing-Jin-Ji collaborative innovation. In recent years, Zhongguancun has gradually accelerated its cross-regional layout through establishing production bases, cross-regional mergers and acquisitions, and co-building parks, achieving coordination of innovation resources and industrial docking and comparative advantages among the three regions, and exploring new pathways for implementing innovation-driven strategies and transforming development modes. Analysis of Zhongguancun branch institution establishment over the past five years shows that by 2019, the total number of Zhongguancun enterprises establishing branch institutions in Tianjin and Hebei reached 8,065, an increase of 6,533 compared with 2014 [12], representing an average annual growth rate of approximately 40%. Specifically, 3,746 were in Tianjin and 4,319 in Hebei. Additionally, Zhongguancun has strengthened

its radiating role by supporting the establishment of branch institutions for innovative incubators and accelerators in Tianjin and Hebei to provide entrepreneurial incubation services, accelerating the transformation and application of Beijing's innovation achievements in Tianjin and Hebei.

(2) Accelerating co-construction of parks and alliances promotes factor agglomeration and industrial collaborative development. By March 2018, Beijing and Tianjin had co-built 55 science and technology parks and 65 innovation bases with Hebei [13]. Currently, cross-Jing-Jin-Ji park chain construction has achieved remarkable results, with Zhongguancun having co-built over 20 parks in the Jing-Jin-Ji region, radiating to most cities including Xiong'an New Area, Tianjin, Qinhuangdao, Baoding, Shijiazhuang, and Langfang, forming a regional innovation network with co-built parks as carriers and providing a solid foundation for innovation element flow and agglomeration and industrial cluster development, as shown in Figure 4 [Figure 4: see original paper].

(3) Co-built institutions and platforms have become breakthrough points for promoting inter-subject collaborative innovation. Investigations show that most co-built institutions and platforms involve local government participation, resulting in high implementation efficiency. From the perspective of spatial connections of these R&D institutions, Beijing has established connections with central cities such as Tianjin and Shijiazhuang and node cities such as Handan, Tangshan, Baoding, Qinhuangdao, and Langfang, particularly maintaining close institutional cooperation with Tianjin and forming a co-built R&D institution core area along the Beijing-Tianjin line. Cooperation fields primarily include agriculture, advanced manufacturing, cultural innovation, environmental protection, and multiple other domains.

(4) Accelerated cross-regional flow of innovation elements brings new momentum to Jing-Jin-Ji collaborative innovation. Over the past six years, Beijing's technology contract transaction volume flowing to Tianjin and Hebei has reached 106.3 billion yuan, with an average annual growth rate exceeding 30%, demonstrating remarkable Jing-Jin-Ji coordinated development achievements. From 2014 to 2018, the number of joint patent applications among the three regions remained at approximately 4,000 annually, with granted patents maintained at around 3,000, indicating obvious joint innovation momentum [14]. In terms of cooperation fields in 2016, the three regions collaborated in culture and sports, optics, electronic information, chemistry, materials, aerospace, construction, electric power, energy conservation, environmental protection, and other fields. However, part of this cooperation involved Beijing's branch or subsidiary companies in Tianjin and Hebei, suggesting that cross-regional technology cooperation intensity needs improvement and cooperation models require exploration. Additionally, analysis of Jing-Jin-Ji gallium nitride technology patent cooperation from 2014-2018 shows that Beijing's R&D institutions cooperate

relatively little with Tianjin and Hebei but more with the Yangtze River Delta and Pearl River Delta, indicating that deep cooperation in intellectual property rights for new technologies such as gallium nitride among the three regions needs strengthening.

Overall, driven by national strategy, collaboration among innovation subjects and local governments has become increasingly strengthened and close, with multiple coordination methods coexisting and achieving remarkable results. However, the region remains in a point-to-point stage, with internal demands and cohesive forces among different regions and subjects requiring further enhancement, and relevant mechanisms needing improvement.

4.3 Innovation Spatial Layout Information Integration Application

In regional planning, static planning maps are typically used to display development spatial layouts, but these suffer significant limitations and convey limited information. Electronic maps can carry richer information content and have broader application scope, using visual digital maps as backgrounds and employing multiple media such as text, images, charts, and animations to display comprehensive regional features. The "Layout Coordination" module integrates and centrally displays relevant information for each important region and node in Jing-Jin-Ji innovation spatial layout based on multi-source data fusion of location and attribute characteristics, greatly facilitating decision-makers and researchers in systematically understanding current status, conducting comparative analysis, and identifying problems. Comparative analysis of important regions and nodes in Jing-Jin-Ji innovation spatial layout yields the following conclusions:

(1) Innovation resource distribution in the "Three Cities and One District" is unbalanced with varying development foundations. Haidian District is the most concentrated, with high-tech enterprises, universities, research institutes, and innovation platforms accounting for nearly half of the city's total, while Huairou, Changping, and the Economic-Technological Development Area account for less than 10%, indicating insufficient innovation element cohesion. Both among the "Three Cities and One District" and within Zhongguancun's one district and sixteen parks, functional divisions show some homogenization, with overlaps in certain scientific fields, projects, and industries.

(2) Regarding development directions of Jing-Jin-Ji's 46 industrial undertaking platforms, many parks exhibit overlapping industrial orientations. For instance, most parks include advanced manufacturing in their industrial orientations, leading to homogenized competition. Further overall planning is needed to improve top-level design, achieve differentiated development, and realize complementary advantages.

(3) Analysis of resource distribution and development status along Jing-Jin-Ji industrial development belts reveals that, on one hand, various enterprises

and park resources have agglomerated around the three industrial development belts. However, from the overall enterprise distribution perspective, randomness remains strong and coupling with regional development is insufficient. Although Beijing and Tianjin have formed large agglomerations, cross-spatial knowledge spillover and radiation driving capabilities need improvement, and the entire Jing-Jin-Ji region has not yet formed a network agglomeration. On the other hand, beyond node cities along the three industrial development axes, most towns and townships have low economic development levels, weak innovation resource foundations, and mixed leading industries, which is not conducive to forming industrial development belts with strong competitiveness and cohesion. Integrated development faces difficulties, requiring urgent clarification of these areas' conditions, formulation of detailed industrial development plans, and targeted and feasible policy measures to address "bottleneck" issues in actual implementation.

5 Conclusion

Practice demonstrates that since enterprises, research institutions, and other innovation activity subjects possess spatial attributes, they provide an excellent convergence point for integrating innovation elements with map elements and GIS. Displaying the spatial distribution status and characteristics of Jing-Jin-Ji innovation resources, the phased effectiveness and problems of collaborative innovation, and correlation relationships among subjects through map visualization provides robust support for studying regional collaborative innovation phenomena from a spatial perspective. The Jing-Jin-Ji Collaborative Innovation Development Map System interprets and centrally displays the collaborative innovation development status of the region from multiple dimensions—resource element coordination, micro-agent coordination, industrial coordination, layout coordination, and policy coordination—providing fundamental data for obtaining key indicators for regional collaborative innovation evaluation and offering scientific foundations for formulating and improving relevant policies.

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Author Contributions

Li Mei: Conceived the research idea, designed the study framework, and wrote the paper.

Zhang Hong: Participated in framework design and data collection.
Sun Yanyan: Participated in framework design and data collection.
Miao Runlian: Project leader, participated in framework design.

Note: Figure translations are in progress. See original paper for figures.