

Emerging Technology Identification and Evolutionary Path Analysis in Industry Based on SCAN-CPM: A Case Study of the New Energy Vehicle Industry Postprint

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Abstract

[Purpose/Significance] Industrial emerging technologies can create or alter the economic structure and development direction of traditional industries; timely and accurate identification of industrial emerging technologies and clarification of appropriate development directions hold important strategic guiding significance for industrial development and transformation. [Method/Process] Based on patent IPC classification information, we construct an IPC node network, use the structural clustering algorithm for networks (SCAN) to identify industrial clusters and emerging technologies, and conduct detailed analysis; then, based on the temporal data of patents in the five identified emerging technology fields, we construct a patent node network, and employ critical path method (CPM) to analyze critical paths under different emerging technology fields, making the identification results more granular and refined. Finally, taking the new energy vehicle industry as an example, we obtain patent information from the INCO-PAT patent database for empirical analysis. [Results/Conclusion] SCAN-CPM-based analysis serves as a beneficial supplement to traditional emerging technology identification methods, demonstrating technology evolution paths from macro to micro and from coarse-grained to fine-grained, providing new perspectives and technical means for comprehensively identifying emerging technologies and detecting technology evolution paths. Empirical analysis results reveal: the internal design and external layout of new energy vehicle charging piles remain top priorities for the industry's development; thermal management technology is increasingly becoming a relatively independent technical field, serving as important technical support for the new energy vehicle industry to achieve "corner overtaking", with clear evolution and diffusion paths; technical issues such as battery pack environment, motor heat dissipation, battery liquid cooling technology, and heat exchanger materials represent important breakthrough

innovation points for the future; the motor drive control system has currently formed relatively high patent barriers.

Full Text

Preamble

Industry Emerging Technology Identification and Evolution Path Analysis Based on SCAN-CPM: A Case Study of the New Energy Vehicle Industry

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Abstract: *[Purpose/Significance]* Industrial emerging technologies can create or transform the economic structure and development direction of traditional industries. Timely and accurate identification of industrial emerging technologies and clarification of appropriate development directions hold important strategic guiding significance for industrial development and transformation. *[Method/Process]* Based on patent IPC classification information, this study constructed an IPC node network and used the structural clustering algorithm for networks (SCAN) to identify industrial clusters and emerging technologies for detailed analysis. Then, using time-series data from patents in the five identified emerging technology fields, a patent node network was constructed and critical path method (CPM) analysis was employed to analyze critical paths under different emerging technology domains, making the identification results more microscopic and refined. Finally, taking the new energy vehicle industry as an example, patent information was obtained from the INCOPAT patent database for empirical analysis. *[Result/Conclusion]* SCAN-CPM-based analysis serves as a useful supplement to traditional emerging technology identification methods, displaying technology evolution paths from broad to specific and from coarse to fine, providing a new perspective and technical means for comprehensively identifying emerging technologies and detecting technology evolution paths. Empirical analysis reveals that the internal design and external layout of new energy vehicle charging piles remain top priorities for industrial development. Thermal management technology has increasingly become a relatively independent technical field and represents important technical support for the new energy vehicle industry to achieve “curve overtaking,” with a clear evolution and diffusion path. Technical issues such as battery pack environment, motor heat dissipation, battery liquid cooling technology, and heat exchanger materials are important future breakthrough innovation points. The motor drive control system has currently formed relatively high patent barriers.

Keywords: emerging technology; technology identification; SCAN algorithm; CPM analysis; new energy vehicle industry

1. Introduction

Emerging technologies are the important foundation for industrial development and transformation, leading future innovation content and paths in industries. Only by identifying and breaking through pain points in industrial emerging technologies can we truly recognize future industrial development directions. The national “14th Five-Year Plan” emphasizes that strategic emerging industries represent the direction of industrial development and technological transformation. They represent deep integration between emerging technologies and emerging industries, constitute major measures for improving the national innovation system, and hold important practical significance for identifying industrial emerging technologies, deeply analyzing their evolution paths, and timely reorganizing, integrating, and building new industrial core capabilities according to domestic and international industrial environments to layout future industrial development in advance and further promote strategic emerging industries to empower socio-economic development.

Emerging technology is defined as science-based innovation that may create a new industry or transform an old one. D. Rotolo et al. summarize that emerging technologies in the new era are innovative technologies that rapidly develop and grow simultaneously as short-term clustered resources formed in the knowledge production process. Industrial emerging technologies possess characteristics of novelty, uncertainty, rapid growth, community nature, and creative destruction, while also tending toward technology evolution based on industrial clusters. Technology identification is the process of obtaining basic data and related characteristics of industrial technologies, then using models and algorithms to further identify emerging technologies among numerous technology sets. Based on actual industrial development, technology trajectories exhibit stronger forward continuity and biased lock-in characteristics, making the development patterns of industrial emerging technologies traceable. Through comprehensive analysis of emerging technology evolution trajectories, we can further 梳理梳理 (clarify) both incremental and breakthrough innovations in technical performance. With social development and progress, numerous emerging technologies continue to emerge, but few can deliver substantial value in industrial fields and related markets. Therefore, seizing opportunities in emerging technology development, identifying technologies with development prospects, and developing these technologies based on deep understanding can help rapidly occupy commanding heights in international industrial fields and provide decision-making support for national industrial forward-looking development.

Current research on industrial emerging technology identification and evolution analysis mainly focuses on macro and meso-level control, lacking micro and refined research that cannot explain the entire process of “industrial emerging technology identification - technology critical path analysis” in fine granularity. This process can identify which patents among numerous ones represent emerg-

ing technologies and finely parse how emerging technologies develop and their critical evolution paths, providing strategic support for industrial technology identification and development. Therefore, based on identified industrial emerging technologies and fully considering the evolution process of industrial technologies, this study employs the SCAN algorithm to identify industrial emerging technologies and uses the CPM algorithm to analyze critical evolution paths of industrial emerging technologies. This approach displays technology development contexts from broad to specific and from coarse to fine, fully understanding technology development trajectories and directions. This helps achieve deep integration of basic research, technological experimental development, and industrial innovation, accelerates breakthroughs in key and core technologies, and provides important auxiliary decision-making basis for scientific and technological innovation and management.

2. Literature Review

With the transformative development of computer data and industrial technology paradigms, the identification and prediction processes for emerging technologies have become increasingly diversified and deep-level, often combined with bibliometrics, text mining, and machine learning methods. Compared with early subjective identification methods mainly based on expert judgment such as prospective analysis and brainstorming, the integrated application of methods further broadens the conceptual boundaries of emerging technology identification and prediction. Bibliometrics-based emerging technology identification uses quantitative indicator systems of past or current technology characteristics to achieve determination and prediction, often employing direct citation networks, co-occurrence and coupling networks of scientific papers or related patents for cluster analysis. It evaluates prediction effects based on cluster density and similarity, and further reveals emerging technology evolution through social network analysis methods by calculating degree centrality, betweenness centrality, and other indicators. The subject-action-object (SAO) structure extraction method based on structural semantic analysis also combines with social network analysis to construct subject-action-object structures in SAO networks that reflect technical characteristics. Text mining-based emerging technology identification mainly analyzes through machine learning algorithms, which can be divided into unsupervised learning and supervised learning. Typical examples include LDA topic models for technology topic division and link prediction combined with neural networks. For tracking technology evolution paths, common methods include technology roadmaps that combine technology resources, human resources, environmental resources, and business planning with temporal changes to display future development trends graphically. Technology roadmap methods emphasize the development process from product to market, reflecting the development process of the same dimension over time. They represent views on the future extension of a certain technology field and focus more on

technology forecasting, being widely applied in technology foresight.

However, the above methods also have relative limitations. Prospective analysis and brainstorming and other subjective identification methods depend heavily on technology experts and are easily influenced by expert subjectivity. Emerging technology identification combined with bibliometrics identifies emerging technologies based on cluster networks but is limited in technology evolution analysis and cannot deeply explain interpretable critical paths of emerging technologies. Identification methods combined with machine learning algorithms focus more on processing and classifying technology topic content rather than truly “identifying” the “newness” and “emergence” of technologies. Overall, current emerging technology identification and technology evolution analysis cannot achieve coherent and effective comprehensive analysis, lacking refined and comprehensive research from emerging technology identification to emerging technology evolution. They either focus on cluster network-based technology identification or technology roadmap-based technology tracking evolution analysis, rarely combining the two. Therefore, this study optimizes existing emerging technology identification methods based on integrated application: first, fully leveraging the advantages of cluster analysis algorithms to quickly and accurately identify emerging technologies in complex patent networks; second, based on identified emerging technologies, reconstructing emerging technology patent node networks to identify critical paths of technology evolution, finely explaining technology accumulation and accurately identifying main directions of emerging technology development trajectories, empowering technological innovation development in industrial fields and achieving two-way 奔赴奔赴 (integration) between academic exploration and practical social development.

3. Research Design and Methods

3.1 Research Framework

Based on literature review and related data queries, this study summarized patent search formulas and used relevant patent data from the INCOPAT patent database to constitute the research sample. Using new energy vehicle-related patent data as the foundation, IPC classification co-occurrence information was extracted from patent data. Vertices were determined based on correlations between IPC classifications, and edges were determined based on similarity between vertices to construct an IPC node network. Community discovery algorithm—the structural clustering algorithm for networks—was used for analysis to further identify emerging technologies in the new energy vehicle industry domain. According to bridge nodes identified in the IPC node network, all corresponding patents were extracted. Based on patent time-series information, a patent node network was constructed, and CPM algorithm was used to realize critical path analysis of industrial technology patents, further deeply mining development contexts and evolution paths of industrial emerging technologies.

The research framework is shown in [Figure 1: see original paper].

3.2 Research Methods

This study combines the network structural clustering algorithm with critical path analysis. The SCAN algorithm can identify potential cluster relationships in large complex networks and identify emerging technology fields with development potential within industrial domains. Based on this, CPM analysis further finely analyzes critical development paths of emerging technologies, making identification results more microscopic and refined.

3.2.1 SCAN Algorithm The network structural clustering algorithm is a new type of graph structural clustering algorithm that measures network structural similarity to cluster network vertices, further exploring hidden network underlying structures, mining clusters, outliers, and bridge nodes in network structures to achieve key node and potential node mining. The SCAN algorithm uses vertex neighborhoods in network structures as clustering criteria, grouping vertices into different clusters according to common neighborhoods, using network vertex structures and connectivity as clustering criteria to achieve division of clusters, outliers, and bridge nodes. Bridge nodes are narrowly defined as isolated vertices bridging different clusters and are key points for knowledge dissemination in complex networks. Outliers refer to isolated vertices connected to at most one cluster and can accurately reflect the latent state of emerging technologies, thus also possessing certain research value. The SCAN algorithm can not only accurately identify bridge nodes and outliers but also only traverses each vertex in the network once to find structural connection clusters, thus possessing advantages of high speed and accuracy.

3.2.2 CPM Analysis Critical path analysis method is based on time-series data of patents in industrial fields. By calculating the total number of paths between initial vertices and latest vertices in complex networks, it further analyzes the main direction of technology development trajectories throughout the entire time period involved. Critical path analysis algorithms can map all possible technology development trajectory flows and finally select the most important development path and direction. Therefore, technology development paths identified through CPM algorithms have high technology accumulation. The CPM algorithm is developed based on search path count (SPC), which calculates edge traversal weights according to main path analysis. Traversal weights can accurately reflect the importance of paths connecting entry vertices to end vertices in complex networks. The CPM algorithm can accurately identify main directions of emerging technology development trajectories, focusing on expressing technology accumulation and evolution, and is suitable for analyzing important technology evolution within recent time ranges.

3.2.3 Comprehensive Advantages of SCAN-CPM Method Application Identification and evolution path analysis of industrial emerging technologies

require identification of key information such as technology emergence time, innovativeness, breakthrough nature, and technology accumulation. Therefore, it requires not only certain scope selection of relevant data but also fine-grained detailed division of technology development trajectories and directions. This study introduces a multi-method perspective at the methodological integration level, selecting network structural clustering algorithm and critical path analysis method to identify industrial emerging technologies and further analyze their evolution paths.

The advantage of the SCAN algorithm lies in its ability to quickly identify bridge nodes and outliers in large network structures. Different from other clustering algorithms that use directly connected vertices as basis, the SCAN algorithm uses vertex neighborhoods as clustering criteria, better conforming to the continuity of patent technology development processes. The advantage of CPM analysis lies in its full integration with the SCAN algorithm, seeing the big picture from small details. Based on SCAN algorithm identification results, it reconstructs patent node networks to finely interpret critical development trajectories and directions of emerging technologies among numerous patent evolution paths, improving the defect of insufficient interpretability of SCAN algorithm results and more microscopically and finely explaining target directions of emerging technology development. Therefore, combining SCAN algorithm with CPM analysis can comprehensively and finely divide industrial clusters from broad to specific and from coarse to fine, identify industrial emerging technologies, analyze technology development contexts within relevant industrial fields, and provide new perspectives and technical means for industrial emerging technology identification and evolution path analysis. SCAN-CPM-based industrial emerging technology identification and evolution path analysis is shown in [Figure 2: see original paper].

4. Empirical Analysis: Case Study of the New Energy Vehicle Industry

Typical selection of industrial emerging technologies is an important content of this study. As an important pillar of the national strengthening strategy, the new energy vehicle industry is explicitly listed in the “Strategic Emerging Industries Key Products and Services Guidance Catalog” (2016 edition). It is a key pathway to ensure future economic growth breakthroughs and energy transformation and an important fortress for national security. As the new energy vehicle industry fully enters the stage of “competing on internal strength,” comprehensively and accurately mastering primary emerging technologies and their development trajectories can achieve balanced effects on technological innovation breakthroughs in the new energy vehicle industry.

4.1 Data Source and Processing

This study used the INCOPAT patent information database as the basic data source, constructing the search formula: TIAB=(((“汽车”AND“新能源”) OR “新能源汽车” OR ((automobile) AND (new energy)) OR (new energy automobile) OR (new energy vehicles OR NEVs OR (green energy) OR (clean energy)))). Since 2018, the State Council and Ministry of Industry and Information Technology have introduced multiple new energy vehicle policies to promote further development of the new energy vehicle industry. Considering that relevant patents have certain timeliness, this study mainly focuses on the phased evolution of this industry, thus determining the search time period as 2018-2021, with search conducted in July 2021. Since foreign patents in the INCOPAT database are not fully open, the analysis part mainly focuses on further evolution analysis of the domestic new energy vehicle industry. This search obtained 10,085 patents, and after identifying and removing irrelevant and interfering patents, the final number of patents was determined to be 9,979.

4.2 Patent IPC Classification Information Extraction

Patents with multiple IPC classification numbers indicate involvement in multiple technology fields. Therefore, this study used Python to extract IPC classification information from the patent dataset and further read IPC data, saving it as a txt format dataset to lay the data foundation for subsequent SCAN algorithm analysis.

The SCAN algorithm is an unsupervised learning algorithm based on graph clustering, using graph structures to cluster patent data. IPC classification numbers in patent datasets distinguish technology field ranges and corresponding characteristics through different digits. Vertices in the network graph structure G represent IPC classification numbers of patents; edges between vertices represent correlations between patents. The correlation between vertices is calculated using formula (1):

$$r(w \rightarrow v) = \frac{|(F(v) \cap F(w))|}{|(F(v))|}$$

In formula (1), $r(w \rightarrow v)$ represents the connection degree of vertex w to vertex v , i.e., the relevance of vertex w to vertex v . $F(v)$ represents the patent set corresponding to IPC classification number v , $F(w)$ represents the patent set corresponding to IPC classification number w , and $|*|$ represents the number of patents in the set. Vertex relevance values are shown in .

The similarity between vertices, i.e., edge weights, is determined based on the similarity degree between two or more vertices or clusters. Vertex similarity represents the degree to which a vertex and its adjacent vertices share common neighbors within the same cluster. Vertex similarity is calculated using formula (2):

$$\frac{|\varphi(v) \cap \varphi(w)|}{|\varphi(v)| |\varphi(w)|}$$

This considers the characteristics of vertices' neighbor vertices, always taking into account common neighbors of vertices during iteration, making cluster division more closely connected with patent directions. In formula (2), $\varphi(x)$ represents the set composed of vertex x and its adjacent vertices. Based on context, parameter σ was adjusted to 0.5. The top 50 vertices with highest frequency were selected, associated with 1,547 IPC classification information pieces. The total number of IPC classification information pieces involved in this study was 4,721, thus the top 50 vertices accounted for 32.8% of IPC classification information, approaching one-third and demonstrating 合理性合理性 (reasonableness). The set of edges between vertices was also traversed and stored. Based on context, the neighbor number was adjusted to 3, finally generating network graph structure G.

Vertex similarity in network graph structure G was calculated by finding common neighbor vertices, i.e., shared neighborhoods. The calculation result was expressed as the ratio of the number of common neighbors of two vertices to the geometric mean of the neighbor numbers of the two vertices. The results were sorted in descending order by similarity value, with top 20 vertex similarity values shown in . Similarity values were rounded to 3 decimal places, and frequency of vertex similarity values was counted (see [Figure 3: see original paper]), showing that similarity values are relatively concentrated in the range [0.3, 0.8]. Further numerical analysis of network vertex similarity showed an average similarity value of 0.564, median of 0.577, mode of 0.577, variance of 0.021, and standard deviation of 0.144.

4.3 SCAN Analysis

The SCAN algorithm was applied to identify emerging technologies in the new energy vehicle industry domain, with results shown in [Figure 4: see original paper]. In the figure, vertices circled by rectangles are in bridge node positions, connecting to multiple clusters within several degrees of range, i.e., having certain influence in multiple technology field scopes, conforming to the community characteristics of emerging technologies. Meanwhile, emerging technologies possess certain novelty, thus having fewer neighbor vertices and being associated with multiple technology clusters, indirectly reflecting the critical nature of emerging technologies. Based on the above analysis, nodes circled by rectangles in [Figure 4: see original paper] represent emerging technologies in the new energy vehicle industry domain, which can be further deeply mined for specific content through IPC classification numbers of patents.

Different circles in [Figure 4: see original paper] represent different clusters, with numbers beside them representing cluster IDs. Clusters have relatively close connections, and emerging technologies also have associations with multiple

industrial clusters. Vertex sizes and edge densities represent relative importance of patents and cluster links. Further analysis of cluster network structures is shown in .

Average node betweenness centrality is closely related to network structure synchronization capability. Larger maximum betweenness of nodes indicates weaker network cluster synchronization capability, i.e., among the 8 clusters, cluster 1 has weaker synchronization capability. Average node degree centrality represents vertex importance in network structure. Cluster 2 has the highest average node degree centrality, indicating its important role and significance in the entire network structure. Average node closeness centrality is represented by distance—larger values indicate closer distances to other nodes and higher centrality. Cluster 2 has the highest average node closeness centrality, indicating higher internal node correlation and similarity within cluster 2, thus showing closer patent continuity.

[Figure 4: see original paper] highlights the richness and complexity of technology development in the new energy vehicle industry domain, generating different technology trajectories and development directions. Based on comprehensive analysis of emerging technology vertices and related cluster IPC classification information, emerging technology node characteristic information was further analyzed in fine granularity, as shown in , with cluster characteristic information shown in .

The first emerging technology has IPC classification F16F15/067, related to new energy vehicle charging pile fields, mainly improving safety performance of new energy vehicle charging piles through designs of sealed doors, buffer plates, buffer springs, vertical plates, inclined plates, and limit springs. The clusters linked to this emerging technology are clusters 2 and 4. Combining IPC classification information from these two clusters, emerging technology 1 is identified as related technology for internal battery component design and system structure safety of new energy vehicle charging piles.

The second emerging technology has IPC classification H02J7/00, related to new energy vehicle onboard charging systems, simplifying equipment, reducing costs, and improving battery efficiency through battery series-parallel combinations. It overcomes low-voltage battery feed issues and increases battery management system safety and system robustness through first and second microcontrollers and other battery management systems, expanding charging range, preventing aging, and improving onboard charging system practicality. It links with clusters 1, 2, and 4. Combining cluster IPC classification information, emerging technology 2 is identified as preparation technology for new energy vehicle onboard charging systems.

The third emerging technology has IPC classification A62C3/16, related to new energy vehicle battery pack protection fields. On one hand, it involves battery boxes for placing batteries and protective mechanisms outside battery boxes that have flame-retardant effects when encountering open flames. On the other hand,

it involves installation brackets for vehicle battery packs, including connection mechanisms, boxes, and cutoff knives. It protects battery boxes and improves battery pack safety. It links with clusters 2 and 4. Combining cluster IPC classification information, emerging technology 3 is identified as preparation technology for new energy vehicle battery protection devices.

The fourth emerging technology has IPC classification B60L58/27, belonging to the new energy vehicle thermal management technology field. According to switching between different states of the first and second pipelines to form heating circuits, it promotes simple pipeline layout of new energy vehicle thermal management systems with fewer components, comprehensively solving most energy distribution and utilization problems and improving comprehensive performance. It links with clusters 1, 2, and 5. Combining cluster IPC classification information, emerging technology 4 is identified as preparation technology for new energy vehicle thermal management systems.

The fifth emerging technology has IPC classification H05K7/20, related to new energy vehicle motor control systems and external protection device fields. Through systematic combination of ventilation devices outside controllers and buffer plates inside boxes, it improves heat dissipation efficiency, protects cables, and extends service life. Meanwhile, by setting water tanks, cooling water curtains, and negative pressure fans, it solves the problem of excessively high external temperatures of charging piles, cooling the main body of the device, thereby reducing external temperatures of charging piles. By setting heat dissipation devices, it solves internal overheating problems, cooling internal electronic components and equipment. By setting pulleys, slide rails, bolts, bolt holes, limit blocks, and anti-collision plates, it solves the anti-collision problem of charging piles. It links with clusters 2 and 4. Combining cluster IPC classification information, emerging technology 5 is identified as preparation technology for new energy vehicle motor unit devices.

4.4 CPM Analysis

Based on SCAN algorithm identification results of emerging technologies, patent data information under technology fields F16F15/067, H02J7/00, A62C3/16, B60L58/27, and H05K7/20 was further extracted. Based on patent time-series data, CPM analysis was conducted to finally obtain critical paths of emerging technologies in the new energy vehicle industry domain. Specific analysis is as follows:

(1) Technology Field F16F15/067. CPM analysis results for technology field F16F15/067 are shown in [Figure 5: see original paper]. This critical path contains 12 nodes, extending upward along the vertical axis, clearly displaying the main path of technology development over time. Further mining of CPM patent content shows this path involves the energy supplementation field, specifically the safety issue of internal components of new energy vehicle charging piles. With technology development, various technologies and components have been

gradually applied to new energy vehicle charging piles. The path terminal result is patent CN213534483U, involving a movable new energy vehicle charging pile technology emphasizing connection issues between mounting plates and buffer plates.

(2) Technology Field H02J7/00. CPM analysis results for technology field H02J7/00 are shown in [Figure 6: see original paper]. This critical path contains 9 nodes, representing the performance optimization problem of new energy vehicle onboard charging systems. Through optimized battery management systems, it increases battery management system safety and improves system robustness. The latest patent in the route, CN108282006B, is a convenient onboard charging system for new energy vehicles. The winding mechanism includes power supply components, guide rails, screw rods, rotating shafts, first sliding blocks, guide rings, second sliding blocks, charging cables, transmission components, braking components, two turntables, and two telescopic ropes. Through the winding mechanism, it not only expands the charging range of the charging system but also orderly stores charging cables inside the charging system, reducing the probability of charging cable entanglement. Through the dustproof mechanism, it not only reduces the amount of dust entering USB interfaces but also reduces the probability of USB interface damage during charging system use, improving charging system practicality.

(3) Technology Field A62C3/16. CPM analysis results for technology field A62C3/16 are shown in [Figure 7: see original paper]. This critical route mainly involves new energy vehicle battery protection technology. The technology content is relatively novel, thus having fewer critical nodes—only three—including battery protection devices that prevent battery combustion through flame-retardant technology, protection technology that prevents deformation components from damaging batteries based on front and rear connection mechanisms, and structurally stable vehicle battery pack installation brackets.

(4) Technology Field B60L58/27. CPM analysis results for technology field B60L58/27 are shown in [Figure 8: see original paper]. This technology field has two critical paths, both involving new energy vehicle thermal management technology. Using CN110281735B as the path branch node, the left critical path is based on vehicle-integrated thermal management systems, integrating previously separate air conditioning systems, battery pack thermal management systems, and power cooling systems into one controller to achieve more precise vehicle control. The right critical path focuses on motor heat dissipation and its circuit control as the main research direction, connecting heat exchangers to the main branch of battery thermal management circuits and the heat exchange branch in air conditioning circuits, enabling heat exchange between air conditioning circuits and battery thermal management circuits. Whether during vehicle driving or charging, it can distribute heat within the system and achieve unified thermal management of electric drive devices, air conditioning, and battery devices.

(5) Technology Field H05K7/20. CPM analysis results for technology field

H05K7/20 are shown in [Figure 9: see original paper]. This critical path contains 13 nodes, with the main technology direction being new energy vehicle charging pile fields, including motor control systems and external protection devices. The initial technology cleverly set first and second spiral rods to optimize charging pile device convenience from a usability perspective, effectively ensuring normal charging pile operation while improving service life. With technology development, improvements were made to charging pile mobility, anti-collision and cooling, cable protection, multi-electromechanical control systems, and efficient heat dissipation. The latest patent is CN112822892A, which uses water storage tanks, submersible pumps, sliding blocks, roller sleeves, support plates, sponge rings, ball screws, second rotating rods, second rolling bearings, first rolling bearings, and first rotating rods to evenly apply water to controller shell surfaces for rapid evaporation and efficient heat dissipation, thereby improving controller service life.

Based on the latest technologies in the five emerging technology fields obtained through CPM analysis, the accuracy of results was verified through literature review and expert validation: (1) The expanded innovation technology field around new energy vehicle charging piles. According to literature and the latest national policies, new energy charging piles are an important industrial direction in the national “new infrastructure” development initiative. The state has increased support for upstream, midstream, and downstream charging pile industries and further intensified strategic layout of their technologies. Therefore, this result is suitable as one of the future technology development layout objects for domestic new energy enterprises. (2) Research on new energy vehicle onboard charging systems further reduces transportation costs and accelerates the “human-vehicle-system platform” trinity integration, representing an important intermediary force for future integration of charging technology and new energy vehicles. Currently, this technology is in a developing state, and the state encourages and supports self-innovation in domestic onboard charging system technology. Thus, onboard charging system technology aligns with national future development plans. (3) New energy vehicle battery protection devices are important technical fields ensuring new energy vehicle safety and comfort. Relevant experts point out that battery protection devices represent further refined research on charging systems and are important future research directions. (4) New energy vehicle thermal management achieves technological breakthroughs from 0 to 1 compared with traditional automotive industries, representing a track with extremely strong growth potential and important technical support for the new energy vehicle industry to achieve “curve overtaking.” Technical issues such as battery pack environment, motor heat dissipation, battery liquid cooling technology, and heat exchanger materials are important future breakthrough innovation points. (5) The motor drive control system, as the main execution structure for new energy vehicle driving and the control center of the power system, has currently formed relatively high patent barriers, but still requires further research in motor mechanical structures, material equipment, etc., to further improve power output of new energy vehicles.

5. Conclusion

From an intelligence research perspective, this study fully utilizes patent data, proposes a method for industrial emerging technology identification and evolution path analysis based on the integrated application of network structural clustering algorithm and critical path analysis method, and effectively verifies the effectiveness and feasibility of this method through empirical analysis of the new energy vehicle industry, providing important guiding significance for future development layout of related industries. This study proposes integrated application of two methods that complement each other, breaking through limitations of using single methods. It enriches research methods and theoretical mechanisms for emerging technology identification, discovers hidden emerging technologies with development potential, and deeply mines their evolution paths, providing scientific and objective effective basis for future development layout of related industries. Future research will explore two aspects in depth: first, addressing the problem of incomplete patent databases, future research will integrate multi-source data to improve emerging technology identification results; second, addressing the subdivision content of the new energy vehicle industry, future research will use machine learning, knowledge graphs, and other methods for in-depth mining and refined research, providing theoretical and methodological references for future industrial development to accurately meet technology and market demands, optimize technology resources, and layout future industrial development in advance.

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Author Contributions

Zheng Rong: Proposed research proposition, research ideas, and paper revision. Wei Mingzhu: Responsible for paper writing, revision, data analysis, and processing. Gao Zhihao: Responsible for literature collection and algorithm verification. Wang Xiaoyu: Responsible for data collection and English translation.

English Abstract

SCAN-CPM-Based Industry Emerging Technology Identification and Evolution Path Analysis: Taking the New Energy Vehicle Industry as an Example

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Abstract: *[Purpose/Significance]* Industrial emerging technologies have a major role in creating or changing the economic structure and development direction of traditional industries. It has important strategic and practical guiding significance for industrial development and reform to identify emerging industrial technologies in a timely and accurate manner and clarify appropriate development directions. *[Method/Process]* According to the patent IPC classification information, this paper built an IPC node network, used the structural clustering algorithm for networks (SCAN) to identify industrial clusters and emerging technologies, and analyzed them in detail. Then, based on the time-series data of the five identified emerging technology patents, it constructed a patent node network and used the critical path method (CPM) to realize critical path analysis under different emerging technology fields, making the recognition results more microscopic and refined. Finally, taking the new energy vehicle industry as an example, it obtained patent information from the INCOPAT patent

database for empirical analysis. *[Result/Conclusion]* Analysis based on SCAN-CPM is a useful supplement to traditional emerging technology identification methods. It displays the technology evolution path from large to small, from coarse to detailed, and provides a new perspective and technical means for comprehensively identifying emerging technologies and detecting technology evolution paths. The empirical analysis finds that: the internal design and external layout of new energy vehicle charging piles are still the top priority for the development of the industry. Thermal management technology has increasingly become a relatively independent technical field and is an important technical support for the new energy vehicle industry to achieve “curve overtaking.” The evolution and diffusion path is clear. Technical issues such as battery pack environment, motor heat dissipation, battery liquid cooling technology, and heat exchanger materials are important breakthrough innovation points in the future. The motor drive control system currently forms a relatively high patent barrier.

Keywords: emerging technology; technology identification; SCAN algorithm; CPM analysis; new energy vehicle industry

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

Source: ChinaXiv –Machine translation. Verify with original.