

# *Analysis of Hot Spots and Trends of Production Line Balance: A Quantitative Research Based on Citespace*

Shijie Shang

*School of Management, Shandong University of Technology, Zibo, Shandong, 255000, China*

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**Abstract:** With the continuous development of science and technology and the emergence of new methods, technologies and ideas, the manufacturing industry has become a pillar industry to promote economic development and an important part of enhancing national economic competitiveness under the impact of the global economic crisis and the COVID-19 pandemic. Production line balance directly affects the cost control and production efficiency in manufacturing industry. Therefore, it is necessary to summarize and sort out the researches related to production line balance in the past 20 years, so as to find new hot spots for research on production line balance and provide theoretical basis for new development of research on production line balance. Using CNKI database as data retrieval source and Citespace literature measurement tool, this paper conducted knowledge graph visualization analysis on literatures related to production line balance from 2000 to 2022, aiming at sorting out the knowledge structure, development history and research hotspots in the field of production line balance, and indicating the future development direction.

## 1. Introduction

The manufacturing industry has played a powerful propelling role in the economic development of our country. Since our country joined WTO, our industry has quickly integrated into the world industrial system with the world, become the main factory of commodity production in the world. Along with the continuous progress of science and technology, the continuous improvement of our industrial system, coupled with the continuous introduction of the government's series of policies, has created favorable conditions for the development of our manufacturing industry. At present, our country has a complete production system, a huge production scale and rich production categories. Rich product categories and quantities are an advantageous condition for us to connect with the world and integrate into the global industrial chain. Made in China 2025 is currently the first program of action for China's industrial revitalization, aiming at guiding China's manufacturing industry to become stronger from large scale, adjusting industrial structure, improving product quality and production efficiency, and finally realizing rapid and stable economic growth [1]. With the continuation of the financial crisis and the end of the epidemic, on the one hand, we need to take various measures to promote the return of manufacturing industry to resist the negative effects of the financial crisis. On the other hand, affected by the epidemic and other factors, although some small and medium-sized enterprises in China are facing increased difficulties, our industry has shown great resilience under the impact of the epidemic. In this context, enterprises should control costs, improve

productivity to achieve production line balance, step by step to achieve steady and good long-term development of Chinese industry.

Self-assembly line production, which greatly improves the production efficiency of the production line, began to be popularized in factories around the world, and scholars also began to pay attention to the balance of the production line. In recent years, with the development of science and technology and the integration of disciplines, more technologies are applied to production, and the methods of production line balance are gradually enriched. Bibliometric method is a quantitative analysis method based on mathematics and statistics. By studying the external characteristics of literature and quantifying the output information content [2-3], it can describe and estimate the research status and future development trend of a certain field, which has been widely used in literature analysis of medicine, management and engineering. Among most knowledge network analysis software, Citespace [4-5] has been widely used in the field of knowledge graph analysis due to its advantages of rich graphical presentation, clear hierarchy, easy application, concise and intuitive analysis results, etc. Although the production line balance problem has been widely concerned by scholars, up to now, there has been little analysis of hot spots and future development trends in this field, and there is a lack of systematic cognition. Based on the data source of CNKI database and the research object of the published core articles related to production line balance or production line optimization, this paper uses Citespace software to carry out visual analysis on the literature to build a visual map, summarizes and analyzes the internal logic of the existing literature, summarizes the development history, research status and hot issues, and points out the future research trend. It provides reference for the development direction of production line balance field.

## **2. Research Methods and Data Sources**

### **2.1. Research Method**

In this paper, bibliometric analysis is adopted, and Citespace software is used to carry out quantitative analysis on the graph of literature with the theme of "production line balance" or "production line optimization". Citespace is a Java-based data mining and visualization analysis software developed by Dr. Chen Chaomei. It mainly makes statistical analysis of the annual number of publications, institutions, journals, authors and keywords in the research field, and displays core journals, core authors and keywords in the field with the help of visual knowledge map to sort out network relationships. This paper reveals the evolution process of the research through the analysis of salient words, and provides the basis for the grasp of frontier hot spots in the future. The software version used in this article is 6.1.R6.

### **2.2. Data Sources**

All literatures in this paper are from the China National Knowledge Network database. The subject word was "production line balance or production line optimization" for retrieval, the literature type was academic journals, the source categories were selected SCI, EI, CSSCI, CSCD and Peking University Core for refining, and the retrieval time span was set from 2000 to 2022. A total of 326 literatures were retrieved. The irrelevant documents are removed and exported in Refwords format, and Citespace software is used to analyze the keywords of the exported documents to form a visualization graph, which is an important basis to study the hot frontier and development trend of the production line balance in different periods.

### 3. Results and Discussion

#### 3.1. Number of Publications Analysis

The number of published papers in a certain field is an external indicator of this field, and the change trend of the number of published papers in this field can reflect the overall development dynamic of this field, and directly reflect the change of the time and heat of the rise of scientific research in this field [6]. The trend chart of the total number of publications was obtained by statistics of literatures retrieved from CNKI database, as shown in Figure 1:

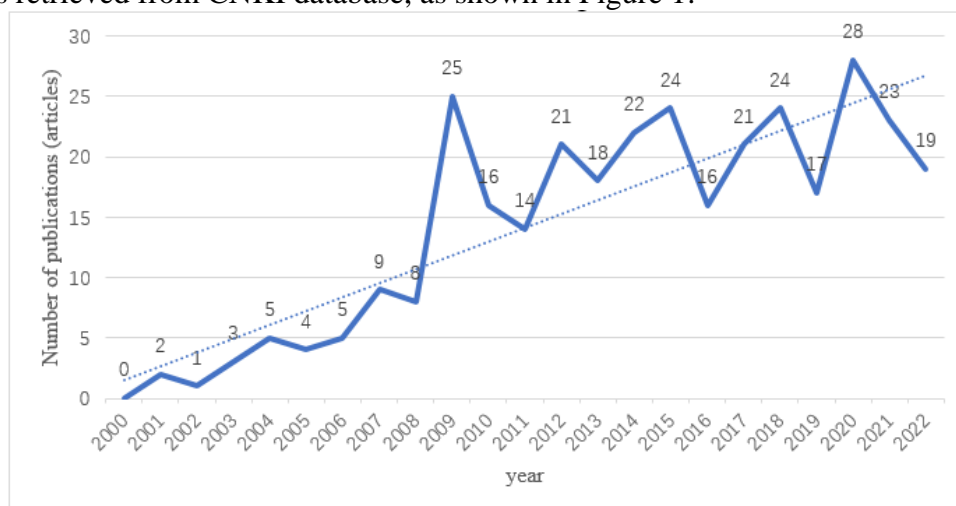


Figure 1: The trend chart of the number of core documents published with "production line balance" or "production line optimization" as the main body

It can be seen that the overall number of documents is on the rise, which can be divided into four stages of studying the balance of production line in the past 22 years.

The first stage: from 2000 to 2008, it was the initial stage of the research. In 2001, Yan Ruishan published an article titled "How to Optimize the Allocation of briquette Production Line" in China Coal, which was the first core journal literature recorded in the library with the theme of production line balance. This article carried out the optimization of the process flow and equipment optimization and other processes to optimize the overall allocation of briquette production line according to the problems existing in the briquette production line at that time. After this article in 2001, the number of key documents in the field of production line balance has increased.

The second stage: 2009, for explosive growth stage. In 2009, there was an explosive growth in the number of core literature publications, and the total number of core journal publications reached 25. Influenced by the economic crisis in 2008, China realized the importance of manufacturing industry to economic growth and put forward a variety of policies to encourage the return of manufacturing industry. Therefore, the attention on manufacturing industry ushered in the first climax, and this year also became the first small peak in the number of core documents published in this field.

The third stage: from 2010 to 2018, the heat peak stage. At this stage, the number of articles published in the core literature of research on production line balance fluctuated significantly, but the number of articles published in the core literature remained relatively high on the whole. The average number of articles published in the core literature was 19.5 per year, and the highest number of articles published in this stage was 24 in 2015 and 2018.

The fourth stage: From 2019 to 2022, it was a stage of stable development, but in 2020, the number of core literature publications reached the peak of nearly 20 years, 28. The reason is that in 2020, China's five major projects (manufacturing innovation center (industrial technology research base)

construction project, intelligent manufacturing engineering, industrial strong base engineering, green manufacturing engineering, high-end equipment innovation project) have achieved significant achievements. In this research stage, the research perspective is more and more broad, the research depth is more and more profound, and the intervention of science and technology is more and more rich.

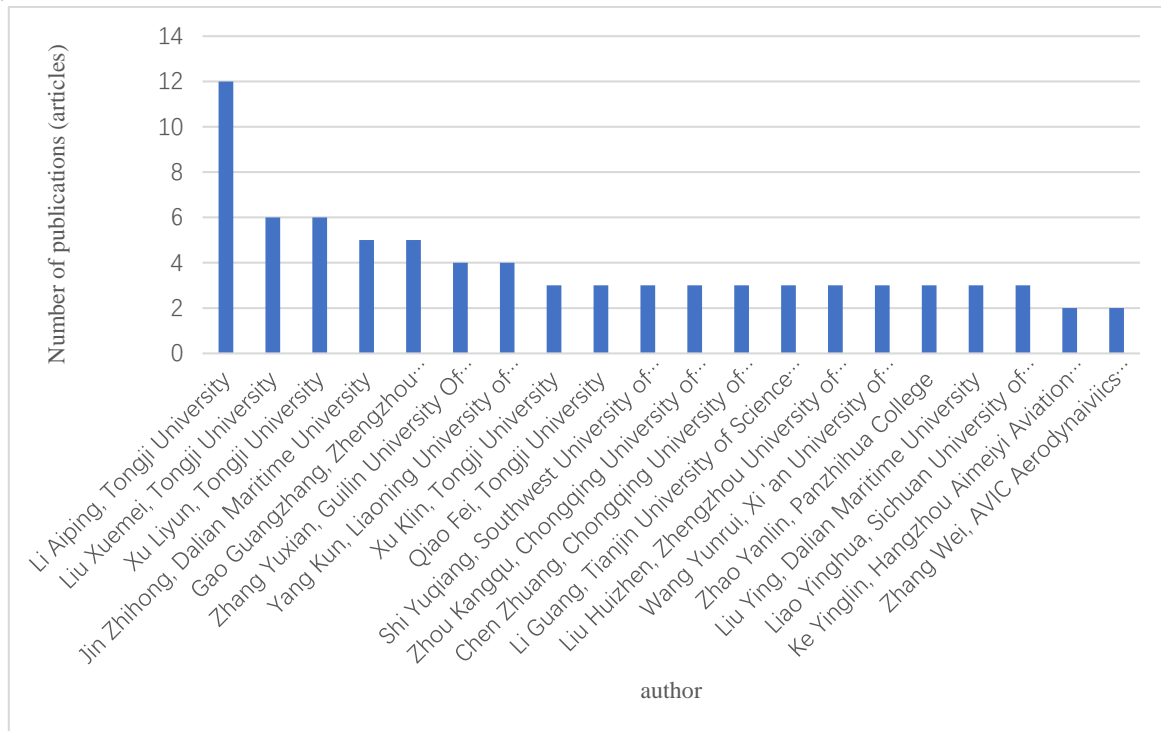


Figure 2: Author distribution

### 3.2. Institutional Analysis, Authors and Sources of Literature

Statistics show that the core literature on the topic of production line balance was completed by 459 authors. Li Aiping from Tongji University published the most papers with 12 papers in total, followed by Liu Xuemei and Xu Liyun from Tongji University with 6 papers. Jin Zhihong of Dalian Maritime University, Gao Guangzhang of Zhengzhou Institute of Aviation Industry Management and other experts and scholars have published numerous papers in this field. Through further analysis of the co-occurrence map of the authors, it is found that there is a cooperative relationship between the experts and scholars belonging to the same institution, such as Li Aiping, Liu Xuemei and Xu Liyun of Tongji University and Xu Kelin You and Qiao Fei. The authors of different institutions rarely cooperate with each other. Research institutions can reflect the distribution of scientific research institutions in this field. This study involves more than 330 research institutions, indicating that this research field has been paid enough attention by experts and scholars, and extensive research has been carried out. The number of articles published by the institutions not only includes universities such as Tongji University, Tsinghua University and Shanghai Jiao Tong University, but also includes enterprises such as Longyan Tobacco Industry Co., LTD., SAIC Volkswagen Automobile Co., LTD., and Shanghai Cigarette Factory. Tongji University, Zhengzhou Institute of Aeronautical Industry Management and Shanghai Jiao Tong University ranked the top three, accounting for 17 percent of the total number of core publications. Other institutions published less than 10 papers. Among the Top10 institutions with the highest number of publications, Tongji University had 34 papers (accounting for 10%); The second was Zhengzhou Institute of Aviation Industry Management, with

13 papers (accounting for 3%); Other institutions accounted for less than 1%. Among the periodical distribution, Journal of Tongji University (Natural Science Edition) published 8 core literatures (accounting for 18%), followed by 5 literatures (accounting for 11%) in Forging & Stamping Technology. Figure 2 to Figure 4 are the visualization graphs of author distribution, institution distribution and journal distribution respectively.

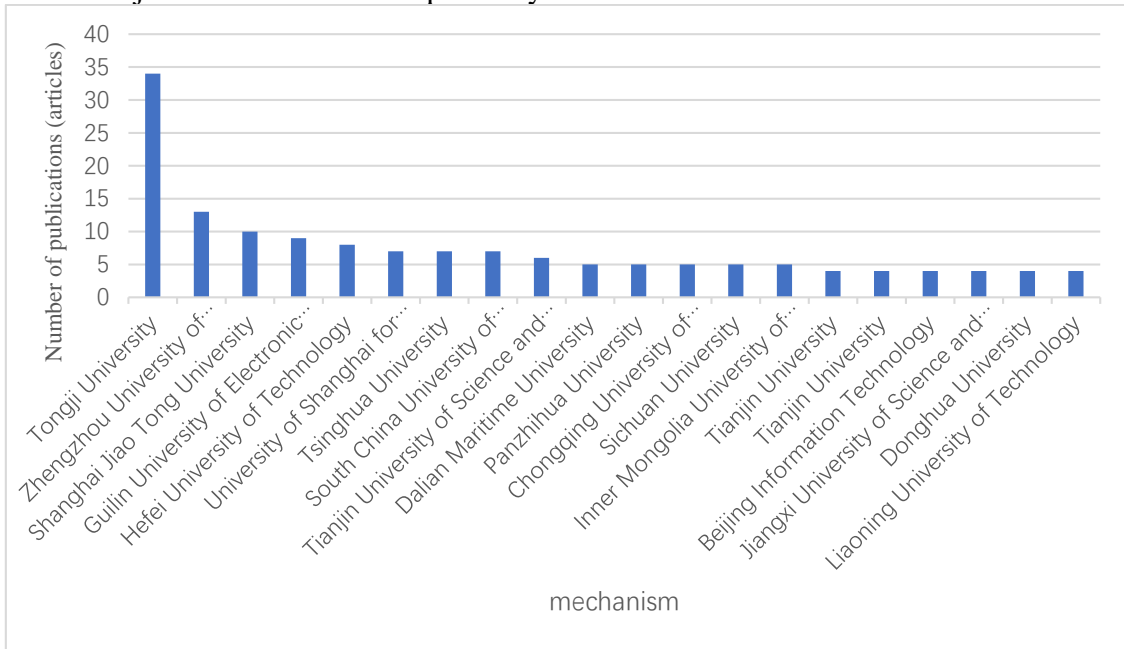


Figure 3: Mechanism distribution

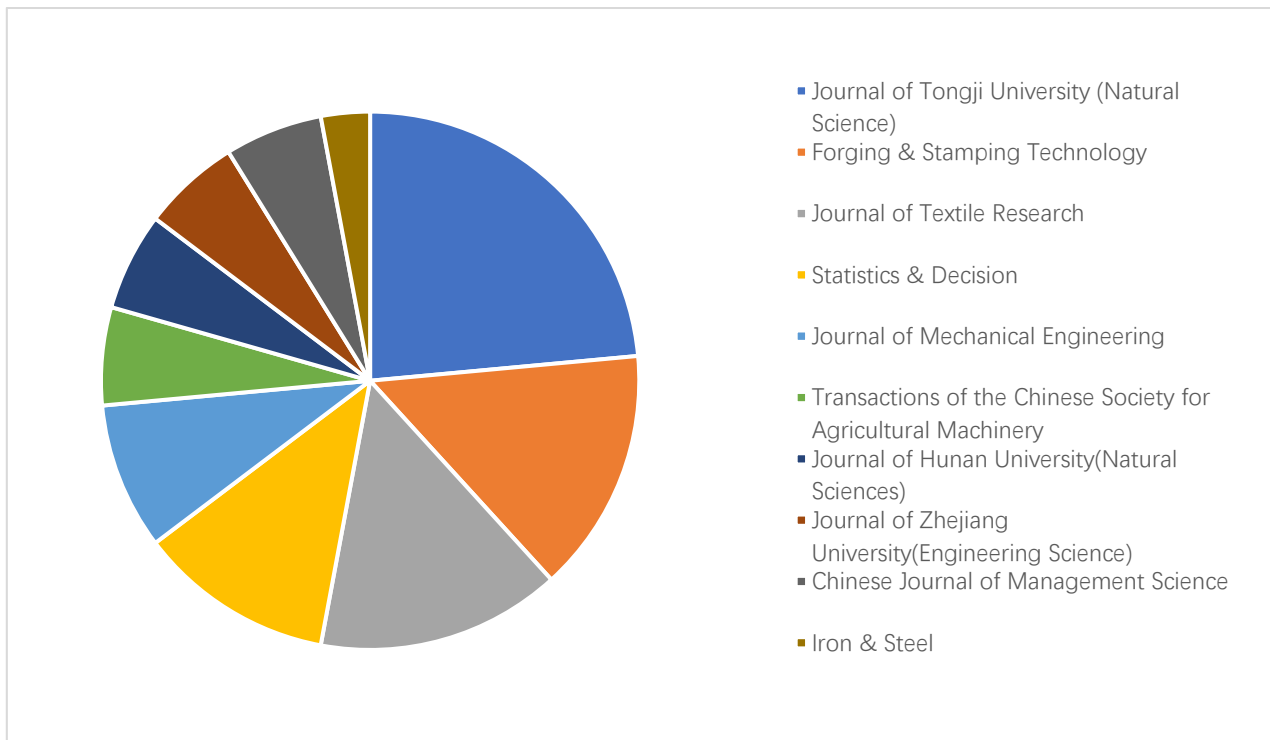


Figure 4: Periodical distribution

## 4. Analysis on Hot Spot and Trend of Chinese Production Line Balance

### 4.1. Research Hotspot

Keywords are the theme idea of the literature, the center and starting point of the research, and clearly reflect the core content of the literature. The frequency of keywords can directly reveal the research hotspot of a certain field. Based on the analysis of keyword frequency and centrality of the retrieved data, Table 1 is obtained.

Table 1: Keywords frequency table

Keywords	frequency	centrality
Genetic algorithm	38	0.2
simulation	33	0.17
Production line	29	0.18
optimization	25	0.13
Industrial engineering	13	0.06
Value stream map	9	0.02
Simulation optimization	8	0.01
Production beat	7	0.02
Lean production	7	0.03
Work study	6	0.01

The keyword with the highest frequency is genetic algorithm, with the highest frequency of 38 times. The second is simulation, production line, optimization, industrial engineering and other keywords. Moreover, the centrality of genetic algorithm, simulation, production line and optimization are all greater than 0.1, and the highest value of genetic algorithm is 0.2, indicating that these keywords have become the focus of research on production line balance in recent years. The combination of simulation and algorithm, especially the combination of genetic algorithm, is the main method to solve the problem of production line balance at present. The software extracts keywords from the retrieved data of CNKI between 2000 and 2022, and constructs the keyword co-occurrence map (Figure 5). It can be roughly divided into six research directions : (1) optimization of the central idea of production line balance (red dots, such as simulation, modeling, plant simulation, human factor engineering, job analysis, etc.); (2) around the production line of research (yellow dot, such as value stream (figure), lean manufacturing, intelligent manufacturing, Numbers, twin, etc.); (3) Optimization algorithms around genetic algorithms (dark green dots, such as function optimization, system simulation, two-line layout, single-line layout and heuristic method, etc.); (4) Optimization research around industrial engineering (light green dots, such as production layout, capacity, operation time, flexible production, production only and load balancing, etc.); (5) Research around motion analysis (light blue dots, such as man-machine analysis, time research, motion analysis, industrial optimization, calm and assembly line, etc.); (6) surrounding the research process (blue dot, including the equipment layout, the collaborative optimization, production scheduling, cache configuration, etc.).

These 6 research directions represent the research direction of our production line balance. Based on the literature analysis of the above clustering keywords, it can be seen that optimization is the research theme of this field, while other clustering basically focuses on optimization. Industrial engineering, motion analysis and process flow belong to the optimization of production line, which is the direction of production line optimization. Genetic algorithm is optimized from the level of algorithm. In addition, simulation is the main method surrounding optimization at present.



## 4.2. Research Trend

Emergent words refer to keywords that increase suddenly in a certain period of time. Through the emergent detection of keywords, dynamic changes of research hotspots in a certain period of time can be understood and future development trend can be predicted [7]. In Citespace, through the spatio-temporal outburst analysis of the core keywords in the research field of production line balance in China from 2000 to 2022, the keywords with significant growth rate from 2000 to now are obtained (Table 2), and the research hotspots and evolution rules in this field can be analyzed, indicating the direction for further research.

Table 2: Spatio-temporal emergence analysis of key keywords in the field of production line balance during 2000-2022

Keywords	strength	start	end	2000—2022
Optimization model	1.13	2003	2008	
Work study	1.85	2009	2011	
Production line layout	0.93	2020	2022	
Lean production	1.74	2014	2015	
Flexsim	1.44	2015	2022	
Value stream map	2.31	2014	2020	
Genetic algorithm	2.61	2020	2022	

As can be seen from Figure 5, among the selected core literature, the key words emerging from 2003 to 2008 were optimization model, during which more attention was paid to production line balance through model construction. From 2009 to 2011, the focus was mainly on work research. This period was the initial stage of research. Method research and work measurement were used to eliminate all kinds of waste in the production process, so as to improve productivity and benefits. In 2014 to 2015, lean production is a focus of this stage. Influenced by Toyota's lean production model, our country began to imitate and popularize it gradually. From 2014 to 2022, a number of emergent words appeared, such as Flexsim, value stream map and genetic algorithm. The emergence of multiple co-occurrence words during this period indicates that the research focus is more on interdisciplinary, and the algorithm plus model to solve the production line balance problem has become a research hotspot in this stage.

As can be seen from the time-line graph of China National Knowledge Network database (Figure 6), cluster 0 optimization, lasting from 2002 to 2022, is the most popular research on production line balance optimization. Balancing production line timing and reducing waiting and waste is the main content of production line balance research.

Cluster 1 production line started in 2004 and lasted until 2021, including hot issues such as beat, equipment layout, industrial engineering, value stream and lean production. Cluster 2 Genetic algorithm lasted from 2004 to 2021. Because of its huge advantages and effectiveness in solving combinatorial optimization problems, genetic algorithm was widely used to solve production line balance problems. Cluster 3 Industrial engineering, the method of industrial engineering is the basic problem in the method of production line balance, the hot topics include work study, simulation optimization, time measurement, process optimization and other keywords, all belong to the basic concepts and methods of industrial engineering. Cluster 4 action analysis lasted from 2014 to 2020,

and the hot topics included production beat, lean production, value stream map and other keywords. The cluster mainly carried out production line balance through lean production. Cluster 5 is the process flow, in which the hot topics include production scheduling, production rhythm, model, equipment layout and other keywords.

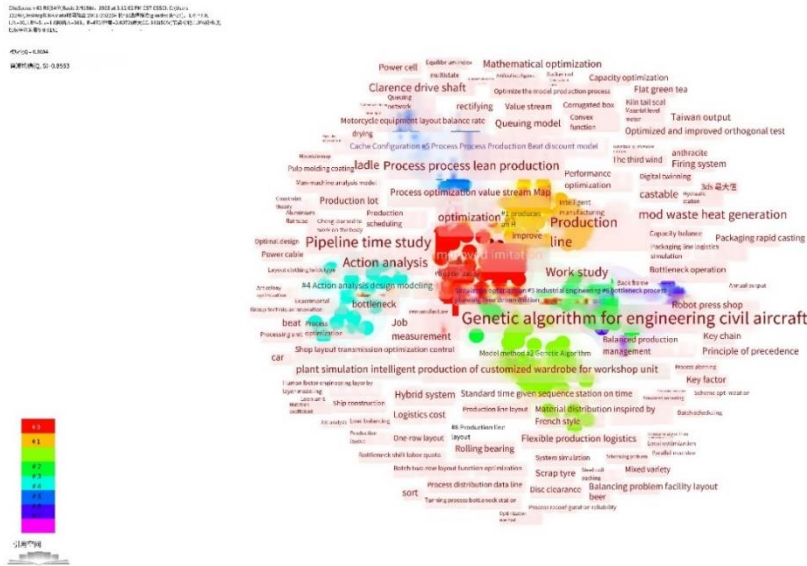


Figure 5: Production line balance keyword co-occurrence map

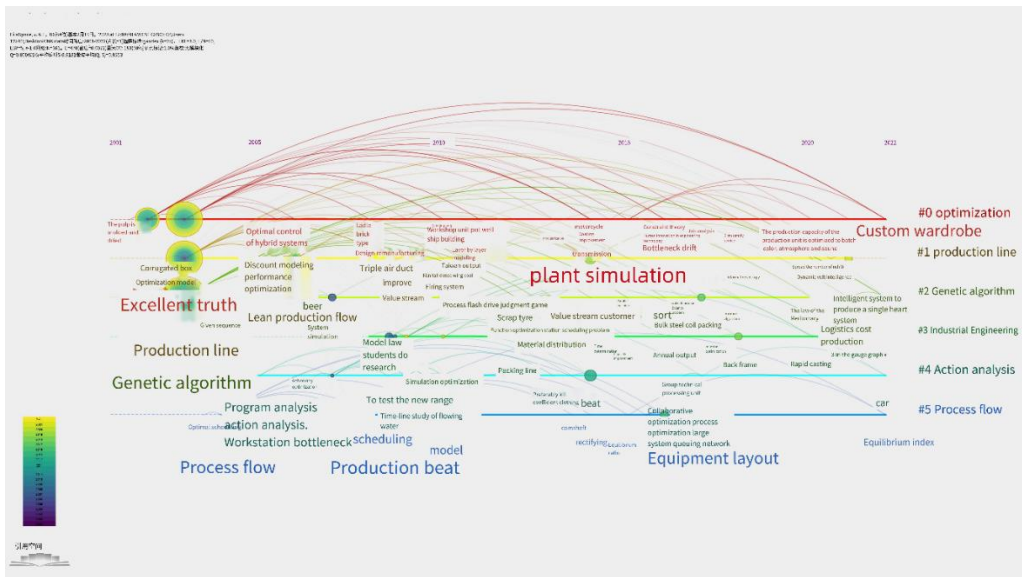


Figure 6: China National Knowledge Network database time graph

At present, our research on production line balance mainly takes enterprise case as the object, and mainly includes four kinds of use methods. The first is the improvement method of industrial engineering, which is the most basic optimization method. ECRS principle, 5W1H questioning technology and action analysis are commonly used to put forward optimization schemes based on the actual situation to achieve the purpose of balancing the production line [8]. The second is mathematical analysis method, which calculates the optimal solution of the problem by establishing a mathematical model [9]. The third is intelligent computing method, commonly used methods include genetic algorithm, heuristic algorithm and particle swarm optimization algorithm. The fourth is the simulation method, using Flexsim and other simulation software to optimize the balance of the



production line [10].

## 5. Conclusion

After more than 20 years of development, the domestic research on production line balance has been further studied. The domestic research on production line balance shows a trend of continuous growth, and certain results have been obtained both from theoretical research and practical application. Using Citespace software, this paper carries out knowledge graph analysis on the core periodical literature of CNKI with the theme of "production line balance or production line optimization" and draws the following conclusions:

First of all, the number of core literatures on domestic production line balance had been growing slowly from 2000 to 2008, but showed an explosive growth in 2009, which was related to the financial crisis in 2008. Affected by the financial crisis, China began to introduce various policies to encourage the return of manufacturing industry. Therefore, the results of production line balance research are widely used in manufacturing industry and have great research prospects.

Secondly, the current research mainly focuses on three aspects: (1) the application of Flexsim simulation in production line balance; (2) Research methods to identify and reduce waste in the production process using value stream maps; (3) Research on the combination of model and algorithm mainly focuses on the wide application of genetic algorithm in the balance of production line.

Finally, the current research on production line balance spans multiple disciplines and is no longer a single industrial issue. Intelligent manufacturing, simulation and genetic algorithm are the hot keywords in the current research field, which precisely shows that this research has evolved into an all-round three-dimensional research field covering a wide range of fields, a large span of disciplines and a wide range of fields after more than 20 years of development. In the future, we should pay more attention to the application of new technology and the cooperation of more disciplines in order to promote the long-term development of production line balance research.

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