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SIMULATION OF STEEL PRODUCTION LOGISTICS SYSTEM BASED ON MULTI-AGENTS

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Abstract

To deal with the complex structure and difficulty in precise expression of the interaction between entities in the steel production logistics system, this paper uses complex network theory and multi-agent system engineering to simulate the complex steel production logistics system, and thereby calculate related parameters, gather statistics, and optimize the steel production logistics system. According to the analysis, the processing of logistics is low in efficiency because 19 pieces of equipment are involved from the beginning of the logistics subject processing to the final formation of steel, while only a few processes are required for about half of the auxiliary material or auxiliary process. The system logistics is not compact because most of the equipment used in steel production has only a single function and a limited service area, whereas a higher degree distribution indicates a higher importance in a piece of equipment in the network. This is a must to guarantee the normal operation of the equipment with a higher degree distribution. The simulation results are basically the same with the actual production results, and the error is within the acceptable range, which proves that the simulation system is correct and effective.

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Key Words: Production Logistics System, Complex Network, Multi-Agent System Engineering, Simulation, Steel Production

1. INTRODUCTION

Steel production is a unique process. Generally speaking, it is a complex system involving multiple production processes, numerous logistics links and a long running flow. Changing between the solid phase and the liquid phase, the logistics subject goes through a multi-stage, continuous physical and chemical transformation. The production logistics system of the steel industry has the characteristics of multi-stage production and multi-stage transportation. Thus, how to improve the production efficiency and orderliness has become a research topic of intense interest.

Previously, researchers mostly used complex system theories and methods to study and analyse the optimization of steel production logistics system [1, 2], but the optimization effect was quite limited due to the low efficiency of the theories and methods. With the development of computer technology, simulation modelling based on the steel production logistics system has become the mainstream approach of logistics system optimization, and the theoretical results provide some guidance to researchers. The modelling simulation of the production logistics system can visually reflect the whole production process, and identify the bottleneck equipment to optimize its operation. The system can be simulated with little or no investment, and the optimal plan can be obtained by constantly modifying the parameters. Therefore, simulation modelling is an effective way to handle the complex production process [3, 4]. Currently, simulation modelling methods for complex systems mainly include queuing network modelling [5], bottleneck shifting modelling of production logistics [6], influence net modelling [7], inventory control modelling [8-10], and Petri net based simulation modelling [11, 12].

With rigorous theoretical expressions, Petri net based simulation modelling supports dynamic analysis as it defines the steel production logistics system as a multi-agent system composed of the management layer, the logistics processing layer and the logistics transport layer through hierarchal abstraction. Nevertheless, because the basic Petri net simulation has so many elements, the state space of the simulation system is likely to break down. How to avoid the model space breakdown during the modelling of complex systems is a focal point in future research. Meanwhile, the steel production logistics system can be viewed as a complex network, and the topology and optimization of the network can be studied with theories related to the complex network [13-21]. So far, little research has been done on modelling of the steel production logistics system on the basis of complex system theories and methods.

To deal with the complex structure and difficulty in precise expression of the interaction between entities in the steel production logistics system, this paper uses complex network theory and multi-agent system engineering to simulate the complex steel production logistics system, and thereby calculates related parameters, gathers statistics, and optimizes the system of steel production logistics system. The simulation results are basically the same as the actual production results, and the error is within the acceptable range, which proves that the simulation system is correct and effective.

2. NETWORK SIMULATION MODELLING OF PRODUCTION LOGISTICS SYSTEM

2.1 Network model

Fig. 1 shows the network model of the production logistics relationship based on the actual production of steel production in an enterprise. The model covers the logistics processes such as the preliminary process, blast furnace iron-making, converter steel production, continuous casting, continuous rolling and finishing. There are in total five blast furnaces (the No. 1 blast furnace has been scrapped) with a total capacity of 3900 m^3. The No. 6 blast furnace is a 2,100 m^3 large-capacity furnace.

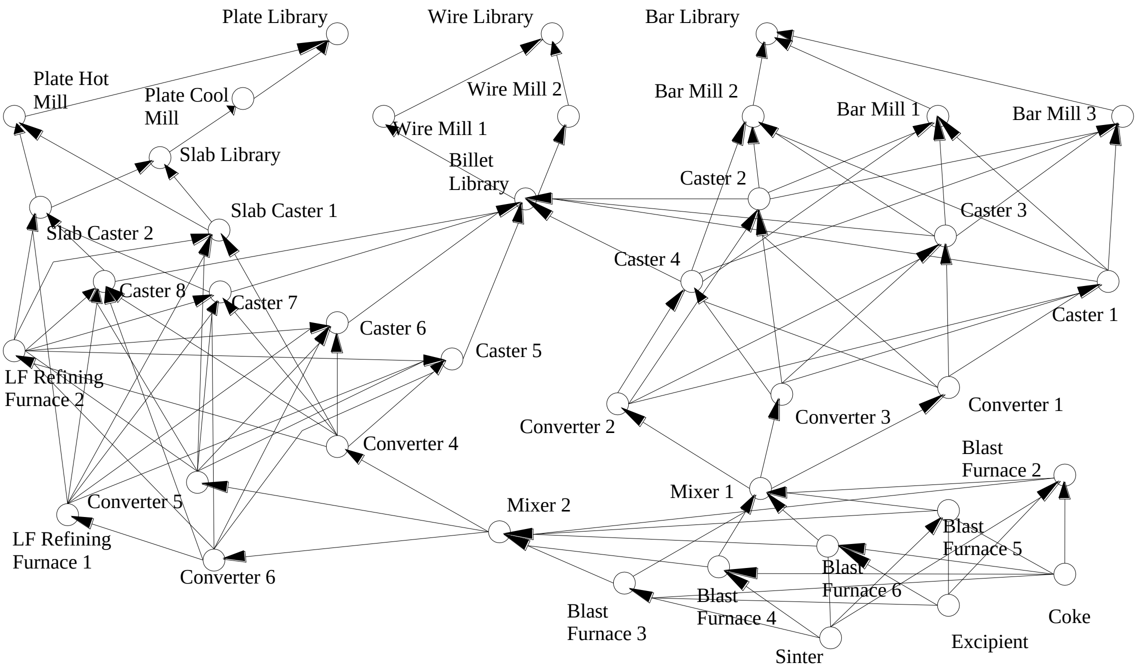

Figure 1: Network model of steel production logistics system.

The simulation system consists of two operating areas. The first area has three converters, a metal mixer and a billet caster. The second area also has three converters and a metal mixer, plus two LF refining furnaces supporting the billet and slab casters. The bar and coil plant has three production lines for bars and two for lines.

A complex network model is constructed for the production logistics system by regarding the whole steel production logistics system as a complex network, the production equipment as the connection nodes, and the logistics relationship between the equipment as the circulation channels, which is expressed in the form of edges in Fig. 1.

2.2 Average logistics process

In the iron and steel production logistics system, the efficiency, smoothness and product quality of the production process hinge on the length of the circulation process of the main subject in each piece of equipment, which is represented by the average path length in the complex network system. If d_{ij}, the distance between any two nodes i and j in the network, is defined as the number of edges for the shortest process needed to connect the two nodes. The average logistics process in the whole network can be expressed as:

$$L = \frac{2\sum_{i>j} d_{ij}}{N\left(N-1\right)} \tag{1}$$

where, N refers to the number of nodes in the network. From Eq. (1), it can be seen that the smaller the value of L, the closer the topological distance between any two nodes, the fewer the useless processes in the network system, and the more efficient the logistics.

Based on the network model shown in Fig. 1 and expressed by Eq. (1), the average logistics process in the whole system $L = 5.2$; that is, the production logistics subject must go through six processes to produce the final product or intermediate products. Fig. 2 shows the percentage of average logistics processes. According to statistics displayed in the figure, in most cases, only one process is needed to complete product processing, which takes up 21 %; 47.5 % of logistics subjects must go through four pieces of equipment to produce the final products; 63 % of logistics subjects must go through eight pieces of equipment to complete the material flow and transformation. Additionally, the figure indicates that 4 % of logistics subjects need to go through 19 processes to complete the final processing. As above, 19 pieces of equipment are involved from the beginning of logistics subject processing to the final formation of steel, resulting in the longest logistics path. Meanwhile only a few processes are required for about half of the auxiliary material or auxiliary process before exiting the production logistics system.

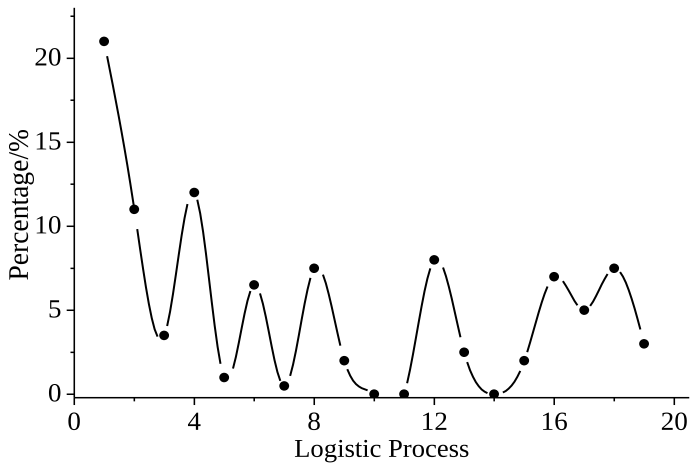

Figure 2: The percentage of production logistics process.

In actual production, individual long processes should be optimized to improve production efficiency, such as improving the production technology, reducing the amount of equipment on the flow path of the logistics subject, increasing the flow rate between pieces of equipment, and abandoning high energy consumption equipment.

2.3 Clustering coefficient and degree distribution

To optimize the steel production logistics system, the aggregation coefficient can be used to define the importance of a piece of equipment in the whole network. When any node has a total of k_i logistics paths to connect it with the surrounding nodes, the clustering coefficient C_i at the node i is defined as:

$$C_i = \frac{\sum_{j \neq m} b_{ij} b_{im} b_{jm}}{k_i \left(k_i - 1\right)} \tag{2}$$

Let b_{ij} be an element of an adjacency matrix, $b_{ij} = 1$ when two pieces of equipment are adjacent to each other; otherwise, $b_{ij} = 0$. The clustering coefficient C_i is the ratio of the number of edges between all adjacent nodes to the maximum number of possible edges. By analysing the clustering coefficient of the logistics network model, a clear picture emerges of the association between a certain equipment node and adjacent equipment nodes in the model. The clustering coefficient of the network system can be expressed as:

$$C_s = \frac{1}{N} \sum_{i=1}^{N} C_i \tag{3}$$

Eq. (3) shows the system's operating efficiency increasing with C_s.

The results of Eqs. (1) and (2), $C_i = 0$ at most nodes in the network system, except for a few nodes, indicate that most of the equipment used in steel production have only a single function and limited service area. The results of Eq. (3), the average clustering coefficient of the model for the logistics system $C_s = 0.11$, indicate that the logistics in the system is not compact, and the network model operating is low in efficiency. Normally, the average clustering coefficient of the network model can be improved by adding equipment or circulation processes to the system. That is, improving the operating efficiency of the whole logistics system can be achieved by optimizing the process flow; namely, putting the equipment with the same function in the same area or abandoning the old equipment.

Degree distribution is also an important indicator to describe the characteristics of nodes in the network system. The degree is calculated with the following equation:

$$k_i = \sum b_{ij} \tag{4}$$

The distribution of k_i is expressed by the probability distribution function $p(k)$; that is, the probability that any node has k edges. The expression for the cumulative degree distribution function is:

$$p\left(k\right) = \sum_{k'=k}^{\infty} p\left(k'\right) \tag{5}$$

Fig. 3 shows the degree distribution of nodes within the network. From the statistics, most of the nodes in the network have relatively low degrees, and nearly 70 % of equipment is connected to other equipment via five or fewer logistics processes, indicating that most of the equipment has a small sphere of influence in the network. The degree of 4 % of the equipment is distributed at 9 and 10. Fig. 1 shows that these pieces of equipment are the two refining furnaces and a billet library. The degree of 8 % of the equipment is distributed at 8, indicating that the equipment has a small sphere of influence in the network and plays a critical role in realistic production. In the logistics system, these pieces of equipment are two mixed iron furnaces and the No. 6 blast furnace. Thus, in actual production, the factory must coordinate the production and processing capacity of other equipment under the premise of the normal operation of the refining furnaces and billet library.

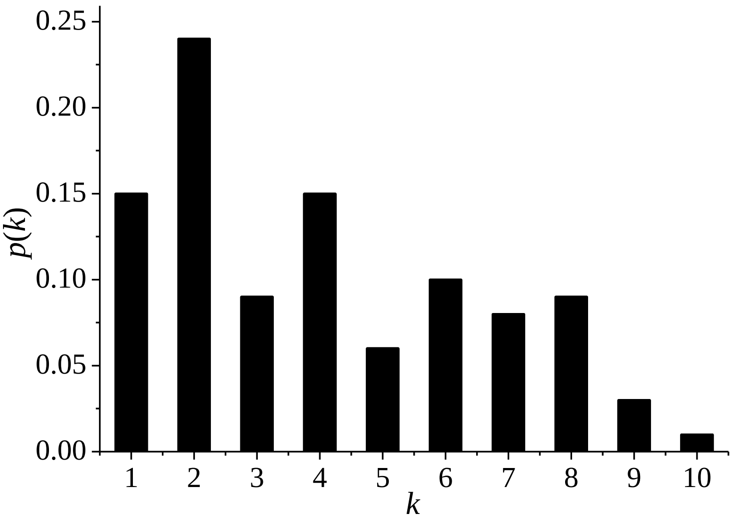

Figure 3: Degree distribution probability of nodes in the network model.

If it is inconvenient to move equipment in actual production, the system's operating efficiency can be improved through adjusting the flow mode of logistics processes within the system. For example, eliminate the logistics process between two pieces of adjacent equipment, and add logistics paths between other equipment. Flexibility is allowed for in actual production to save resources and optimize the system.

3. CONSTRUCTION OF COMPLEX STEEL PRODUCTION LOGISTICS SYSTEM BASED ON MULTI-AGENT SYSTEM

While the previous section discusses the optimization of the logistics process based on a complex network system, this section plans to further optimize the steel production process by constructing the complex steel production logistics system based on multi-agent system engineering. This is because the efficient operation of the steel production logistics system not only demands optimizing the function and improving the reliability and controllability of a single piece of equipment, but also relies on the improved hardware and optimized capacity of the logistics transport system which provides the means of transport and regulation between different processes. Effective scheduling is the key to ensuring the consistency, coherence, and effective control of the logistics between different processes.

3.1 Multi-agent system engineering

The agent technology has a strong autonomy. It independently deduces the processing units of subsequent targets on the basis of analysing and perceiving a given external environment. Multi-agent system engineering refers to the software development method for the heterogeneous multi-agent system. Applicable to a variety of operating environments, implementation technologies and development platforms, the method describes agent behaviour in UML language.

In multi-agent system engineering, the modelling process mainly consists of the analysis phase (target capture, role definition, etc.), the design phase (definition, agent construction, system deployment, etc.) and the construction of a model for the complex production logistics system through different iterative calculations based on the analysis phase or design phase.

3.2 Modelling of complex steel production logistics system

The overall requirements of the steel production logistics system are to complete the production tasks with low cost and high efficiency. Therefore, the following sub-objectives can be set according to the overall objectives: operation plan management, real-time tracking of logistics main subject, transport and production scheduling management. Then, this author establishes agent systems with functions corresponding to these sub-objectives. According to the complex network in the previous section, the multi-agent system can be divided into management agent, production and transport equipment agent, task agent and result agent. In this way, this author employs a figure to illustrate the classification of agents in the complex steel production logistics system. (See Fig. 4) In the figure, the boxes represent the types of agents, and the link arrows represent the answers, which are directed to the responder from the initiator of the session. The different types of agents are either in one-to-one or many-to-one relationships.

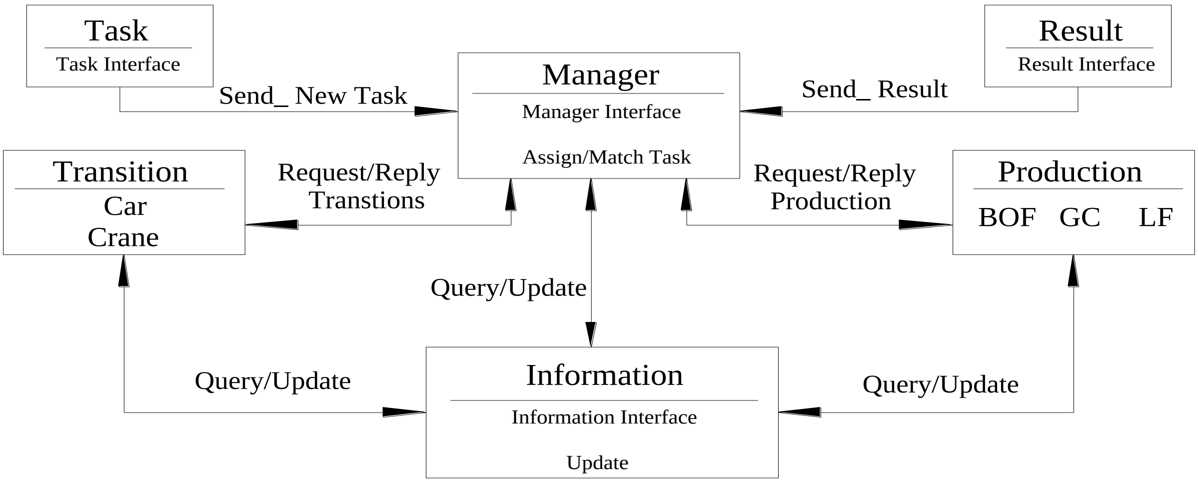

Figure 4: Complex logistics system based on multi-agent system.

After defining the relationship between different types of agents, the session protocols are defined for different types of agents. For example, if the ladle has received the molten steel from the converter, it can automatically define the properties of subsequent tasks, such as the starting and ending time, and reward and punishment for a certain task. In light of its own capacity, the refining furnace can analyse the probability of completing a certain task on time, breaking down the task into action sequences, executing the actions, and providing the results to the agent on the next superior level.

The final production deployment plan is prepared through static analysis of complex steel production logistics system and the dynamic realization of each function module. With the help of the existing simulation platform AnyLogic, the deployment of complex steel production logistics system is realized based on multi-agent system engineering by modifying and expanding the corresponding function modules, thus completing the simulation and optimization of the production logistics system.

3.3 Case study

The effectiveness of the established model is verified by setting up a simulation model for the production logistics system in Fig. 1, selecting 12 groups of production periods at a certain time defined in light of the enterprise's production statistics, using the groups as inputs to the simulation system, and adjusting the parameters in view of the realistic production environment of each type of equipment. To ensure the authenticity and reliability of the results, each group of data is simulated 30 times, and the results of the 30 simulations are averaged. See Fig. 5 for the comparison between the final simulated mean time and the actual mean time of production logistics. The figure shows that simulation results are basically the similar to the actual production results, and the error is within the acceptable range, which proves that the simulation system is correct and effective.

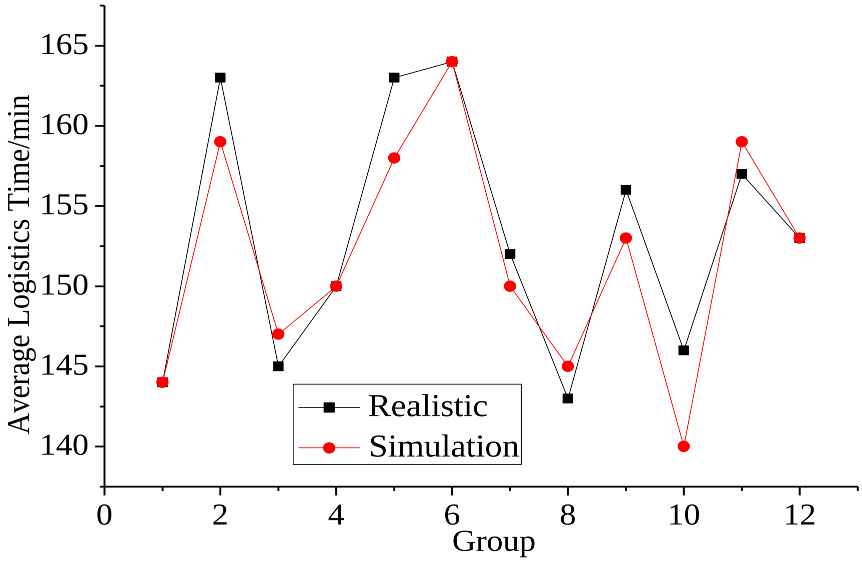

Figure 5: Comparison between simulation results and realistic results of logistics mean time.

See Table 1 for the simulation results of the multi-agent production logistics system according to the four different feed rates of molten iron (10 min/ladle, 12 min/ladle, 15 min/ladle, and 20 min/ladle) and three different production rates of the converter (19 min/ladle, 22 min/ladle, and 25 min/ladle). Each group is simulated 20 times to minimize the error.

Table I: Average waiting time for queuing.

No.	**Average time** (min)		
	Desulfurization	Converter	Slag Skimming
1	5.86	2.24	0.42
2	6.77	1.17	0.319
3	8.48	5.93	0.394
4	17.93	12.4	0.41
5	8.11	0.979	0.451
6	12.3	3.94	0.327
7	16.49	8.89	0.484

In observation of the simulation results of the seven various cases, it can be inferred that desulfurization takes more time than the other two processes, indicating that desulfurization is the production bottleneck of the system, necessitating upgrading the desulfurization equipment or adjusting the logistics flow path. Moreover, the long queuing time of the converting process reflects the critical importance of the process in the whole steel production system. In actual production, the factory can either shorten the smelting cycle of the converter or speed up the transport speed in the upstream. Hence, system modelling and simulation analysis can detect logistics bottlenecks in the system, providing a reference and useful guidance to improve the system logistics balance and equipment utilization.

4. CONCLUSION

The following conclusions are drawn from the simulation modelling based on complex network theory:

(1) In the processing process of the logistics subject, 19 pieces of equipment are involved from the beginning of logistics subject processing to the final formation of steel, resulting in low production efficiency, while only a few processes are required for about half of the auxiliary material or auxiliary processes before exiting the production logistics system. Individual long processes should be optimized to improve production efficiency, such as improving the production technology, reducing the amount of equipment on the flow path of the logistics subject, increasing the flow rate between pieces of equipment, abandoning high energy consumption equipment, etc.

(2) The calculation of the clustering coefficient shows that most of the equipment used in steel production has only a single function and a limited service area, indicating that the logistics in the system in not compact. The calculation of degree distribution shows that the higher the degree distribution, the higher the importance of a piece of equipment is in the network. So, it is essential to guarantee the normal operation of the equipment with higher degree distribution.

This author arrives at the following conclusions based on the simulation results of the multi-agent complex steel production logistics system:

The simulation results are basically similar to the actual production results, and the error is within the acceptable range, which proves that the simulation system is correct and effective. In light of the results, the steel enterprise should shorten the smelting cycle of the converter, speed up the transport speed in the upstream, and either upgrade desulfurization equipment or adjust the logistics flow path.

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