A review of the application of discrete event simulation in manufacturing

Dongping Qiao, Yajing Wang*
Zhengzhou University of Light Technology College of Mechanical and Electrical Engineering, Key Laboratory of intelligent manufacturing of mechanical equipment in Henan Province, Henan Zhengzhou, China

*Corresponding author e-mail: 331902010064@zzuli.edu.cn

Abstract. Simulation is an important technical means to verify the efficiency of discrete event systems. This paper summarizes the research system of plant simulation software based on discrete event system, including production layout, routing, material distribution, production line and other aspects. Finally, in view of the shortcomings of plant simulation in simulation, the future improvement and research direction are pointed out.

Keywords: Simulation, discrete event systems, plant simulation.

1. Introduction
Manufacturing system is a complex discrete event dynamic system, and accidents may occur in the production line. For example, poor equipment layout design will occur during production, which will affect the production efficiency of workshop production line; or idle waiting state of personnel and equipment due to station blockage of production line; or the warehouse management is unreasonable, the supply exceeds the demand or the supply exceeds the demand, resulting in loss or waste...It is difficult to get the optimal solution by traditional analytical method, but it can be solved by simulation. The focus of production system simulation is production planning, through the simulation technology, the planning of production layout, equipment configuration and material transportation is realized. On the basis of modeling, analysis, evaluation, find out the existing problems in the system and make adjustment and optimization, thus effectively reduce the cost, shorten the construction period, improve efficiency and so on.

Discrete event system simulation is a hot spot of academic research at home and abroad in recent years. In this paper, the related fields of discrete event simulation are reviewed by plant software. From the perspective of application, discrete event simulation is divided into production line layout simulation, path simulation, material distribution simulation, production line simulation and other aspects of simulation, and the research characteristics of each field are evaluated. Secondly, it analyzes the progress of discrete event system simulation optimization and the principles of simulation; And summarizes the five aspects of simulation; Finally, the further development direction of discrete event system simulation is proposed.
2. Development and application of discrete event simulation

2.1. Discrete event system

Discrete event system[1] refers to the system in which the state of physical system changes discretely at some random time points. Events in discrete-time systems often occur at random time points, and events are discrete variables of time. The dynamic characteristics of the system cannot be described by mathematical equations such as differential equations, only the activity diagram or flow chart of events can be used. Therefore, the main purpose of simulation of discrete event system is to analyze the statistical characteristics of system events.

2.2. Simulation

Simulation refers to the study of an existing or designing system through the experiment of simulation system, establishing a computer simulation model to simulate the dynamic system of reality, and performing various experiments on the simulation model to evaluate and improve system performance. With the development of technology, different simulation software developed. For example, flexsim, anylogic, plant simulation, extendsim and so on. However, the emphasis and advantages of each simulation technology are different. Flexsim focuses on the simulation of logistics industry; anylogic prefers logistics simulation of service industry, while plant simulation focuses on discrete manufacturing system.

System simulation must follow three principles, as shown in Figure 1:

![Figure 1. Principles of production system simulation](image)

2.3. Development of simulation technology

In the early stage, simulation technology was used to establish water conservancy model and carry out hydraulic research. Vansteenkiste G[2] found out the current situation of modeling technology for water resources system and waste problems. Subsequently, simulation was applied to the fields of aviation, aerospace and atomic energy, which promoted the progress of simulation technology in this period. The second Department of the Ministry of Aerospace Industry[3] has made contributions to aviation economy and systems engineering since the 1950s. Li Jianghe[4] found a simulation device suitable for the formation of atmospheric boundary layer in NH-2 wind tunnel on the basis of various artificial accelerated boundary formation methods in aviation wind tunnel, and extended this simulation device to the engineering of NH-2 wind tunnel. Liu Jingcai[5] described the characteristics of the space shuttle and electronic and electromechanical systems based on the data of American Airlines, and derived from these characteristics the local simulation technology required. Simulation has been widely used in nuclear power field, including control and safety system design, accident analysis and so on. R. N. ray[6] introduced the work of BARC reactor group in nuclear power field. Later, computer technology developed by leaps and bounds, which provided advanced tools for
simulation technology and accelerated the development of simulation technology. Liang Bingcheng[7] discussed the application of modern hybrid computer in aircraft system and the outstanding effect and economic benefit when combined with simulation method.

In this paper, the plant simulation software is used to simulate the production system and other objects. Plant simulation[8] is a simulation software developed by Tecnomatix to realize production, logistics and engineering. It is an object-oriented, graphical and inherited modeling and simulation tool. The system structure and implementation meet the object-oriented requirements[9][10]. It can be used to optimize production, solve bottleneck problems and minimize work in process, analyze and optimize production layout. According to the academic classification, plant simulation is a typical discrete event simulation software tool.

3. Overview of problem application

There are many literatures on the simulation optimization of discrete production system by using plant simulation software. The feasibility of this scheme can be judged by the optimization results of the model, which usually starts from the following five aspects: simulation optimization oriented to production layout, path oriented, material distribution oriented, production line oriented and other simulation optimization. Most of the research objects are production lines, factories and workshops, there will also be a small number of simulation objects that will be some application service system. It can be combined with genetic algorithm, ant colony algorithm, heuristic algorithm and other algorithms combined with simulation. This paper classifies the literature according to the problems in all aspects of discrete event system, and classifies the literature according to the above criteria.

3.1. Simulation optimization for production layout

PLP(Production layout problem) refers to the planning and layout of equipment in a given space, the objective function is optimized on the premise of satisfying certain restriction conditions. The design of production layout is a combinatorial optimization problem with nonlinear, NP-hard and other characteristics. Reasonable production layout can not only reduce the operation cost, improve the utilization rate of equipment and personnel and production efficiency, but also has great guiding significance to enhance the competitiveness of enterprises. Cui Jing[11] studied the process layout of the aviation composite material production line, aiming at improving product quality, production efficiency and reducing production cost. Plant Simulation software is used to model the layout of the plant by compiling method in simtalk language. For this project, the simulation mainly solves two problems: optimize the quantity of process equipment, and conduct quantitative analysis and comparison from the aspects of material flow and equipment occupancy, so as to find the optimal solution to realize the process layout. Li Hui[12] takes the minimum material flow and the optimization of downstream flow degree as the objective function, carries out simulation through the combination of plant simulation and genetic algorithm to solve the optimal sequence of equipment in "U" type layout. Hou Zhi[13] transformed the multi-row arrangement of the equipment into a sorting problem, and wrote the program using the genetic algorithm toolbox and SimTalk language built in plant Simulation software to achieve the optimal layout. Zhang Chao[14] combined genetic algorithm with simulated annealing algorithm to solve the layout of production facilities with plant simulation software. In order to optimize production layout, simulation software is generally combined with SLP(systematic layout planning), and the necessity of developing layout design experiments has been given by Zhou Jinping[15]. Zhou Ermin[16] and Peng Fei[17] both used plant Simulation software combined with SLP to optimize and evaluate the production layout of the workshop. The difference is that the latter planning method can make up for the deficiency of SLP method. Peng Jieyan[18] combined the advantages of simulated annealing algorithm and genetic algorithm into a hybrid algorithm. Combined with an example, the superiority of the hybrid algorithm was proved by using plant simulation software. Zhang Zhi[19] used plant simulation software to study the layout of different production lines, evaluated the productivity of the production line based on the actual situation, found out the bottleneck process and improved it, and put forward the optimization logistics distribution strategy. Xu Liyun[20] used the
plant simulation software to model the workshop layout. In solving the problem, the adaptive crossover and mutation strategies in genetic algorithm were used to make the crossover rate and mutation rate change with the individual fitness value of the population. In order to effectively optimize the production layout and configuration, Yang, S.L.[21] proposed a method based on discrete event system modeling and optimization, established a workshop layout model, and solved it with genetic algorithm. Zhang Zhan[a][22] proposed and developed a simulation framework. In the simulation, mathematical algorithm and heuristic algorithm were combined to balance the operation performance and cost planning, which could better realize the layout design of the factory.

The layout of production system directly affects the operation cost and efficiency of production system. Most of the research on production layout based on plant simulation is the optimization of facility layout, without considering the fixed station of facility layout.

3.2. Path oriented simulation optimization
AGV (automated guided vehicle) is the core part of intelligent logistics, which has the characteristics of high sensitivity and high degree of automation. As the quantity, operation path and speed of AGVs will affect the cost and efficiency of materials, therefore, the rational use of AGV plays an important role in the development of intelligent logistics. Due to the different perception of AGV of the external environment, the path planning problem can be divided into global path planning and local path planning.

Zhong Meisu[23] and Yang Yongsheng[24] both adopted the virtual island-circling strategy aiming at the bottleneck of wharf operation. According to the operation mechanism of AGVS(Automated Vehicle System), they compared the impact of different driving paths of AGVS on the efficiency of wharf operation by changing the number and location of branches. The results show that different paths have different effects on the dock operation. Liu Jian[25] used plant simulation software to model the number of AGVs under the automatic verification line of electric meters, exploring a way for the application of AGVs in production practice. Traveling salesman problem (TSP) is the most basic path optimization problem, as well as a special case of single Vehicle in VRP(Vehicle Routing Problem). It is also a classic case of NP (Non-deterministic Polynomial). Zhou Min[26] modeled TSP through plant simulation software and optimized it with the idea of mountain climbing method. Ant colony algorithm is a probabilistic technology used to seek optimal path. Peng Chuan[27] designed an ant colony algorithm to solve the logistics distribution path optimization problem by applying the ant colony algorithm to the path optimization problem of logistics distribution, and through the simulation of an example, it shows the effectiveness of the algorithm. Lin Jianjun[28] used AGV to simulate workflow scheduling and path selection, and obtained the optimal AGV configuration by setting different parameters.

3.3. Simulation optimization for material distribution
Material distribution refers to the transportation activities in which the required materials are sorted goods, distributed and delivered to the users according to the order requirements of the users, including the common use of logistics resources, the common use of logistics facilities and equipment, and the common use of logistics management.

Jiang Jianqiang[29] analyzed the complexity and uncertainty of the workshop production environment, established a simulation model by using plant simulation to determine the optimal distribution interval and material distribution strategy with the minimum distribution cost and maximum full load ratio as the objectives, and solved the model with the constraints of travel path and material demand time, combined with genetic algorithm to solve the model. Wang xueyang[30] compared the number of ladle online and ladle logistics parameters under the two systems through plant simulation software, and obtained the optimal logistics scheme. Ren Yunting[31] improves automobile production by introducing SPS logistics supply line mode, analyzes and evaluates the status after the introduction through modeling, analyzes its feasibility, so as to provide decision-making basis for actual transformation. According to the three different types of
paper products produced, Dushan[32]used plant simulation software to improve the problems existing in the production logistics system, and made the production logistics system more reasonable by changing decision parameters and increasing the number of machines.

To realize the timely exchange of workshop material consumption information and distribution information between warehouses, the materials in the production process need to realize fixed-point, fixed material, quantitative and "beat" distribution, which can reduce the material accumulation in the station line side warehouse or stop production due to material shortage, and truly achieve the balance of supply and demand between station assembly and material distribution, which is extremely important for enterprises to improve production efficiency and economic benefits important practical significance.

3.4. Simulation optimization for production line

Production line simulation is an effective means to carry out production planning, production scheduling and production planning. The basic principle of production line is to decompose a repeated production process into several sub processes. The former sub process creates the execution conditions for the next sub process, and each process can be carried out simultaneously with other sub processes. That is, functional decomposition, sequential in space, overlapping and parallel in time. Production line balance is a technical means and method to adjust all processes and adjust workload so as to make the operation time as close as possible. Whether the production line is balanced or not affects the benefit of the whole production and manufacturing system, and how to use the lowest production cost and maximize the production efficiency is the problem that enterprises need to solve.

Literature[33]-[35]studies the optimization problem of production line, and Li Shudong[36]studies the problem of capacity maximization. Both of them take the equipment utilization rate, production efficiency and the existence of bottleneck stations as indicators to measure whether the production line is balanced. Shi Wenling[37]introduced the application of plant simulation software in the planning of BIW Welding production line. Based on this, Lin Juguang[38]evaluated the production efficiency of the production line with the equipment utilization rate and bottleneck process as the index, and fired multi factor cross experiment with the throughput of the production line as the target. Han Xiaodong[39]used the plant simulation software to model and simulate the production status of an engine inspection production line, compared the ideal state with the actual state of the engine detection production line, found out the bottleneck position and solved it. The simulation operation results show that the simulation can optimize the unreasonable part of the production line and improve the productivity. Li Yan[40]used plant simulation software to simulate the production process of a certain type of missile. Starting from analyzing station allocation, productivity balance, planning the number of AGVs and driving paths, this paper puts forward a method that combines simulation technology and management operations research to deal with the problem, and the results prove the effectiveness of this method. Chen Jie[41]solved the problems of low equipment utilization and low production efficiency in a diesel engine cylinder block production line by using plant simulation software, combined with genetic algorithm, configured buffer zones for bottleneck processes, optimized the buffer capacity, and adjusted the operation mode of the production line. The results showed that the average utilization rate and productivity of the production line were improved. Li Hui[42]and Liu Zhenhai[43]respectively established simulation models by using plant simulation, and simulated with capacity, equipment utilization rate and other aspects as optimization indexes, and optimized by optimizing processing technology and increasing buffer, so as to achieve maximum productivity. Sun Zhichao[44]established a model for an automobile production line based on plant simulation software, analyzed the equipment utilization rate and failure of the production line, improved the bottleneck station, and focused on the evaluation of the production capacity of the whole production line, so as to provide the basis for the formulation of production plan and production adjustment. Wang Qiang[45]used plant Simulation software to model the assembly line of the locomotive driving device, providing a decision basis for the improvement and adjustment of the process layout of the enterprise. Zhang Wei[46]analyzed the status and production process characteristics of the workshop
piston mixed flow production line, improved and optimized the production line, and improved the utilization rate of workers and machine tools. Lu Jinxing[47] adopted AGV as the transport unit on the production line, and made simulation by plant simulation, and obtained the optimal combination of AGVS system parameters through the random test of changing the number of AGVS and running speed. Wang pinyue[48] transformed the production mode through modern intelligent simulation technology, and improved the utilization rate of workers in the production line by using the method of production line balance, so as to release the potential capacity to the maximum extent. Chen Zhaoming[49] used the object-oriented modeling method to simulate the automatic production line of a certain part, and simulated and optimized the bottleneck process and the number of key equipment. It is an effective way to improve the efficiency of the production line to solve the bottleneck process of the production line, reasonably allocate buffer zone, reasonable process planning and production scheduling scheme.

3.5. Other simulation optimizations
Simulation can also be used in production scheduling and other aspects, which is to organize the execution of production schedule plans. It is based on the production schedule plan, which needs to be realized by production scheduling. As the scheduling problem is a typical NP complete problem, it needs to be solved with heuristic optimization algorithms. The scheduling problem can be divided into repair scheduling problem[50] and reentrant scheduling problem[51]. Literature[52][54] separately studied the problem of shop scheduling. The former is better to use Palmer heuristic algorithm to sort the completion of the workpiece than to use autonomous job scheduling based on Queue Length Estimator (QLE). The latter two use the genetic algorithm built in plant simulation software to optimize and simulate them in combination with the shortest operating time rule to improve production efficiency. Wu Yanming[55] used the group transportation strategy and GA to find the better RGV scheduling in the case of large volumes, and used the plant simulation software to compare the grouping method and the first-come-first-served method which is the better, which verified the effectiveness of the model. Dai Boyao[56] proposed a hybrid driving mechanism based on cumulative delay, and modeled the mechanism. BDS and PRS were compared under the same simulation platform, and the results verified the effectiveness of the hybrid drive mechanism.

In the process industry, the scheduling problem is divided into the schedulable problem and the unschedulable problem because it involves the scheduling optimization of long-term or short-term production job plans. The schedulable problem is that when the production plan changes, there will be no production stagnation or discontinuity. Wang Hao[57] analyzed the schedulability of refining process with the help of plant simulation software, and verified the schedulability conditions, so as to achieve the purpose of optimizing production operations. Wang Jianbin[58] simulated the AGV scheduling process and obtained the optimal configuration satisfying the actual project of the assembly plant by setting the loading station, travel path and other parameters. Job shop scheduling is one of the famous machine scheduling problems and one of the most difficult combinatorial optimization problems. For the previous scheduling problems, the basic premise of research conditions is based on sufficient orders. In the case when the production capacity is greater than the number of orders, it is the focus of the production cost is as small as possible while completing the limited order is the focus of research. Li Ji[59] proposed a production cost optimization scheduling method based on factory simulation and genetic algorithm, which realized the related scheduling of minimizing production cost and solved the problem.

Since most of the simulation objects are discrete event systems, in addition to the above four cases, there are also discrete systems to simulate. Wang Xi[60] studied the queuing problem on the basis of discrete system modeling and simulation, using plant simulation software to model, combined with factor analysis and experimental design, and found that when the number of service desks is greater than \(\lambda/\mu\), taking average waiting time as an indicator, the number-calling service method is superior than the traditional service method. It provides decision-making basis for enterprises to implement better queuing services in the future. Liu Zhixiong[61] and Li Minghui[62] respectively used SPSS
software and the combination of Petri net and plant simulation to carry out simulation modeling, so as to realize the optimization design of production system. Anqi[63] combines RFID data acquisition technology with plant simulation software, uses RFID reader to collect material information dynamically, and uses simulation software to optimize the bottleneck of the system.

In the workshop with improper sorting, there will be too much waiting time and queuing time in the production cycle. In addition, the inventory time and other time will prolong the production cycle, increase the number of work in process, and occupy a lot of funds. Reasonable job sequencing can effectively shorten the production cycle and save money. Job sequencing can be divided into static sort and dynamic sort according to the situation of the workpiece arriving at the workshop, and can be divided into single machine sorting and multi machine sorting according to the type and quantity of machines. The latter can be divided into single job shop sorting and flow shop sorting according to the processing route. The job scheduling problem can be solved by genetic algorithm, heuristic algorithm and other optimization algorithms. By using plant simulation software, Guo Hu[64] proposed an optimization design method for solving job shop scheduling problem based on process coding, and combined with genetic algorithm to simulate and optimize this kind of problem.

Both job sequencing and shop scheduling are NP-Hard problems, which are characterized by high complexity and difficult to solve. Generally, the problem is solved by combining simulation and genetic algorithm, and other random factors can also be considered in the modeling process to make the model more consistent with the actual situation.

Plant simulation can be used not only for the simulation of production and logistics systems, but also for the simulation of operating systems such as amusement services. Cao Huanhuan[65] used plant simulation software to simulate and analyze the operating conditions of amusement parks on holidays and amusement facilities configuration, explore optimization methods, and put forward reasonable suggestions for reference and reference for the planning and operation of similar amusement parks.

4. Conclusions and Suggestions for Future Work

Scholars at home and abroad have made achievements in the theory and practice of discrete system simulation, but there are some deficiencies in modeling and simulation of discrete systems. For example, there will be simplification and assumption of the system model when modeling, which are different from some aspects of the actual system; most of them are built in static stable environment without consideration of dynamic and uncertainty. Using plant simulation to optimize the discrete event system can be further studied from the following aspects:

1) Improve the modularity of the model and optimize the parameters of the algorithm.

2) In order to improve the depth and breadth of application, more constraint functions can be introduced in the simulation, instead of restricting the existing conditions.

3) When plant simulation is combined with other algorithms, the advantages and disadvantages of this algorithm should be considered to avoid the randomness and blindness of the intermediate process.

4) Comprehensive optimization of multiple aspects of the system can be considered. Comprehensive optimization is more complicated than a single optimization problem, but the effect may be better.

5) Plant Simulation can be combined with other optimization algorithms, such as ant colony algorithm, neural network, etc.

References
[1] Andreas Mayr, Tobias Lechler, Toni Donhauser, Maximilian Metzner, Eike Schäffer, Eva Fischer, Jörg Franke. Advances in energy-related plant simulation by considering load and temperature profiles in discrete event simulation[J]. Procedia CIRP,2019,81.

[2] System stimulation in water resources: Vansteenkiste G. (Editor),Proceedings of the IFIP Working Conference held at Bruges, Belgium from September 3â5,1975.North Holland Publishing Company,1976, Dfl.105.000[J]. North-Holland,1978,20(2).
[3] Institute of Computer Application and Simulation Technology, Second Academy of the Ministry of Aerospace Industry. Computer engineering and design, 1988(05):61.

[4] Li Jianghe, Luo Jiaquan. Simulation of atmospheric boundary layer in aviation wind tunnel. Journal of Nanjing University of Aeronautics and Astronautics, 1988(04):65-72.

[5] Liu Jingcai. Simulation technology in space shuttle development. Foreign missiles and space vehicles, 1988(12):37-46.

[6] R. N. Ray. Simulation: its application in the nuclear power industry. Engineering Sciences, 1981, 1(4):345-359.

[7] Liang Bingcheng, Wang Xuexiao. Application of hybrid computer real time simulation in aerospace composite material production line process layout based on plant simulation. Aviation manufacturing technology, 2019, 62(04):56-62.

[8] Li Hui, Ji Jiangyu, Zhang Chao. Research on equipment layout of machining unit based on plant simulation. Electromechanical engineering technology, 2018, 47(06):96-101.

[9] Hou Zhi, Ma Guoqing. Optimization of workshop equipment layout based on genetic algorithm. Mechanical design and research, 2019, 35(02):171-174.

[10] Zhang Chao, Li Hui, Tian Kai. Research on layout simulation of aviation integrated aircraft workshop based on plant simulation. Journal of engineering design, 2019, 20(03):199-207.

[11] Zhou Jinping, Su Ping. Design of experiment platform for facility planning based on simulation technology. Experimental technology and management, 2012, 29(08):84-87.

[12] Zhou Ermin, Wang Guiyong, Zhu Jin. Facility layout planning of bench drill plant based on SLP method and EM-plant simulation. Modern manufacturing engineering, 2016(04):89-97.

[13] Peng Fei, Ma Zhi. Study on workshop process layout design based on SLP and plant simulation. Advanced manufacturing system management and operation, 2019(09):28-36.

[14] Peng Jieyang, Wang Jiahai, Shen Bin. Shop layout optimization of aerospace thin-walled structural parts based on optimized simulated annealing algorithm. Manufacturing automation, 2019, 41(07):82-84.

[15] Zhang Zhi, Li Yufan, Xu Shuangxia. Research on product production line layout simulation based on plant simulation. Computer and network, 2019, 45(07):68-70.

[16] Xu Liyun, Yang Shouyin, Li Aiping. Multi-objective optimization and simulation analysis of production workshop layout. Mechanical design and research, 2011, 27(06):55-59.

[17] Yang, S. L., Xu, Z. G., Wang, J. Y., Modelling and Production Configuration Optimization for an Assembly Shop. 2019, 18(2):366-377.

[18] Zhinan Zhang, Yin Wang, Xiaohan Wang, etc. A simulation-based approach for plant layout design and production planning. ORIGINAL RESEARCH, 2019(10):1217-1230.

[19] Zhong Meisu, Yang Yongsheng. Simulation and optimization of AGV path of automatic terminal under unloading operation mode. Water transportation engineering, 2018(04):122-127.

[20] Yang Yongsheng, Wang Nannan, Liang Chengji. Simulation and optimization of AGV path for automated terminal based on the strategy of roundabout. Journal of railway science and engineering, 2018, 15(01):240-246.
[26] Zhou Min, Yu Zhaojiang. Simulation research on path optimization problem based on eM-plant[J]. Science and technology square, 2013(11):13-15+19.
[27] Peng Chuan, Zha Weixiong. Optimization of logistics distribution route based on ant algorithm[J]. Transportation technology and economy, 2011,13(03):89-91.
[28] Jianjun Lin, Yang Sun, XiaoJun Zheng. Optimal AGV configuration by simulation of flow shop scheduling in an assembly plant[J]. Advanced materials research,2014,926-930:3132-3136.
[29] Jiang Zengqiang, Jin Yang, Liang Junyi. Dynamic material distribution strategy of mixed flow assembly workshop under uncertain environment[J]. Computer integrated manufacturing system,2017,23(10):2108-2118.
[30] Wang Xueyang, Xu Anjun, He Dongfeng,etc. Simulation and optimization of ironmaking plant logistics based on plant simulation[J]. Steel research, 2017, 45(01):17-22.
[31] Ren Yuntong, Lu Zhiqiang. Feasibility analysis of SPS logistics model based on plant simulation[J]. Logistics technology, 2016,35 (11):94-97.
[32] Du Shan. Based on the carton production logistics dynamic process simulation[J]. Logistics technology, 2015,34(01):176-179.
[33] Yang Bin. Simulation and optimization of automobile welding production line based on eM-plant[A].write by Zhou Zhili, "GAC Trumpchi Cup" proceedings of the eighth academic conference of Guangdong automobile industry[C].Guangdong: Guangdong Automobile Industry Association,2015,65-73.
[34] Hou Rui, Yin Hong, Hu Xiaoxing. Research on the balance of capacitive screen production line based on simulation technology[J]. Mechanical design and manufacturing engineering, 2013, 42(09):22-25.
[35] Yuan Zhengyu, Guo Wei, Lu Zhaohui, etc. Simulation research on balance problem of decomposing production line of retired automobiles[J]. Journal of Wuhan University of Technology, 2015,37(08):90-97.
[36] Li Shudong, Zhao Yunfeng, Ding Jieqiong, etc. Production capacity analysis of metro vehicle body based on plant simulation software[J]. Journal of Nanjing Institute of Technology (Natural Science Edition) ,2017,15(01):78-82.
[37] Shi Wenling, Zhang Zhe, Wu Peng, etc. A brief discussion on the application of digital simulation in Geely Automobile welding production line planning[J]. Scientific Consultation (Science and Technology · Management), 2016(11):37-38.
[38] Lin Juguang, Wu Wenjie, Cai Lei. Simulation and optimization of BIW side wall welding line based on plant simulation[J]. Modular machine tool and automatic processing technology, 2015(08):111-114.
[39] Han Xiaodong, Liu Dong, Cong Ming, etc. Simulation analysis of engine inspection production line based on plant simulation[J]. Modular machine tool and automatic processing technology, 2015(11):58-60+64.
[40] Li Yan, Xu Zhigang, Wang Bingxu. Research on simulation technology of missile assembly production line based on plant simulation[J]. Tool technology, 2016,50(08):51-54.
[41] Chen Jie, Zhang Song, Du Zhigang, etc. Simulation and configuration optimization of diesel engine cylinder block production line based on plant simulation[J].04 special, 2019(03):31-36.
[42] Li Hui, Sun Yuanliang, Zhang Chao. Simulation analysis and optimization of aero-engine blade machining production line based on plant simulation[J]. Modular machine tool and automatic processing technology,2019(07):116-118.
[43] Liu Zhenhai, Zhou Youxing, Xu Changfeng. Research on production capacity optimization scheme of street lamp pole parts production line based on plant simulation[J]. Modern manufacturing engineering,2020(01):35-42.
[44] Sun Zhichao, Gao Changshui. Research on simulation technology of automobile production line based on plant simulation[J]. Information Technology,,2014,43(06): 161-165.
[45] Wang Qiang. Simulation and optimization of locomotive drive assembly line based on plant simulation[J]. Railway rolling stock, 2016, 36(03):16-23.

[46] Zhang Wei, Zeng Sitong. Simulation and optimization of piston mixed flow production line based on eM-plant[J]. Journal of Longyan University, 2017, 35(05):28-33.

[47] Lu Jinxing, Tao Jianhua. Simulation research on AGVs system of foam ceramic production line based on plant simulation[J]. Electromechanical engineering technology, 2020, 49(03):58-60.

[48] Wang Pinyue. Research on simulation of workshop staffing based on eM-plant[J]. Journal of Guangdong Radio and Television University, 2013, 22(03):110-112.

[49] ZhaoMing Chen. Design and Simulation Study on Automobile Parts Production Line[C]. International Society for Information Technology and Engineering. Proceedings of 2016 4th International Conference on Machinery, Materials and Information Technology Applications(ICMMITA 2016). International Society for Information Technology and Engineering: Computer Science and Electronic Technology International Society, 2016:759-763.

[50] Li Aiping, Guo Haitao. Repair scheduling analysis of automobile assembly production system based on plant simulation[J]. Chinese Journal of Construction Machinery, 2018, 16(01):75-81.

[51] Chen Xiaohui, Zhang Qizhong. Research on computer simulation and optimization of reentrant production shop scheduling[J]. Computer science, 2009, 36(09):297-299+302.

[52] Wang Zhibin. Research on job scheduling simulation based on plant simulation[J]. Logistics engineering and management, 2019, 41(09):72-75.

[53] Chen Gong, Gu Jinhua. Simulation and optimization of ship steel pretreatment workshop based on plant simulation[J]. Machinery manufacturing, 2015, 53(614):65-67.

[54] Xiangke Tian, Jian Wang. The Simulation Optimization for Job-Shop Scheduling Based on Plant Simulation Using Genetic Algorithm. 2012, 2024:1444-1448.

[55] Wu Yanming, Liu Yongqiang, Zhang Dong, etc. Research on RGV dynamic scheduling based on genetic algorithm[J]. Lifting and transportation machinery, 2012(06):20-23.

[56] Dai Boyao, Hu Changwei, Wu Lihua. Simulation of the driving mechanism of die shop rescheduling based on plant simulation[J]. Mold operation and management, 2012, 38(08):1-7.

[57] Wang Hao, Wang Long, Su Ping, etc. Scheduling analysis based on eM-Plant oil refining system[J]. Electromechanical engineering technology, 2013, 42(08):38-43.

[58] Jian Bin Wang, Lu Yang Hou, Wei Li, et al. Simulating an AGV Scheduling in Job Workshop for Optimal Configuration. 2014, 3181:1562-1565.

[59] Ji Li, Pingan Du. Cost Optimization of Scheduling Based on Simulation[J]. Advanced Materials Research, 2011, 201-203:1039-1043.

[60] Wang Xi. Research on the queuing system based on plant simulation[J]. Logistics engineering and management, 2018, 40(09):150-153.

[61] Liu Zhixiong, Xiong Yang, Deng Xingyu, etc. Research on operation simulation of general cargo terminal based on plant simulation[J]. Journal of system simulation, 2018, 30(05):1980-1987.

[62] Li Minghui, Shi Yuqiang, Wang Junjia. Simulation study of packaging manufacturing system based on Em-plant[J]. Manufacturing automation, 2015, 37(12):24-27.

[63] An Qi. Design and Simulation of production material management system based on Internet of things technology[J]. Logistics Engineering and Management, 2016, 38(03):120-121.

[64] Guo Hua, Liu Tingting, Wang Yuan. Optimization design of job shop scheduling based on plant simulation platform[J]. Modern manufacturing engineering, 2016(02):108-112.

[65] Cao Huanhuan, Xu Zhipeng. Research on regional coordination and optimization of large amusement park based on plant simulation[J]. Value engineering, 2016(13):227-230.