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Research Article

Modeling and Optimization for Automobile Mixed Assembly Line in Industry 4.0

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Industry 4.0 promotes the development of traditional manufacturing industry to digitization, networking, and intellectualization. Smart factory is composed of network that includes production equipment, robot, conveyor, and logistics system. According to the characteristics of the mixed flow assembly, a simulation platform of automobile mixed flow assembly is built based on industry 4.0 in the paper, which operates and manages automobile assembly, logistics warehouse, and CPS effectively. On this basis, FlexSim software is adopted to establish the auto-mixed assembly model that finds out the bottleneck of auto-mixed assembly problem. By means of parameter adjustment, rearrangement, and merger of process, the whole assembly time of the 500 automobiles dropped by 33 hours, the equipment utilization rate increased by 20.19%, and the average blocked rate decreased by 21.19%. The optimized results show that the proposed model can greatly increase manufacturing efficiency and practical application in industry 4.0.

1. Introduction

Manufacturing industry has experienced three stages, which are industry 1.0 (mechanization), 2.0 (electrization), and 3.0 (information). Each technology breakout had led to the rapid development of manufacturing industry. Today, the German government officially puts forward industry 4.0 strategy, which integrated industrial robots, networking, cloud manufacturing, and other advanced technology to build a highly intelligent industry 4.0 system [1–3]. Some researchers who came from research institutions and universities as well as SIEMENS, BMW, and other companies have built up research teams, trying to make an intelligent and automated industry 4.0 system [4]. Professor D Zuehlke has set up a demonstration project about the industry 4.0 smart plant, which took liquid products production as an example and designed a set of procedures including order, production and delivery through wireless network, radio frequency identification, bluetooth communication, tablet PC, wearable devices, and other technologies, and it is the first demonstration model of industry 4.0 in the world [5]. Dr. Ruth, who is a chief executive of industrial business in SIEMENS, said that the cross enterprise production network integration is the first thing of industry 4.0, the second one is the combination of virtual reality, and the third feature is the Cyber-Physical Systems (CPS) [6]. In 2015, Chinese government proposed made-in-China 2025, intended to stimulate vitality and creativity, named as Chinese version of industry 4.0 [7]. Lee has analyzed the service innovation of industry 4.0 and big data environment and also explained the relationship between service innovation and industry 4.0 from the production line information flow, equipment state prediction, industry model, and other aspects [8]. Müller analyzed how industry 4.0 drove the change of business model through collecting the sample of 68 small and medium-sized manufacturing enterprises in Germany. First, industry 4.0 means digital, intelligent, and interconnected. Second, industry 4.0 changes the business model of value creation, value acquisition, and value provision [9]. Luthra found out challenges and opportunities of India in industry 4.0 by 96 responses on questionnaire; the study showed that technical and strategic challenge play important roles in industry 4.0 [10]. Shu ZHANG [11] has pointed out two meanings of industry 4.0: one is intelligentization, greenization, and hommization; the

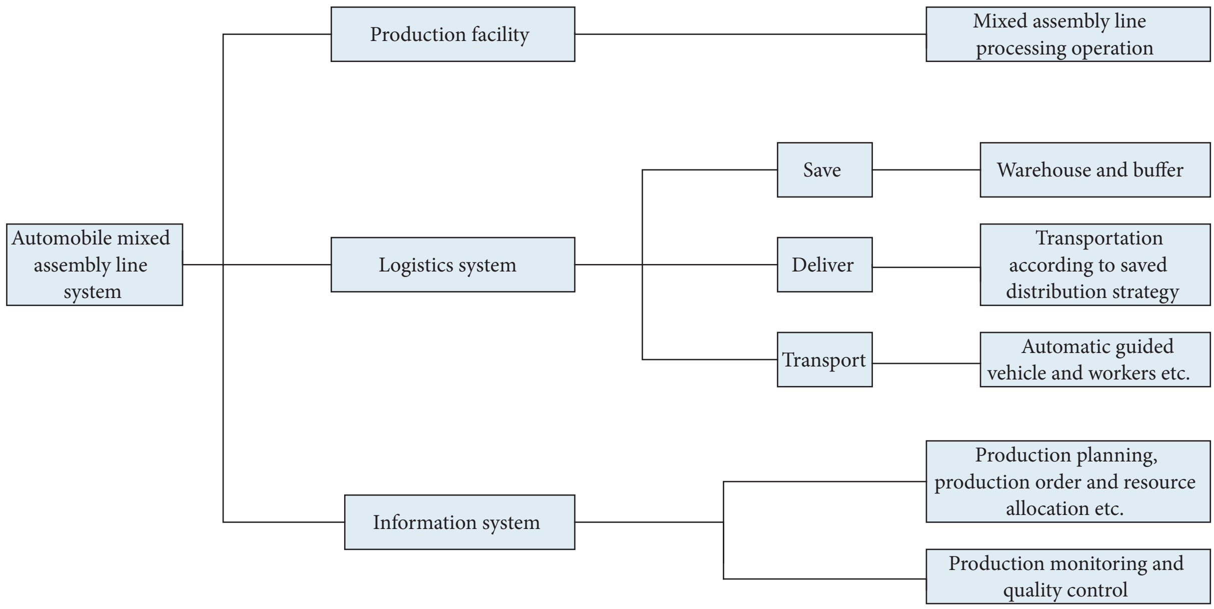

Figure 1: The composition of automobile mixed assembly line system.

other is the deep integration of the network and CPS. He provided Chinese enterprises countermeasures when facing challenges of industry 4.0, which took Shenyang Machine Tool Co., Ltd., as an example. Ping WANG et al. [12] summarized characteristics of management information system (MIS), framework standard, and service of MIS 4.0. Fuquan ZHAO et al. compared industry 4.0 and made-in-China 2025 and pointed out that automobile industry transformation and upgrading are important [13]. As a largest automobile production country, China has carried out some intelligent attempts in the exploration of industry 4.0. For instance, the FAW Volkswagen Foshan Factory has used the MBQ modular technology to produce the Audi and Volkswagen, which realized whole intelligent management. Meanwhile, BYD company has proposed an intelligent strategy concerned with intelligent vehicle, intelligent driving, and intelligent security [14].

However, the automobile assembly process is very complicated. During the implementation of the industry 4.0 intelligent production, it needs to build a reconfigurable assembly line system. The line of production was intelligently optimized and adjusted to satisfy demands of varieties, personalized customization of automotive according to bottleneck of process. Therefore, industry 4.0 automobile mixed assembly line system and optimization simulation platform have been built in the paper, and the modeling technology of FlexSim software has been used to optimize the bottleneck of automotive process. The result shows that proposed method can effectively improve the production efficiency.

2. Automotive Mixed Assembly Line in Industry 4.0

2.1. Characteristics and Framework of Mixed Assembly Line in Industry. The mixed model assembly line system, also known as the mixed assembly line, is the application of the flexible principle in the field of assembly production. The function and operation mode are almost the same in mixed assembly line when different products are mixed and continuously assembled, so it is widely applied for automotive and electrical household appliances. Sometimes, mixed assembly line also refers in particular to the automobile mixed assembly line, in which various automobiles can be assembled and produced in an assembly line. There are five characteristics in industry 4.0 of intelligent production: intelligent factory, intelligent product, mass customization, staff's work, and network foundation.

The obvious difference between modern mixed assembly line in industry 4.0 and traditional machining production line is that modern mixed assembly line is a highly automated system under the control of CPS computer. In process of assembly, CPS can make special function of assembly, and it is a process of information transmission and processing. Characteristics of CPS are equipment automation and interconnection, intelligent and configurable product, intelligent machinery and processes, and personnel with advanced analysis and modeling ability.

The automobile mixed assembly line system is an interconnected and interdependent whole not only including the production equipment, but also the logistics system and the information control system [15, 16]. The framework is shown in Figure 1

It can be seen from Figure 1 that the automobile mixed assembly line system is composed of production facility, logistics system, and information system. Production physical equipment closely cooperates with the logistics system and information systems to complete the specific processing operations. And logistics system is an important part of the mixed assembly system, which allocates and manages the materials or parts by MRP/ERP for data sharing and intercommunication. The main functions of information system are reasonably allocating resources, collecting data of quality

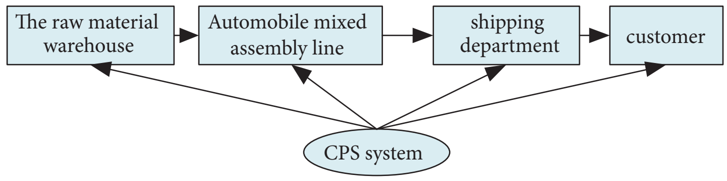

FIGURE 2: The model of industry 4.0 automobile mixed assembly line.

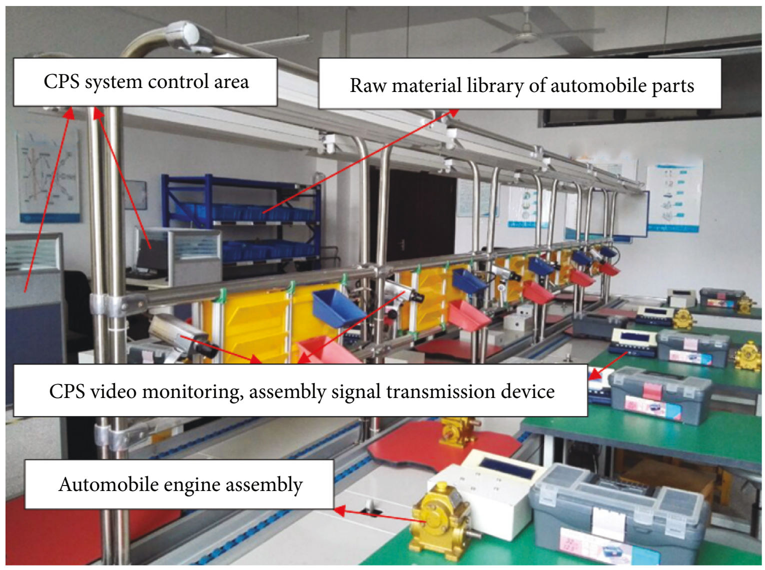

FIGURE 3: Simulation platform of mixed assembly line for industry 4.0 (a).

control, and monitoring operation state of assembly line. Three subsystems run closely to ensure that the production line works properly.

2.2. The Simulation Platform of the Mixed Assembly Line in Industry 4.0. The automobile parts are machined and manufactured with standard and repeatable ways from raw material to processor, and to warehouse in traditional assembly line. In industry 4.0 circumstances, the whole life cycle of products is integrated into Internet; consumers participate in design and manufacture of product in the Internet, so it is required that each process allows feedback on the information processing and adjusts production in real time. Furthermore, the auto-parts are divided into several modules to produce and assemble parts intelligently. The feedback and customization are controlled by CPS from the raw material to processor and then to warehouse. The whole life cycle of products is linked by CPS, and the data analysis system is used to manage and intelligently analyze design, production, and sale. Compared with the traditional automobile production, the main function is the CPS, as shown in Figure 2.

Because industry 4.0 and made-in-China 2025 strategy are still in initial implementation stage, the intelligent manufacturing ability of existing automobile and parts manufacturing enterprises is still between industry 2.0 and industry 3.0. It is not negating and canceling the existing production, but it is the high integration of existing automobile assembly system even if when updating to industry 4.0. A simulation platform of the automobile mixed assembly line has been built in the paper using the resources of the key laboratory on advanced manufacturing technology of auto-parts after referring to theories of cloud manufacturing and digital manufacturing [17–20], as is shown in Figures 3 and 4.

The automobile mixed assembly line simulation platform of industry 4.0 is composed of raw material library, automobile mixed assembly line, finished product automated warehouse, and CPS.

(1) Raw Material Library. Automotive parts and raw materials are stored in raw material library. The inventory management information system created month or week demands of raw material according to order and provided the purchase list to supplier automatically. After these parts reach raw material library, they are stored in the light of inventory prompt. When CPS of mixed assembly system gave the orders, the AGV car and industrial robot executed the orders and sent the raw material to the designated assembly station, and the inventory management information system was updated automatically at the same time.

(2) Automobile Mixed Assembly Line. The process of automotive mixed assembly line is complex, so more flexibility and robustness need to be considered. Monitoring of automobile mixed assembly line is mainly carried out through the production monitoring system, while in this paper, each process of automobile mixed assembly line is monitored in

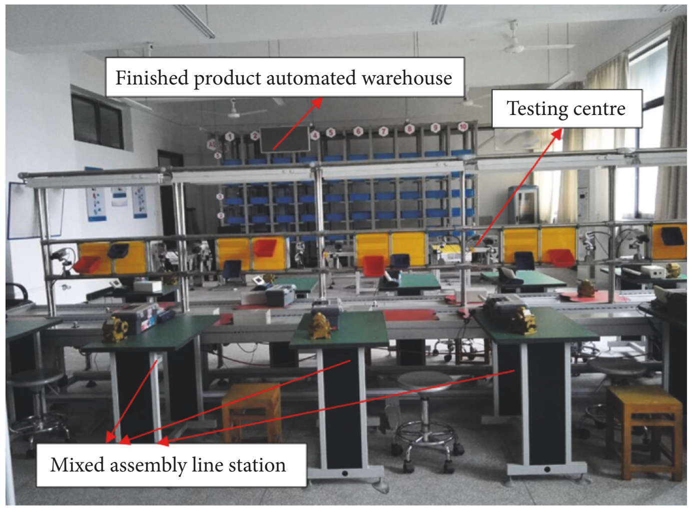

Figure 4: Simulation platform of mixed assembly line for industry 4.0 (b).

time by means of high speed cameras. The desktop e-reader can obtain information of employee ID, label of parts, and assembly process. These data were sent to CPS information system center by the network, and CPS is used for centralized monitoring, intelligent scheduling, and orderly production.

(3) Finished Product Automated Warehouse. Production was entered into finished product warehouse after being tested and assembled. This paper puts forward the automated warehouse to store vehicle for space saved. Also the warehouse is controlled and guided by PLC system and King-view software. CPS gave storage order according to warehouse inventory. Drivers send the finished automobile to specific location, and the PLC system transports the automobile to the warehouse automatically according to the order.

(4) CPS. CPS is the core of intelligent production, which integrates MRP, ERP, MEMS, and other functions. It is a set of highly intelligent expert systems; amount of data are produced and delivered by sensor, video, network, and robot. The software frame of CPS is composed of the terminal, middleware layer, monitor layer, functional layer, and application layer, as shown in Figure 5. CPS is the brain of intelligent production, being in charge of the whole life cycle of production process including analysis, processing, and mining to achieve intelligent production of industry 4.0. The terminal is computer, smart phone, which consults and searches for automobile assembly information online. And the middleware layer runs on the CPS cloud, providing access control and data processing. The monitoring layer mainly keeps watch on automobile assembly quality, logistics, security, robot state, and vehicle transportation through various interfaces and data acquisition components. Accordingly, the functional layer divides the logic relation between the industrial 4.0 intelligent production and scheduling function, so that the upper CPS can call the corresponding function at any time. The application layer is an integrated CPS, which integrates MES, ERP/SCM/CRM, PDM, order management, scheduling management, and quality management.

3. Modeling and Optimization of Mixed Assembly Line for Automobile

3.1. Automobile Assembly Process. Automobile mainly consists of the body, chassis, electrical equipment, and engine. The stamping, welding, painting, and assembly are four processes of the automotive manufacturing. Auto-parts have been assembled on the assembly line after being stamped, welded, and painted. The main production lines include interior assembly line, chassis assembly line, and terminal assembly line, in addition to power assembly and instrument panel assembly [21]. The main process of automobile assembly is shown in Figure 6.

3.2. Modeling of Automobile Assembly Line for FlexSim Software in Industry 4.0. The entire life cycle of products in industry 4.0 is integrated into the production system; consumers participate in the entire life cycle of the product through Internet. Thus each process can give feedback and handle information. Automobile assembly is a complex system; a station of actual assembly can complete the multiprocess. If we take all the processes as object, the assembly line model will be extremely complex, directly affecting the modeling results. Therefore, the main processes were modeled in the paper. The automobile assembly process is shown in Figure 6, the automobile body after painting is sent to the assembly shop and then successively sent to the interior assembly line, chassis assembly line, terminal assembly line, and auto-testing line; finally qualified automobiles are sent to finished warehouse. In order to facilitate modeling and optimization, we propose the following assumptions:

(1) Suppose that the production line assembles three kinds of automobiles, which constitutes a mixed assembly line.

(2) Suppose that there are 10% repair rate in the whole production process.

(3) Suppose that the time interval for the three kinds of automobiles production is 125s.

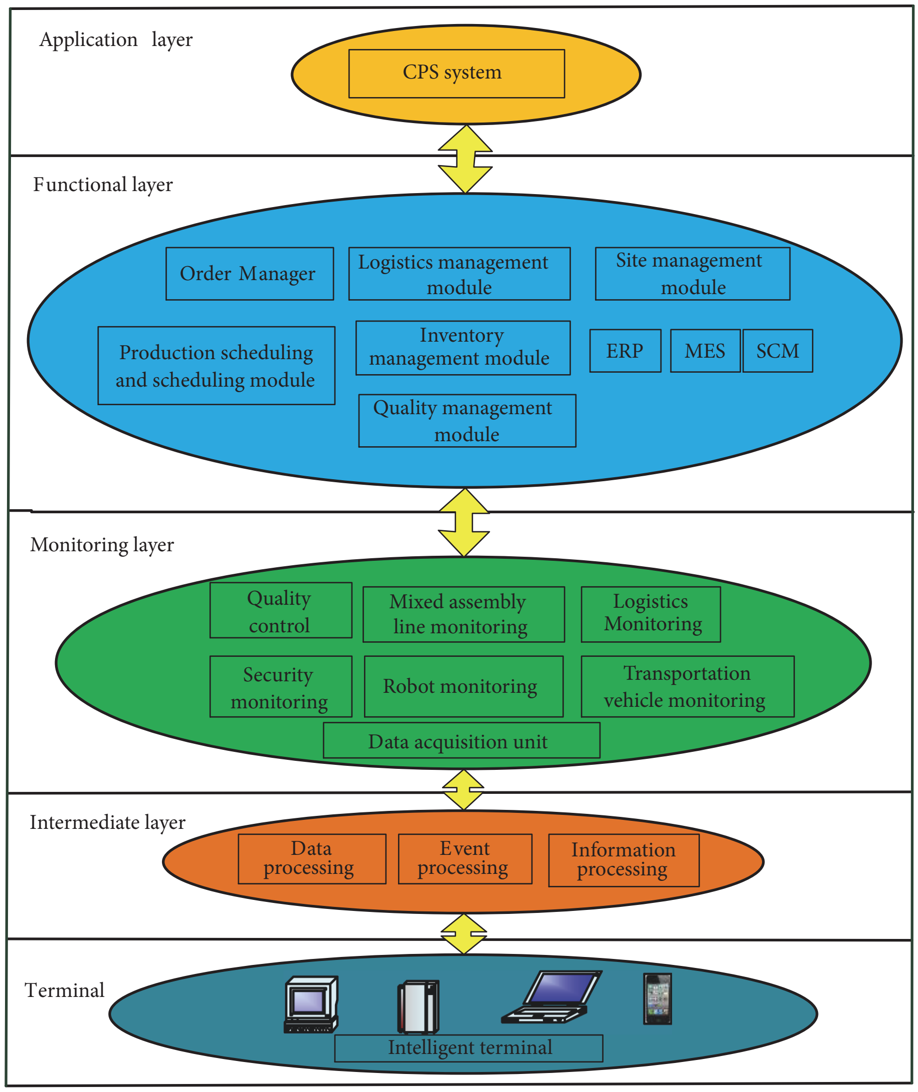

Figure 5: CPS framework.

(4) Suppose that the mixed assembly sequence of the three types of automobiles is as follows: two type 1 automobiles, two type 2 automobiles, and one type 3 automobile. Namely, the scheduling sequence is 1(type)-1(type)-2(type)-2(type)-3(type), and the scheduling cycle is 100 times.

FlexSim is three-dimensional simulation software that is object-oriented for discrete systems, supports C++ language, and is widely applied for manufacturing [22]. The production model of automobile mixed assembly line is built by FlexSim software according to automobile assembly process (Figure 6). Now set the number of model entities, as shown in Table 1.

The processes of automobile mixed assembly are as follows.

Firstly the automobile frame is transported to the first buffer according to the production rhythm. When the first part is received, the first interior processing line starts to run. Then the completed parts are sent to the next interior processing station by conveyor and entered successively in the chassis assembly line, the terminal assembly line, the automobile testing line, etc. The qualified automobiles are sent directly to the finished warehouse with the seventh conveyor, but unqualified automobiles will be sent to the automobile repair area, tested again with other finished cars together, in turn repeated, and finally entered in the finished warehouse until the testing is passed. According to the automobile mixed assembly process and the modeling assumptions, the FlexSim software simulation model of automotive assembly is shown in Figure 7.

FlexSim software simulation modeling attributes and parameters of automobile assembly are set as follows.

(1) Set Source (Generator) Physical Parameters. According to assumptions (3) and (4), we can set the source attributes. Firstly, select Schedule Arrival in the drop down menu of Arrival Style, and change the Number of Arrivals to 6. Then modify the product reached time interval in the Arrival menu, in the ItemName option to modify the type of product,

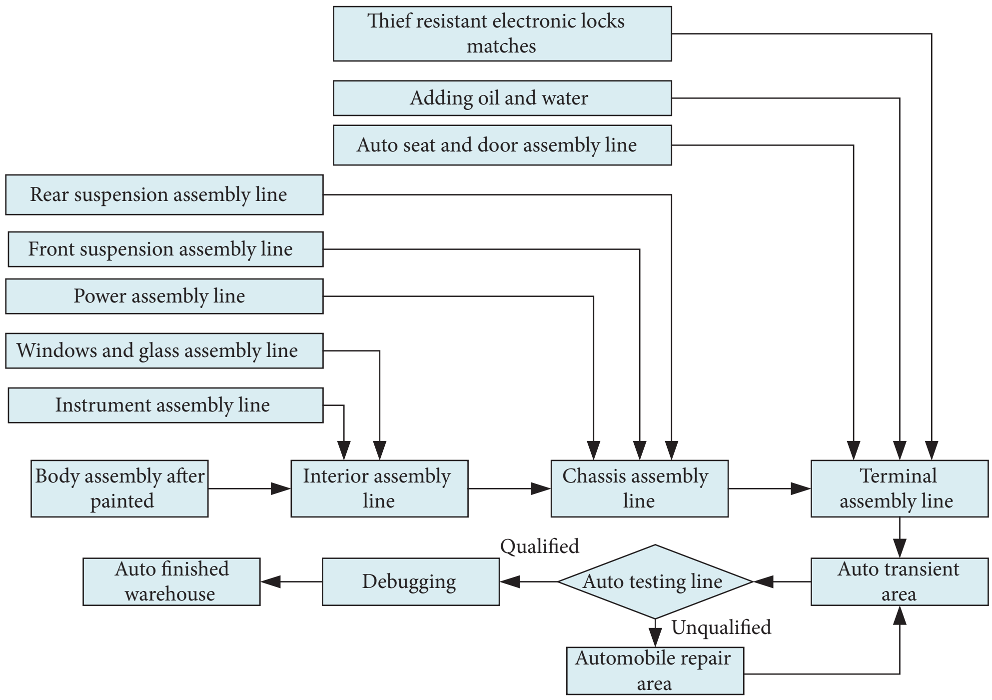

Figure 6: Automobile assembly process.

Table 1: Number and name of model entities.

Entity name	generator	buffer	processor	detector	conveyor	absorber
Number	1	2	5	1	8	1

and in the Quantity option to modify the output of product, as shown in Figure 8.

(2) Set the Buffer (Queue) Parameters and the Processor Parameters. In order that buffer can be enough to store the finished products, set the buffer capacity to 500 to avoid congestion. Because the time for which automobiles stay in the interior line, chassis line, terminal line, and testing line is different, set the processing time as shown in Table 2.

(3) Set Model Stop Time. In order to get running state accurately and data of the FlexSim software simulation model of the mixed automobile assembly system, the model will be automatically stopped while the assembly is completed. The receiver is stopped until accepting 500 assembly automobiles, the code is as follows.

```
If (
getoutput (current) = = 499)
stop()
```

(4) Set Repair Rate. Set the two output ports of the automobile testing center are, respectively, 90% and 10%. 90% indicates the percentage of qualified automobiles, and 10% indicates the percentage of unqualified automobiles which need to be repaired.

The parameters of system simulated model are set and connecting each entity, and the automobile mixed assembly system simulated model based on FlexSim software is built up.

3.3. Simulated Model Analysis and Optimization. After the operation of FlexSim software is finished, the data information of the mixed assembly process can be obtained, as shown in Table 3.

From Table 3 it can be known that the average total assembly time of the 500 automobiles is 399648s; conveyor 1 and conveyor 2 are seriously jammed, whose blocked rates are, respectively, 91.55% and 99.39%, and the load of interior processing line 1 and 2 is large. What is more, the processing rate of chassis line is up to 99.47%, but the buffer 2 is idle. Therefore, the assembly line needs to be optimized and improved.

Because the automobile mixed assembly line is a whole, it cannot be optimized from a single station, but by considering the whole assembly system. Analysis of the production line shows that the bottleneck of the assembly line is the chassis assembly line. The process has a long processing time and high processing rate, which caused the situation that previous processes are jammed, but the follow-up process waited for a long time. The chassis assembly is a necessary process by analyzing the real production system, which cannot be canceled, merged, rearranged, or simplified. So a set of chassis assembly line is added (that is, adding the chassis assembly line 2) to reduce the processing time. At the same time the

TABLE 2: Time parameter setting (unit: s).

Assembly line	Work section	Type 1 automobile	Type 2 automobile	Type 3 automobile
Interior line	Interior 1	375	377	382
Interior line	Interior 2	440	441	445
Chassis line	Chassis assembly	788	790	793
Terminal line	Terminal assembly	355	353	358
Testing line	Testing	202	200	205
Repair line	Repair	221	220	223

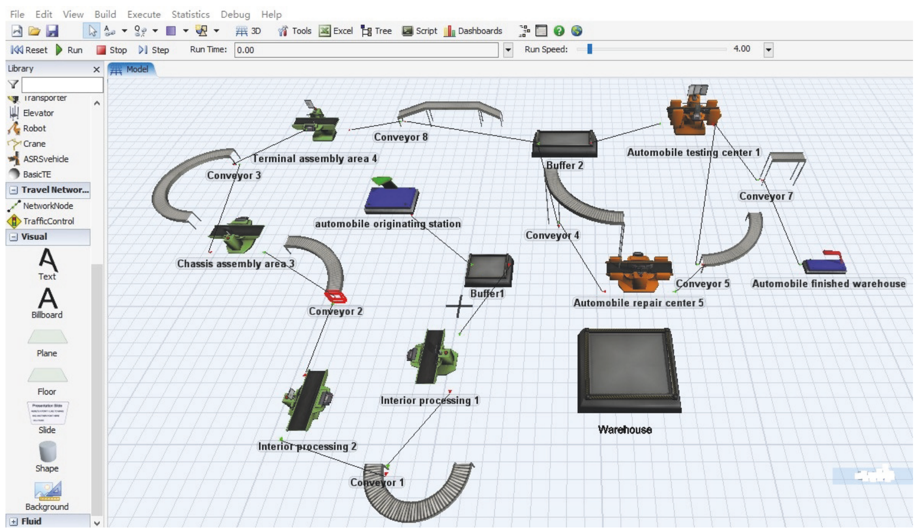

FIGURE 7: FlexSim software simulation model of automotive assembly.

idle rate of the buffer 2 is very high and should be canceled to save space.

The new optimization model is shown in Figure 9. Compared with the original model, the model passed interior processing stations 1 and 2 and then entered conveyor 2, and the percentage of parts that two chassis assembly equipment ports (the chassis assembly area 2 and 3) allocated is 50%. Meantime cancel the low utilization rate of the buffer 2 (the conveyor 6 is also canceled). Automobiles are directly sent to testing center to be checked by the conveyor 8, and qualified productions are sent to finished products warehouse.

The optimized statistic data are shown in Table 4.

Compared with the previous statistic data before optimization, the whole assembly time of the 500 automobiles dropped from 399648s to 280671s; taking the first interior assembly line, for example, blocked rate decreased from 49.58% to 27.55%, and the equipment utilization rate increased from 50.29% to 71.48%, significantly improving the production efficiency. In addition, the empty rate of the buffer 1 increased from 0% to 14.71%; that is, inventory pressure got remission. Compared with before, the blocked rate has dropped by about 10%; that is, it has been improved on some grade. Because the automobile repair center is an essential process line, it cannot be canceled, merged, rearranged, or simplified. Aiming at low utilization rate of automobile repair center, it must be analyzed and considered from updating equipment, improving the technical level of the workers, coordinating production management scheduling, and so on. In short, after the modeling and optimization, the efficiency of the whole automobile mixed assembly production process is effective, which shows that the optimized model and method are feasible and have good practical application value.

4. Conclusions

The successful implementation of industry 4.0 in the future will save a lot of cost for enterprises and bring huge economic benefits. The paper analyzes the automobile mixed assembly line system and builds industry 4.0 automobile assembly line simulation platform with the CPS as the core, to achieve industry 4.0 intelligent production and scheduling. And then, FlexSim software modeling technology can be very good for multiple objectives and complex modeling when solving the problem of manufacturing, logistics, and service. Automobile assembly is a modular production. FlexSim modeling technology can easily build the model of automobile mixed assembly line, quickly find the bottleneck process, and put forward the optimized program. The optimized results show that the optimized model and method proposed in this paper are good guide and reference for solving the complex multiobjective modeling problem.

Data Availability

The statistic data used to support the findings of this study are included within the article.

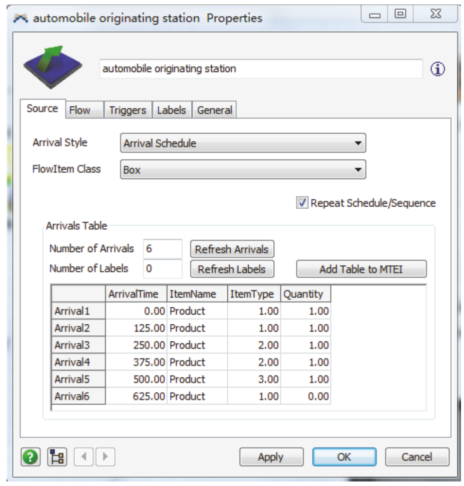

FIGURE 8: Production tack time and interval time setting.

TABLE 3: Statistical data of mixed assembly process.

Object	Class of entity	Input (number)	Output (number)	Stay Time Avg (s)	Since (s)	Idle (%)	Processing (%)	Blocked (%)	Empty (%)
Automobile originating station	Source	0	1034	53500.79	400875	0.00%	0.00%	80.47%	0.00%
Buffer 1	Queue	1034	534	157169.6	400178	0.00%	0.00%	0.00%	0.03%
Interior processing 1	Processor	534	533	750.8	400556	0.00%	50.29%	49.58%	0.00%
Conveyor 1	Conveyor	533	520	9609.4	400236	0.00%	0.00%	91.55%	0.09%
Interior processing 2	Processor	520	519	768.8	400621	0.29%	57.29%	42.29%	0.00%
Conveyor 2	Conveyor	519	505	10711.67	400175	0.00%	0.00%	99.39%	0.53%
Chassis assembly area 3	Processor	505	504	790.79	400175	0.40%	99.47%	0.00%	0.00%
Conveyor 3	Conveyor	504	503	1256.64	400640	0.00%	0.00%	0.00%	0.60%
Terminal assembly area 4	Processor	503	502	355.8	400641	55.42%	44.46%	0.00%	0.00%
Conveyor 8	Conveyor	502	501	1039.83	400456	0.00%	0.00%	0.00%	1.00%
Buffer 2	Queue	556	556	0	400456	0.00%	0.00%	0.00%	100.00%
Conveyor 4	Conveyor	556	555	785.4	399647	0.00%	0.00%	0.47%	11.39%
Automobile testing center 1	Multi-Processor	555	555	223.39	400595	69.05%	30.95%	0.00%	0.00%
Conveyor 5	Conveyor	55	55	785.4	399647	0.00%	0.00%	0.00%	89.38%
Automobile repair center 5	Multi-Processor	55	55	221.09	399647	96.96%	3.04%	0.00%	0.00%
Conveyor 6	Conveyor	55	55	628.32	399647	0.00%	0.00%	0.00%	91.47%
Conveyor 7	Conveyor	500	500	3	400598	0.00%	0.00%	0.00%	99.63%
Automobile finished warehouse	Sink	500	0	0	399648	0.00%	0.00%	0.00%	0.00%

Table 4: Statistic data of mixed assembly process after optimization.

Object	Class of entity	Input (number)	Output (number)	Stay Time Avg (s)	Since (s)	Idle (%)	Processing (%)	Blocked (%)	Empty (%)
Automobile originating station	Source	0	706	208.7	282000	0.00%	0.00%	0.00%	0.00%
Buffer 1	Queue	706	535	27778	282000	0.00%	0.00%	0.00%	14.71%
Interior processing 1	Processor	535	534	523.8	282314	0.78%	71.48%	27.55%	0.00%
Conveyor 1	Conveyor	534	521	6449	281988	0.00%	0.00%	81.71%	0.15%
Interior processing 2	Processor	521	520	539.9	282368	0.41%	81.44%	17.96%	0.00%
Conveyor 2	Conveyor	520	506	7027	281927	0.00%	0.00%	88.52%	3.53%
Chassis assembly area 2, 3	Processor	264	264	802.1	280671	24.55%	74.29%	1.07%	0.00%
Conveyor 3	Conveyor	242	241	808	281928	30.93%	67.52%	1.47%	0.00%
Terminal assembly area 4	Processor	505	503	1347	281893	0.00%	0.00%	16.21%	0.85%
Conveyor 8	Conveyor	503	503	355.8	282247	36.59%	63.23%	0.00%	0.00%
Buffer 2	Queue	535	533	1045	282144	0.00%	0.00%	1.07%	1.42%
Conveyor 4	Conveyor	-	-	-	-	-	-	-	-
Automobile testing center 1	Multi-Processor	533	533	223.4	282369	57.83%	42.17%	0.00%	0.00%
Conveyor 5	Conveyor	33	33	785.4	282369	0.00%	0.00%	0.00%	90.82%
Automobile repair center 5	Multi-Processor	33	32	221	282369	97.50%	2.50%	0.00%	0.00%
Conveyor 6	Conveyor	-	-	-	-	-	-	-	-
Conveyor 7	Conveyor	500	500	3	282372	0.00%	0.00%	0.00%	99.47%
Automobile finished warehouse	Sink	500	0	0	280671	0.00%	0.00%	0.00%	0.00%

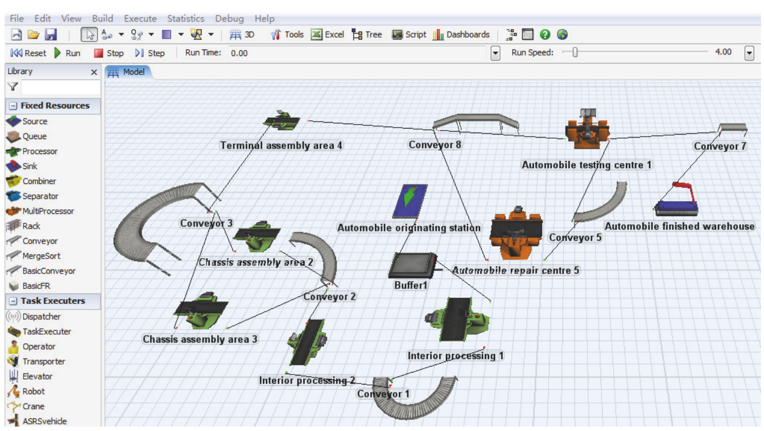

Figure 9: Optimization model of mixed model automobile assembly line.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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