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Research Article

Keywords: Intelligent manufacturing workshop, Production system optimization, Digital twin, Textile production

Posted Date: June 2nd, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-554403/v1>

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Version of Record: A version of this preprint was published at The International Journal of Advanced Manufacturing Technology on October 9th, 2021. See the published version at

<https://doi.org/10.1007/s00170-021-08171-3>.

Construction of intelligent integrated model framework for the workshop manufacturing system via digital twin

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Abstract:

With the drastic development of the globally advanced manufacturing industry, transition of the original production pattern from traditional industries to advanced intelligence is completed with the least delay possible, which are still facing new challenges. Because the timeliness, stability and reliability of them is significantly restricted due to lack of the real-time communication. Therefore, an intelligent workshop manufacturing system model framework based on digital twin is proposed in this paper, driving the deep inform integration among the physical entity, data collection, and information decision-making. The conceptual and obscure of the traditional digital twin is refined, optimized, and upgraded on the basis of the four-dimension collaborative model thinking. A refined nine-layer intelligent digital twin model framework is established. Firstly, the physical evaluation is refined into entity layer, auxiliary layer and interface layer, scientifically managing the physical

resources as well as the operation and maintenance of the instrument, and coordinating the overall system. Secondly, dividing the data evaluation into the data layer and the processing layer can greatly improve the flexible response-ability and ensure the synchronization of the real-time data. Finally, the system evaluation is subdivided into information layer, algorithm layer, scheduling layer, and functional layer, developing flexible manufacturing plan more reasonably, shortening production cycle, and reducing logistics cost. Simultaneously, combining SLP and artificial bee colony are applied to investigate the production system optimization of the textile workshop. The results indicate that the production efficiency of the optimized production system is increased by 34.46%.

Key words: Intelligent manufacturing workshop, Production system optimization, Digital twin, Textile production

1. Introduction

With the drastic development of the globally advanced manufacturing industry, the transition of the original production pattern from the traditional industries to the advanced intelligent is finished with the least delay possible, which are still facing new challenge. Because of the dynamic nature of customer orders, the uncertainty of resource acquisition, the complexity of manufacturing process, and dynamic liquidity of the production chains and logistics information in the traditional workshop manufacturing system is worse, leading to the

perspective of global optimization to realize harmonious operation ^[1, 2].

The manufacturing and logistics linkage of dynamic decision-making method can achieve each link of production and logistics unit in harmony with the aspects of production planning, resource allocating, workshop system and decision parameters, that is the key reason to implement the efficient working of the workshop manufacturing. Therefore, building a well-functioning production system has become an urgent problem for the manufacturing enterprise that needs to be resolved imminently.

The dynamic communication of the workshop manufacturing system plays a decisive role in the timeliness, stability, and reliability. The construction of a favorable production system can effectively promote various production links between the deep integration of information and physical and the dynamic interaction of the data. The prominent dynamic interaction problem has always existed in the manufacturing system from the intelligent production workshop, which is also a problem that researchers have been trying to solve ^[3, 4]. The design of the manufacturing system is a reasonable configuration that provides the layout of the entire manufacturing workshop using scientific methods, and means to form a harmonious and efficient working workshop. Once its design is not reasonable, depth cooperation, information coordination and producing efficiency of the production links may be significantly delayed.

In recent decades, with the progress of optimization algorithm and computational technology, the optimized model of the workshop manufacturing system has been developed rapidly. In view of establishment of the intelligent system in the layout, lifecycle, scheduling and other aspects of the manufacturing workshop, scientific researchers put forward the concept of digital twin ^[5-7]. The functional system of digital twin with physical entity and twin model can achieve local dynamic optimization, which makes a tremendous impact in driving the intelligent management and production of the manufacturing workshop ^[5-8]. Therefore, utilization of digital twin can solve the critical problems of intelligent model from the workshop manufacturing system ^[9]. The results made clear that the production capacity of welding workshop can be increased up to 29.4% by optimizing the layout of discrete manufacturing workshop with digital twin ^[10]. In order to reduce the defect rate and stock of the products and improve production yield, a digital dual drive production management system (DTPMS) for production lifecycle management was established in the manufacturing process of heavy truck gearbox, which implemented the real-time synchronization, better fidelity and virtual integration of the network physics by carrying out meticulous process ^[11]. Moreover, for the sake of enhancing the effectiveness of intelligent scheduling strategy in the actual production of aero-engine gears, a fast and effective intelligent

scheduling method for workshop operational plan was proposed owing to the advantages of digital twin and super network ^[12]. The uncertain factors from the production activities were managed and controlled comprehensively by above method. Consequently, the planning and scheduling scheme in the production process can accurately and availably guide the actual production ^[13, 14].

Nevertheless, many researchers have illustrated that the application of digital twinning technology to optimize the manufacturing systems also has some limitations ^[14-16]. First, the possible and dynamic results of whole physical entity is not real-time tracked and provides a passive response using the algorithm. Second, the algorithm with the poor circulation leads to a large deviation between the local optimization results and the global optimized solution. Finally, the best optimization effect is not reached for the workshop manufacturing. So far, few papers have been published on the implementation of optimization algorithms in the process of transforming and upgrading of the digital workshops in intelligent manufacturing. In order to reinforce the interaction of the information system in the intelligent manufacturing workshop, it is necessary to combine the algorithm optimization with the advanced technologies composing of the intelligent digital network, the digital technology platform and the application architecture, etc.

Systematic layout design (SLP) is a set of methodical, gradual and

applicable methods for the layout of a design project. The method is carried out to optimize the layout of the manufacturing workshop, the layout of each operation unit and the planning and adjustment of the equipment. The implementation process of this method is divided into the following steps. First, the relationship with the logistics and non-logistics is analyzed. Then the locations of the operation unit and the related charts are drawn. Finally, the optimized evaluation is carried out to choose the best workshop layout scheme, for instance, the recycled rubber plant site was divided into the different regions using the SLP method. The site layout and regional resource allocation of the recycled rubber plant were then optimized from the perspective of logistics and non-logistics, which worked out the optimal layout scheme of the recycled rubber plant ^[15]. However, the single SLP method is difficult to control the total volume and lower the layout area in the manufacturing workshop. However, the researchers combined SLP with genetic algorithm, and applied to the workshop layout to successfully achieve the reduction of the logistics quantity and transportation cost ^[16]. The results suggest that the SLP method is only limited to the local optimization of the physical entities, and fails to the interconnection of other production systems in the workshop. To address this issue, an intelligent algorithm is supplied to integrate and communicate information between upper and lower layers ^[17-19]. At present, the most popular intelligent algorithm used as the layout

optimization of the industrial workshop is artificial bee colony (ABC) algorithm. It is a fresh global optimization algorithm based on swarm intelligence, which is derived from the honey-gathering behavior of bees. According to their respective division of labor, the information sharing and communication is realized by the bees carrying out different activities to find the optimum solution of the problem. When SLP method is combined with intelligent algorithm to solve the multi-objective problem of the optimized workshop layout, the former has some problems with strong subjective intention and large error of the scheme design. For the latter, the initial conditions of the intelligent algorithm, such as ABC algorithm, are generated randomly and are easy to fall into the local optimum and the convergence speed is slow in the later stage of evolution. Therefore, the application of the algorithm in the digital twin for the manufacturing system of the traditional workshop still has the following limitations: (1) the specific application model is not clear enough, and the integration and management of physical spatial data and information spatial data in the manufacturing process is lacking; (2) The interaction between workshop physical space and information space is an open-loop process, that is, the information space directs the production of physical space in one direction.

In the light of the issues above, a intelligent workshop manufacturing system model framework is proposed based on digital twin in this paper.

Compared with the traditional digital twin method, this paper takes the four-dimensional collaborative model as the guiding principle. A more detailed and optimized construction is carried out for each building layer. More emphasis is placed on the liquidity of dynamic data as well as the comparative analysis and interactive fusion between the virtual and the real-time to achieve the real-time, continuous, and transient simulation and optimization.

Through the interaction between virtual model and physical entity, the production process of physical workshop can be accurately simulated to provide decision and support for production activities. Simultaneously, in the construction of the information layer and case application, the optimization algorithm is improved and upgraded, and the diverse artificial intelligence algorithm is incorporated into overcoming the shortcomings of each algorithm. This the decision has a more real-time guiding significance for the actual manufacturing workshop. Then, the proposed method is applied to a textile manufacturing workshop.

The remaining part of this articles is described in detail below. In the second section, the fundamental thought of constructing digital twin workshop is introduced on the basis of four-dimensional collaborative model. In the third section, the traditional digital twin framework is refined, optimized, and upgraded. A refined nine-layer intelligent digital twin model framework is established. In the fourth section, the

framework of the proposed digital twin in workshop manufacturing system is conducted in case study of a textile workshop, which is optimized for the workshop layout according to the requirements of the textile workshop. Finally, the conclusions and prospects are described.

2. Digital twin

Digital twin is defined as a technique of digital mapping and twin body model reconstruction in the virtual space conducting full factor elements, such as composition, function, performance, process, and state of the real space objects in the whole lifecycle ^[20]. Based on entity object information and virtual framework data, the digital twin can perform hyper-realistic mapping and transmit the twin data feedback into the real space, which provides information reference and decision-making support for entity object and enhances the coupling time of limitation between physical objects and digital twins in a timely and accurate manner ^[21]. The information carrier of data twin is the software system integrated with digital technologies such as big data and artificial intelligence. It can obtain data and information beyond the existing cognition and then predict the future development trend of the real space. At the same time, Virtual control of the entity object is realized through the fusion of the integration of virtual reality. Thus, the entity object can implement the transmission and reception of digital twin virtual analysis information through the perception, control, and IoT. Finally, the optimization and

improvement of the entity object can be promoted.

2.1 Basic hierarchy structure of digital twin

The digital twin falls into three basic parts: physical evaluation, data evaluation and information evaluation. The physical evaluation reflects the interrelation and connection between objective entities for the manufacturing workshop. It is not only the main link in the production processing, but also the connecting hub of enterprise management, playing a role of a connecting link between the preceding and the following in the manufacturing workshop. Workshop production activities are carried out by the physical layer. In addition, all aspects of information data in the physical space layer are provided to the upper level by the physical layer, such as material flow, equipment operation data, personnel management information, production environment monitoring, etc.

The data evaluation is primarily employed to perform acquisition, processing, analysis on the system data. Stored real-time data in the workshop system is being widely used in fields of controlling workshop production activities and layout due to its diverse system model, high-speed transmission, multi-source heterogeneous information system.

With the help of the workshop data processing and analysis system, the collection, arrangement, analysis, and conclusion of the data will be used as the information evaluation which is an important decision-making

basis for the regulation of workshop production activities. It is a pivotal bridge connecting the physical evaluation and the information evaluation. According to the production workshop requirements and work dynamic changes, the information evaluation serves as the information management platform of the workshop production activities to realize the comprehensive scheduling operation and management analysis of the system model framework.

2.2 The intelligent integrated design ideology of digital twin

In this paper, as shown in **Figure 1**, the integrated design ideology of intelligent manufacturing system mainly has four fundamental characteristics as follows:

In the course of the design and implementation, by applying the analysis of the actual demand, this period identifies the primary production targets for the workshop activities in the lifecycle of information systems. The set predetermined production target is carried out by allocating the specific task breakdown and efficient programming reasonably in the given time. Based on the optimization analysis of alternative structural design schemes of adopting the swarm intelligence algorithm, this paper verifies the correctness of the scheme on feasible structure of swarm intelligence algorithm by the experimental data. Consequently, a lifecycle thought provides a reliable guarantee for the specific implementation of the program and the operation and maintenance guarantee of daily

production.

The design ideology of the physical entity is that the foundation of system design is analyzed from the physical object of the manufacturing workshop as the foundation template, including all kinds of machining equipment, underground logistics system, storage equipment system, sub-system controlling system, an overall controlling system in the workshop. Subsequently, with the help of the new physics entity it successfully explains the idea from the local to the whole by the analysis of digital twin theory, such as individual equipment, production space, sub-controlling system, master controlling system, etc.

The process elements of product production are composed of five factors: product, output, technological process, auxiliary department and time. For example, the logistics demand and material flow of raw materials, the similarity of operation nature, the continuity of process flow, noise, vibration, and other environmental factors.

Construction of the physical objects in the manufacturing workshop is conducted by virtual space including 3D modeling of the workshop, twin data, process optimization, and task programming. Then, the two-way interaction containing information, resources, and data between entity space and virtual space is realized by the controlling system. Simultaneously, the fusion of multi-source data, for instance, the whole process, all elements, the whole system, and the whole discipline, in the

production workshop is implemented by the controlling system.

Figure 1. The integrated design ideology of intelligent manufacturing system.

3. Construction of an integrated model framework

The method of information system integration in the traditional production workshop is prevailingly employed to obtain effective data of manufacturing equipment and logistics equipment. According to different production tasks, the information collection method for arranging the workshop of work area layout and production activities is mutually independent in the process of data processing, for instance, the implementation process of the manufacturing execution system. In spite of the execution of the system, the automation level of the manufacturing workshop has been elevated to a certain extent. Nevertheless, the respective work areas, and information exchanges in the manufacturing workshop are carried out independently, leading to blockage of dynamic

transmission of information, lacking the exchange of information and lowing intelligent level of management and control. To strengthen the interdependence, intelligence, and integration of production information system, artificial intelligence algorithm, data dynamic acquisition, IoT, and other advanced digital technology are introduced into the production information system to resolve the above information system defects. After considering dimensions of the lifecycle, physical entities, process elements, and virtual space, the intelligent production system of the integrated workshop based on a digital twin is developed in this paper.

3.1 Physical evaluation

The construction of physical evaluation is mainly composed of workshop entity, physical modeling, auxiliary detection equipment, and workshop interface layer, as shown in **Figure 2**.

The workshop entity is defined as the indispensable entity elements of daily production and processing in the production workshop including interaction effect factors comprised of processing equipment, material carrying system, operators, and production environment. Meanwhile, the entity elements in accordance with the real entity size and function are transformed into the simulation environment, including equipment model, raw material model, virtual environment, and virtual personnel, which is constructed in a Software environment by combining three-dimensional entity modeling and entity mapping method. The operational performance

of the equipment in the production workshop, the transportation of the materials, the working conditions of the operators, and the production environment need to be assisted by auxiliary monitoring equipment, consisting of the configuration of sensor, controller, PRID, and industrial camera, to monitor the production requirements in the real-time. The real-time data is stored and dynamically transmitted to the controlling system in the perceiving process. In such cases, the task commands from the interface layer are received and obtained via the controller and the controlling terminal interface. Subsequently, the information control system is fed back to the interface layer accessible regarding the decision information to realize the dynamic interaction of perceptual controlling, decision instructions, and information.

The interface layer of the workshop, mainly composing of a local area network (LAN), Fieldbus, platform network, server, and client, can achieve physical synchronization of information between virtual space and physical system. The communication interface network between the virtual space OPC client and the physical system OPC server is established by utilizing LAN, Fieldbus, and platform information network communication system under the functional definition of data mapping. The interface information transmission between the virtual space and the physical system is finally available.

Figure 2. Physical evaluation structure.

3.2 Data evaluation

Data evaluation is a technology that can manage, process, and analyze data during the interaction between the database management system and the data processing operation platform, as shown in **Figure 3**. The database management system mostly comprises three aspects: logistics data, non-logistical data, and basic data. The logistics data focuses on managing the fresh material consumption, the division of operation area, the transportation path of AGV, and the operation as well as maintenance of logistics equipment in the manufacturing workshop. Whereas, non-logistical data is divided into the manufacturing workshop personnel, the cycle time of the processing equipment, the relevant data of the production environment, and the inspection of the processing process. Moreover, the basic data aims to cover all aspects in dealing with the total

area of the manufacturing workshop, the essential occupied area of the processing equipment, and the area required for the reserved safety channel. The whole data system in the manufacturing workshop is fundamentally covered by collecting the above-mentioned three broad categories of data.

The data processing operation platform performs data activities that are essentially relegated to the real-time data and the twin data system, such as cloud computing, big data, data storage, and deep learning. Nevertheless, the collection, storage, processing, and analysis of the intelligent production system in the workshop can be realized attributing to the adoption of cloud computing and big data processing technology. Then, the data processing operation platform is triggered extracting effective information and realizing the association and transmission of multi-source heterogeneous data through data storage, deep learning and other technologies. Ultimately, the big data storage and processing in the manufacturing workshop is acquired by accounts of large-scale distributing cloud computing data processing and analysis platform.

Figure 3. Digital evaluation structure.

3.3 Information evaluation

Figure 4 exhibits that the detailed structure diagram of the information evaluation consists of the system layer, functional layer, algorithm layer, and scheduling layer.

The system layer is responsible throughout the whole process of workshop production, including quality traceability, equipment perception, operation and maintenance guarantee, data analysis, and experience learning, which can advance the interconnectivity of each segment.

The function layer predominantly consists of order analysis, process design, structural analysis, operation and maintenance evaluation, health management, fault prediction, and life evaluation. For the production process in the whole lifecycle of the workshop production system, the service menu bar of the overall design is developed according to the requirements of the system layer divided into various service functions.

The workshop requirements are optimized by the algorithm layer by combining artificial intelligence algorithms with data layer collections under the adjustment of correction conditions and actual constraints. Then, the optimization results are outputted to the receiving layer through the algorithm layer.

The scheduling layer receives the final optimization results outputted by the algorithm layer, which governs the adjusting AGV scheduling,

workshop layout optimization, processing equipment management, process optimization, and personnel management to enable a quick response to the dynamic workshop production process and task orders.

Figure 4. Information evaluation structure.

4 Case study

This paper takes textile workshop production as the case study object and develops the integrated layout framework of the intelligent production system in the textile workshop via the actual case analysis using the research method of a digital twin. The integrated layout framework includes the whole process of task analysis, physical modeling, data collection, information analysis, and result optimization.

4.1 Construction of physical evaluation

The spindles are the key object of investigation for the production process of electronic grade glass fiber cloth in the intelligent textile workshop and are related to timely feeding the logistics links and operating state of the

textile machine. One of the textile fresh materials is transported by accessing services of the AGV to dominantly provide for three stages:

(1) intelligent logistics conveying equipment for weaving process and drawing fresh materials equipment from warehouse district through the AGV services; (2) fresh materials equipment of the textile transported to automatic feeding and unpacking area, the manipulator taking out the spindles and putting a double-layer reflux displacement device for transmission according to the feeding transmission requirements; (3) multiple AGV distributing in different textile regions to carry out the real-time state detection of the textile machine and travel between the feeding point and various textile areas to ensure automatic delivery and recycling of textile spindles.

Based on the process of building the above physical evaluation, 3D modeling technology is conducted in the light of the above processing process and physical analysis. The structure diagram of the physical layer in the textile workshop is shown in **Figure 5**.

Figure 5. Construction of physical evaluation.

Among them, fresh materials of the textile are dominantly executed by accessing services of the AGV system. The transmission routes for spindles transportation in the textile workshop are shown in **Figure 6**.

Figure 6. The transmission routes for spindles transportation.

Dimensions of the textile workshop are 130 m in length and 280 m in width. Accordingly analyzing operation process rationally, the designated operations areas for the textile workshop are divided and labeled in the

process of creating the physical layer. The designated operation areas and each working area with their respective occupation size in the textile workshop are shown in Table 1.

Table. 1 Area of each operation unit

Serial number	Area name	Length/m	Width/m
1	Fresh material storage area A	20	15
2	Fresh material recovery area A	15	10
3	Fresh material storage area B	15	10
4	Fresh material recovery area B	10	5
5	Textile area 1	50	38
6	Textile area 2	50	38
7	Textile area 3	50	38
8	Textile area 4	50	38
9	Fresh material temporary storage area	5	5
10	Automatic unpacking and loading device	5	1.5
11	Empty container temporary storage area	10	5
12	Double-layer reflux displacement device	22	1.2

4.2 Construction of data evaluation

The establishment of the data evaluation in the textile workshop aims to evaluate the relationship of logistics and non-logistical between the working areas. The starting point of investigating engineering layout problems is defined as five basic elements, which are: product P, output Q, process R, auxiliary department S, and time T, and are analyzed comprehensively [8]. In this case, the comprehensive relation of each working area can be obtained and the layout of the workshop can be optimized. The statistics of logistics factors comprise the usage amounts of spindles and logistics quantity of other textile fresh materials. Meanwhile, non-logistics factors data of the textile workshop is collected, such as the similarity of working nature, the continuity of the

technological process, influence of noise, vibration, textile random thread on the environmental factors.

Subsequently, the essential information of the data evaluation is partially processed and analyzed by the SLP algorithm. Major factors affecting the logistics in the manufacturing workshop are: the logistics quantity, the distance of transmission, and the direction of fresh materials transportation between different working departments. SLP analytical methods commonly expressed by the relation diagram method is prevailingly divided into six levels containing A、E、I、O、U、X [13], meaning and relationship of which are shown in Table 2.

Table 2. Meaning and relationship levels between working departments

Symbol	Quantification	Closeness	Proportion
A	4	Absolutely important	Less than 5%
E	3	Particularly important	5%—10%
I	2	important	5%-15%
O	1	commonly	10%—25%
U	0	unimportant	40%-75%
X	-1	negative correlation	

According to the actual production situation of a textile Co., Ltd, the logistics intensity is obtained by the following summary table, as shown in Table 3.

Table 3. Summary table of logistics intensity

Operation unit	Logistics volume/kg	Hierarchy
1-9	4485120	E
2-11	336384	U
3-9	3363840	E
4-11	224256	U
5-12	840960	O
6-12	2522880	I
7-12	2522880	I
8-12	2522880	I

9-10	7848960	A
10-11	560640	O
12-10	8409600	A

In accordance with the characteristics of production equipment from company, the reasons for the degree of mutual affinity among the working departments are formulated, as illustrated in Table 4. The relationship diagram of non-logistics working departments on account of results formulated in Table 4 is drawn, as indicated in **Figure 7**.

Table 4. Reasons for mutual affinity of each working department

Symbol	Closeness	Number	Reason
A	Absolutely important	1	Continuity of Workflow
E	Particularly important	2	Material handling
I	important	3	Production services
O	commonly	4	information transfer
U	unimportant	5	Personnel contact
X	negative correlation	6	Supervision and management
		7	Safety and pollution
		8	Noise, vibration, coil

Analyses are carried out by the influence of the warehousing logistics and non-logistical factors, the intensity of logistics, and the close degree of non-logistics are classified into A=4, E=3, I=2, O=1, U=0, X=-1. Meanwhile, the comprehensive relationship value of the working departments is calculated on the basis of the quantifiable levels and the experts determining weights, which is correspondingly transformed into six grades of A, E, I, O, U, X. Finally, the comprehensive interrelation diagram of the working departments is obtained, as shown in **Figure 7**. The proportional value of logistics and non-logistics is respectively 0.7 and 0.3, according to the real demand for processing production.

Figure 7. Analysis of the comprehensive interrelation of each working department.

4.3 Construction of information evaluation

The dynamic of information feedback and the dynamic data for information evaluation is respectively obtained and uploaded owing to the logistics information and basic information collected by data evaluation calculated preliminary.

Taking workshop layout as an example, a multi-objective optimization function is established to lower the production cost, maximizing the production efficiency, and minimize the area occupied by the working area. As follows:

$$C = \min \left(\sum_{i=1}^n e_i + \sum_{j=1}^m m_j + \sum_{k=1}^p h_k \right) \quad (1)$$

Where C is the total costs of production and transportation in the textile workshop, e is the cost of transportation and auxiliary equipment in the textile workshop, m is the cost of processing materials, h is the cost of labor workers.

$$E = \max \sum_{i=1}^n \sum_{j=1}^m s_i t_j \quad (2)$$

Where E is the total efficiency of the production and transportation in the textile workshop, d is the production efficiency of mechanical processing, t is the efficiency of spindle transport.

$$S = \min \sum_{i=1}^n \sum_{j=1}^m l_i d_j \quad (3)$$

Where S is the total area of the site area required for the production and transportation of the machinery in the textile workshop, l is the area occupation of the equipment, d is a safe reserved distance between devices.

Therefore, multiple objective functions are converted into a single objective function.

$$\min F = -w_1 f_1 \max E + w_2 f_2 \min C + w_3 f_3 \min S \quad (4)$$

Where w_1 is the weight of total production efficiency, w_2 is the weight of total production cost, w_3 is the weight of total production area, and the sum of the three parameters is equal to 1: $w_1 + w_2 + w_3 = 1$.

In order to unify dimensions, the normalized factors f_1 , f_2 , and f_3 are as follows:

$$f_1 = \frac{1}{\sum_{i=1}^n \sum_{j=1}^m s_{\max} t_{\max}} \quad (5)$$

$$f_2 = \frac{1}{\sum_{i=1}^n \sum_{j=1}^m \sum_{k=1}^p e_{\max} m_{\max} h_{\max}} \quad (6)$$

$$f_3 = \frac{1}{\sum_{i=1}^n \sum_{j=1}^m l_{\max} d_{\max}} \quad (7)$$

The ABC algorithm first initializes the defined parameters for ensembles of models. The close relationship degree between logistics and non-logistics of working departments determined using the SLP method limits the range of the initial population so that the randomly generated population is closer to meeting the real workshop demands. Random generation of NP population is the sum of leading bees and scout bees. If the amount of honey sources is equal to half of the population quantity, the superior and lower boundaries of the initial honey source position are corresponding to ub and lb , where ub is the lower boundary of the parameter, lb is the superior boundary of the parameter. The maximum number of times for the honey source searched is defined as a “limit”, which means that a honey source fails to improve after passing the “limit” for several times of the experimentation and is then abandoned by hired bees. The maximum number of iterations for a honey source refers to “maxCycle”, which is also the number of foraging cycles.

Figure 8. Overall system structure diagram.

4.4 Optimization routine and parameter design

In this case study, the comprehensive affecting factors on transportation cost, production efficiency, and production area are considered. Hence, the enactment weighting coefficients in the objective function are $w_1=0.20$, $w_2=0.45$, and $w_3=0.35$, respectively. The comprehensive influencing factors between logistics and non-logistics are confirmed by the SLP method, imposing restrictions initially generated population by the artificial honey colony algorithm. Here, the initial population (NP) is 24, the number of honey sources (FN) is 12, The maximum search iteration number of a honey source “limit” is 100, and the maximum number of iterations “maxCycle” is 500. In order to avoid accidental errors, the random simulations of 15 times are conducted by running MATLAB to obtain the optimization solution. The final layout is shown

in **Figure 8**, GlobaMin=0.75.

In the digital twin-based textile workshop production system, the layout of the workshop is simulated and optimized according to the production factors. Considering the correlation of each process, logistics distance, area of occupation, cost and other aspects, the high-fidelity model is employed for simulation verification. The comparison of the layout of the workshop production factors before and after optimization is shown in **Figure 9**. The optimization plan implementation effect indicates that the digital twin-based intelligent manufacturing system model framework has a fine effect in the textile manufacturing workshop.

The optimization results obtained are shown in Table 5 after employing the digital twin-based intelligent manufacturing system model framework, as follows.

Figure 9. Comparison of the layout of the workshop production factors before and after optimization.

Table 5. Optimization effect of digital twin-based intelligent manufacturing system model framework

Optimization program	Before optimization	After optimization	Optimization effect
Timely logistics	73%	89%	Increased 16%
Equipment utilization	78%	93%	Increased 15%
Transport of fresh materials	350 m	145 m	Decreased 58.6%
Usable area	8358.9	8106.1	Decreased 0.03%
Auxiliary area	5941.1	4635.84	Decreased 21.97%
Amounts of staff	8	3	Decreased 62.5%
Reserve amounts	2048	512	Decreased 75%
Residual area	356m ²	2968m ²	Increased 733.7%
Auxiliary time	180s	60s	Decreased 66.6%
Total logistics	33638400	248587776	Decreased 26.1%
Production efficiency	55.19%	89.65%	Increased 34.46%

5. Conclusions and prospects

In this paper, the main objective of this investigation is the construction of the intelligent manufacturing system model framework based on digital twin. Firstly, based on the fundamental thought of the four-dimensional collaborative model, a nine-layer model framework of intelligent digital twin is established by refinement, optimization and upgradation of the traditional digital twin. Secondly, the algorithm for the information layer is optimized and upgraded by combining with SLP and artificial bee colony algorithm to overcome the shortcomings of SLP and artificial bee colony itself. The proposed digital twin model framework in workshop manufacturing system is conducted in case study of a textile workshop, which is optimized for the production system according to the requirements of the textile workshop. Finally, the presented model framework is applied to a textile manufacturing workshop system. The

experimental results manifest that the optimized auxiliary time per single and transport of fresh materials are reduced by 66.6% and 58.6%, and the optimized timely logistics and equipment utilization increased by 16.0% and 15.0%, respectively.

At present, the digital twin technology applied to the manufacturing workshop has not been widely popularized, that is a certain gap between digital twin technology and the described real-physical entity. Future work focuses on virtual debugging, production scheduling, energy consumption management and other aspects related to the manufacturing workshop, and establishes an effective evaluation tools of digital twin model. With the continuous integration and fast development of industrial big data, IoT, artificial intelligence, virtual reality and other technologies, it is believed that digital twin technology will have a promising future in the field of intelligent manufacturing.

Author contributions Zhongyu Zhang: Writing-original draft, methodology. Zhenjie Zhu: Writing-review and editing, formal analysis. Jingkun Wang: conceptualization, validation, supervision. Jinsheng Zhang: Investigation.

Funding Science and Technology Innovation Special Project of Rizhao of Shandong Province (No.2020CXZX1201).

Availability of data The data used to support the findings of this study

are included within the article.

Compliance with ethical standards

Competing interests The authors declare that they have no competing interests.

Ethical approval Not applicable.

Consent to participate Not applicable.

Consent to publish Not applicable

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Figures

Figure 1

The integrated design ideology of intelligent manufacturing system.

Figure 2

Physical evaluation structure.

Figure 3

Digital evaluation structure.

Figure 4

Information evaluation structure.

Figure 5

Construction of physical evaluation.

Figure 6

The transmission routes for spindles transportation.

Figure 7

Analysis of the comprehensive interrelation of each working department.

Information fusion layer

Figure 8

Overall system structure diagram.

Figure 9

Comparison of the layout of the workshop production factors before and after optimization.