*Industrial Engineering and Applications*
*L.-C. Tang (Ed.)*

*doi:10.3233/ATDE230073*

# Establishment and Implement of Digital Twin Model for an Intelligent Workshop

Chaozhong Guo [a], Xiang Li [a], Lizhong Zhao [a] and Jihong Yan [a,1]
[a] *School of Mechatronics Engineering, Harbin Institute of Technology, China*
ORCiD ID: Chaozhong Guo https://orcid.org/0000-0001-7093-0180,
Xiang Li https://orcid.org/0009-0002-2738-5951,
Lizhong Zhao https://orcid.org/0000-0001-8594-1480,
Jihong Yan https://orcid.org/0000-0003-0764-5365

**Abstract.** For multi-variety and small batches production, great challenges have been brought to production organization and management of workshops. This paper proposes an establishment and implement framework of digital twin model for intelligent workshops, which mainly consists of four layers. The production behavior and rules of production factors in the workshop are digitally established. Interconnection and communication scheme between each layer are designed and established. At the application level of the digital twin model, the Automated Guided Vehicle (AGV) intelligent scheduling algorithm based on genetic algorithm is combined with Augmented Reality (AR) technology in order to realize visual intelligent scheduling of workshop logistics. And the efficiency of logistics scheduling can be improved. The validity of the proposed framework is verified in an actual production workshop.

**Keywords.** Digital twin, workshop visualization, Augmented Reality, logistics scheduling

## 1. Introduction

In recent years, a new round of global technological revolution and industrial transformation has accelerated. The transformation of traditional workshops towards digitization, informatization and intelligence is an inevitable trend in the future development of manufacturing industries in various countries. Intelligent manufacturing has become one of the main driving forces for manufacturing industry, the core value of which lies in reducing the overall cost of manufacturing enterprises and improving the quality and efficiency.

Digital twin is a two-way dynamic interconnection technology between the physical world and the virtual world. Since the dynamic interaction and efficient management capabilities, this technology has become a key technology for realizing discrete intelligent workshop modeling and operation control, and is used as an important method to build intelligent workshops.

Some researchers studied the establishment and application of digital twin technology in intelligent manufacturing. Tao et al. [1] proposed a concept of digital twin workshop in 2017, and clarified that digital twin workshop realizes multi-level

[1] Corresponding Author: Jihong Yan, E-mail: jyan@hit.edu.cn

integration of workshops, workshop production and control optimization through two-way mapping and real-time interaction between physical space and virtual space. Digital twin technology can effectively integrate and manage multi-source heterogeneous dynamic data generated in the whole life cycle of manufacturing, which can be regarded as the necessary basis for the construction and realization of Cyber-Physical Systems (CPS). He et al. [2] designed a management system of an intelligent manufacturing unit with digital twin technology, and realized real-time management and control of the visualization unit by virtual-real mapping and simulation control technology. Ostrosi et al. [3] studied the intelligent virtual manufacturing unit based on cloud manufacturing platform technology, and solved the discontinuous problem of traditional units by nesting virtual manufacturing units layer by layer. Zhang et al. [4] proposed a system architecture in the intelligent manufacturing unit to realize the intelligent perception, analysis and autonomous decision-making of the unit, and carried out verification experiments in the robot and equipment unit. Forghani et al.[5] developed a mathematical model to determine the layout of machine cells, shop floor physical machines, and manufacturing cells, using a population-based simulated annealing algorithm for optimal scheduling.

In order to adapt to the dynamic scheduling in flexible production units, manufacturing companies introduce Automated Guided Vehicle (AGV) to obtain efficient operation of workshop logistics. Miyamoto et al. [6] simplified the AGV scheduling problem to an integer programming problem model, and solved the collision avoidance problem with path planning. Rashidi et al. [7] used the standard network simplicity algorithm to solve the scheduling problems of dock AGV. Sahin et al. [8] proposed a multi-agent based system to simultaneous scheduling of flexible machine groups and AGVs working under a manufacturing dynamic environment. Research by Kaoud et al. [9] showed that the modeling and simulation method is a key performance analysis tool for AGV scheduling and control. Traditional analysis methods focus on simplifying the AGV scheduling problem into a mathematical programming model. Kamoshida [10] proposed a method incorporating dynamic flexible facility layout planning (FLP) to solve job shop scheduling (JSS), and evaluated it on a benchmark dataset. It can be seen that in the literature several frameworks of digital twin model of workshop and the dynamic scheduling methods of AGVs have been proposed. However, how to implement the digital twin modeling in details, especially how to realize the two-way dynamic interconnection of AGV scheduling, is still a key problem that is unsolved.

This paper proposes an establishment and implement framework of digital twin model for intelligent workshops considering the flexible logistics scheduling of manufacturing units with four layers as shown in Figure 1. Firstly, each layer is designed and developed to build a digital workshop model based on the production factors of the physical workshop. Secondly, the interconnection and communication between layers are established, and the interaction schemes of each layer are designed. Finally, based on the proposed AGV intelligent scheduling algorithm, twin system integration is carried out with the data center as the core, and production control and visual logistics scheduling are realized in the Augmented Reality (AR) environment.

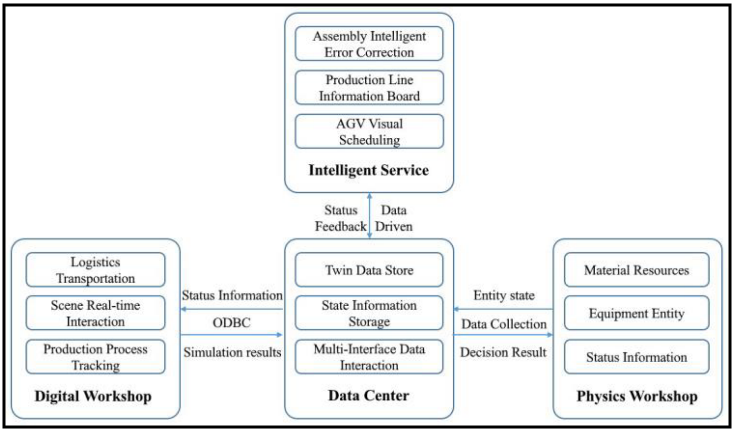


**Figure 1.** Digital twin model architecture of workshop

## 2. Model of Intelligent Workshops

The digital twin model of intelligent workshop established in this paper is mainly composed of four layers, including digital workshop layer, physical workshop layer, data center layer and intelligent service layer. Each layer is composed of multiple modules.

### *2.1. Physical Workshop Layer*

The physical workshop layer is a collection of actual production elements, including a series of contents that actually exist in the physical environment, such as production equipment, logistics equipment, products, and workshop layout, etc. Compared with ordinary workshops that are lack of interconnection, the physical workshop layer of the digital twin system not only has basic production logistics function, but also has status feedback and real-time data collection capabilities. The collection and storage of state information of production factors is an important basis for the system to implement data-driven and real-time mapping. In this paper, the workshop to be modeled is a reducer assembly workshop. Production elements include assembly line, AGV equipment, reducer products, and buffer areas. The transportation of products and materials is controlled by the AGV operating system. All the interconnection data are collected and stored so that the digital twin model of the workshop can be established.

### *2.2. Digital Workshop Layer*

The digital workshop layer includes multi-module development such as workshop 3D modeling, logistics and transportation process simulation, and full production process tracking. The digital workshop layer not only completes the extraction and description of production behavior and production rules, but also undertakes the task of implementing production decisions. This layer is essentially the fusion of multiple models, which is a multi-dimensional description of the virtual manufacturing unit, and constructs digital structures and rule constraints for various production links in the model. The construction of this layer can truly simulate the actual production and logistics process of the physical manufacturing unit, and visually present it to user. Through the digital workshop layer, possible problems and risks in the planning process can be discovered in time. The synchronous production flow of the manufacturing unit updates the running status of the digital model in real time. This paper builds a digital workshop model as shown in Figure 2, based on the Unreal Engine 4 platform, and develops interactive modules in the digital model to realize the interconnection between layers.

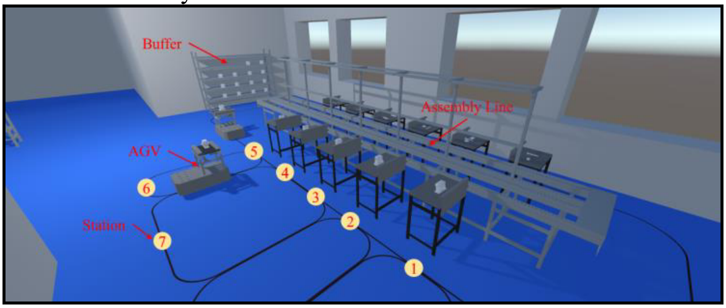


**Figure 2.** Digital workshop model

## *2.3. Data Center Layer*

The data center layer is composed of multi-module data such as physical workshop status data, digital model operation data, decision data from the intelligent service layer and temporary storage data. The interconnection and interaction of each layer takes the data center layer as the core. Through the design and data storage of various tables in this layer, the temporary storage, extraction and analysis of data at other layers are realized. In this paper, a data center is built based on the MySql database, and all kinds of data are stored in a unified format. The table structure is designed to realize the unified storage of data, which is convenient for other layers to call. The multiple management and access methods provided by the MySql database are also conducive to the extraction and transfer of data at other layers.

## *2.4. Intelligent Service Layer*

The intelligent service layer acts as the "brain" of the system. It controls the "sensory nerves" of the system, and also completes the "judgment and decision-making" of the system. The intelligent service layer is the upper-level application of the twin model and twin data. This layer includes modules such as state-aware analysis, logistics decision-making feedback and AGV visual scheduling, which respectively complete the tasks of optimal allocation of scheduling tasks, state awareness of the production process, and transmission of logistics tasks to the model layer and physical layer.

# **3. Modelling and Implement Process of Digital Twin Workshops**

## *3.1. Modeling of Digital Twin Workshop*

Digital model establishing is to model multi-dimensional elements such as factors, behaviors, and rules in the physical workshop, and to obtain the corresponding model to truly restore the physical workshop. Therefore, it is necessary to extract and analyze the production behavior and production rules of the physical workshop's production factors. The digital workshop and its logistics system are built according to the actual production and logistics layout.

After a 3D model for each production element of the physical workshop is established with UE 4 platform, what is more important is the logical operation relationship between the production factors. Through the internal C++ development language of the platform, the connection interface of various elements is established for digital workshop. Different from the static model simulation, data collected by sensors forms a data flow in the digital workshop, which also controls the real-time interaction and behavior mapping between the digital workshop and physical workshop.

### *3.2. Interaction Design between Digital Workshop and Physical Workshop*

The development of the interactive interface of digital workshop is to achieve the data transmission and interaction between digital model and system data center layer, and to realize the transmission, reading and writing of data. This paper adopts the Open Database Connectivity (ODBC) data connection method, which has an open service system structure and provides a standard database access interface for users to use. The reading content of ODBC data connection must be the data source established by the system, so it is necessary to set the ODBC data source to ensure the real-time access of the digital model to the data center. The connection and control methods are written in the interactive module to realize database connection, data reading and writing and communication between the model and the data center layer.

After completing the design and construction of the interactive module in digital model, the twin data of the model is synchronized to the data center in real time. And at the same time, the status is updated in the entity control program of equipment at the physical workshop layer. The PLC data of AGV is transmitted through the Socket interface to sense the AGV in real time. The state information of AGV is written into the data center to accomplish the synchronous update of state.

### *3.3. Interaction Design between Physical Layer and Intelligent Service Layer*

The interactive function development of the intelligent service layer is aimed for the intelligent algorithm, while that of the physical workshop layer is aimed for state perception module respectively. The physical entity of AGV is controlled by intelligent algorithm search iteration results. The state perception module extracts and analyzes the AGV operating state.

Firstly, the decision-making results of intelligent algorithm optimization and the production information are accurately and completely input into the data center layer to provide plans and instructions for the circulation and logistics distribution of the physical workshop layer. The algorithm interaction interface is developed by Python toolkit to realize the program's reading and writing of database data. Then, a unified database extraction functional area is designed for the state awareness module of the intelligent service layer, and the access and extraction of database state information is completed with the Pymysql toolkit. The status perception and real-time interaction of the physical workshop are realized, and timely feedback is given when there are disturbances. Based on the above design, the physical workshop layer is controlled and perceived by the intelligent service layer.

### 3.4. Implement of the Digital Twin: AGV Intelligent Scheduling

In this part, a case study of digital twin used for logistics scheduling is provided. And herein genetic algorithm is used to optimize the logistics distribution tasks of an AGV. The details of algorithm design are shown below.

#### 3.4.1. Fitness Function Calculation and Selection Operation

For multi-variety and small batches production, minimizing the production cycle time is commonly selected as the optimization goal for algorithm iteration. The reciprocal of the optimization objective is set as the fitness function. In an order-fixed mode, the optimization target is the time to complete all order tasks in the unit. In urgent order insertion mode, the optimization goal is the time to complete all delivery tasks.

The simulation-based optimization method enables precise calculation of production cycle times. In this paper, a method based on simulation optimization is used to calculate the fitness value. The output of the simulation module is used as the fitness value of the algorithm for the re-optimization of the genetic algorithm, and new generation population generated by the genetic algorithm is used as the iterative input of the simulation model again. The flow chart of the simulation output fitness value is shown in Figure 3.

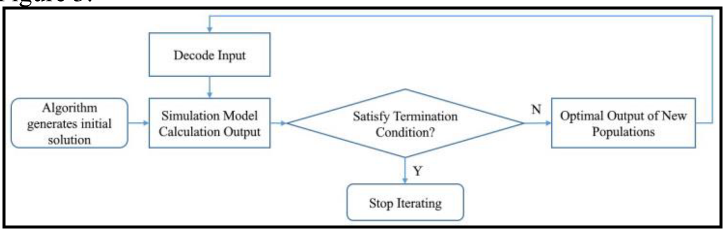


**Figure 3.** The flow chart of the simulation output of the fitness value

#### 3.4.2. Chromosomal Crossover and Mutation Operation

The crossover operator is an important part of the genetic algorithm, and its operation process is similar to the way of parental gene transmission in nature. The update and optimization of genes is realized by individual recombination, and the positions of some gene fragments between the parent individuals are exchanged to complete the generation of new individuals. The crossover operator table is shown in the Table 1.

**Table 1.** Crossover operator table

| Chromosome name | Crossover operator name |
|---|---|
| Transport chromosome | Single-point crossover |
| Sequential chromosome | Partial matching crossover operator |
| AGV chromosome | Two-points crossover |

#### 3.4.3. Calculation Test and Verification

The applicability and search optimization capabilities of the algorithm are tested against the fixed pattern of orders, and the fitness value is calculated with a simulation-based optimization method. It provides an evaluation basis for the iterative optimization of the algorithm. The test verification process is shown in Figure 4. The assembly tasks in the workshop are converted into logistics distribution tasks. The production task in a certain month is taken as the task target, and the parameters listed in the table are used to carry out the calculation example test to complete the optimal search for the transport chromosome.

The test fitness value is the time to complete 20 distribution tasks. The initial time is 551s, and the optimized time reaches 174s, effectively shortening the logistics delivery time by 337s, which fully proves the effectiveness and adaptability of the algorithm.

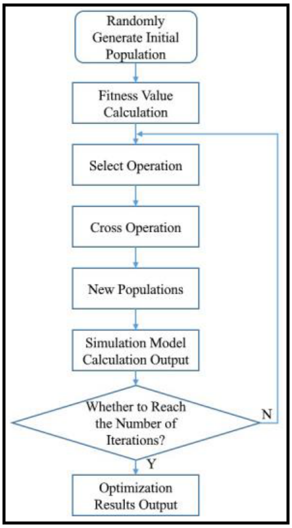


**Figure 4.** AGV scheduling flow chart based on genetic algorithm

### *3.4.4. Interaction between Digital Workshop and AGV*

A communication connection between AGV and digital workshop is established to enable a two-way interaction between physical workshop and digital workshop. The real-time data driven structure is shown in the Figure 5. Two WebSocket clients are established in the digital workshop, one is used to send motion instructions to the AGV, and the other is used to receive real-time status data from the AGV and display it visually in the workshop. The server is responsible for accepting and processing requests from the workshop layer, and the database is responsible for storing the operation status data of the digital workshop. The data acquisition system is connected to the AGV equipment system in the workshop to directly obtain the AGV status data.

After receiving request from the server to obtain real-time data, the data acquisition system will feed back the real-time data to the server. The server first performs the corresponding format conversion and regularization operations to standardize and unify the data. Then the database language is used to convert the obtained real-time data which is written into the database to complete data storage work. After receiving the request from the workshop layer, the server sends data query instructions to the database through query statements, and the database feeds back the query results to the server to obtain data.

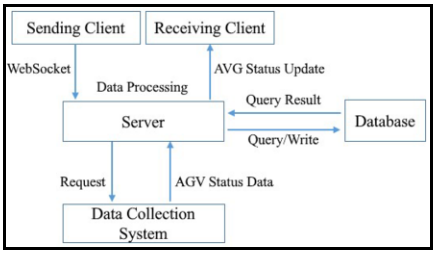


**Figure 5.** Schema structure of data driven

### *3.4.5. Visual Scheduling Display*

With AR technology, the visual monitoring and scheduling of AGV can be carried out in a virtual environment. Through the reprogramming of the Unreal Engine 4 open interface, the AR device and the AGV control system are connected and communicated with the digital workshop model. The logistics scheduling and AGV path planning are automatically or manually performed with the visual interface, and the decision data is saved in the data center. Starting from the overall management optimization plan of the manufacturing unit, distribution of logistics tasks is optimized, and the results are used as feedback to control the physical system in real time, as shown in Figure 6.

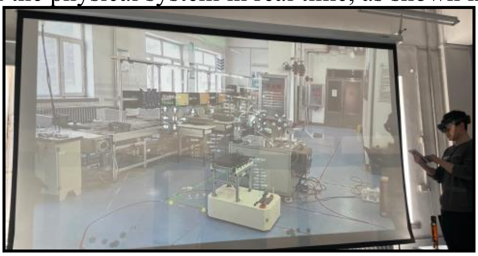

**Figure 6.** Schema structure of data driven

In addition, multiple program parameters such as AGV scheduling time, AGV failure rate, and AGV battery information can be set in the model to realize flexible and variable logistics scheduling strategies within the unit. An electronic panel is generated in the digital workshop to present product information in the physical workshop in real time and logistics status, as shown in Figure 7. Therefore, a digital twin model of the reducer assembly workshop with AGV logistic scheduling is achieved.

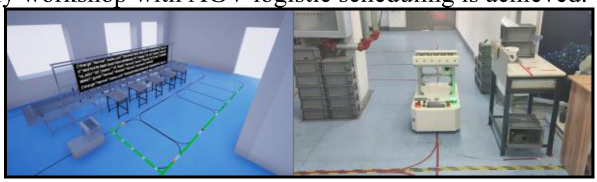

**Figure 7.** Visual monitoring of AGV operating status

## 4. Conclusion

In this paper, a framework for the establishment and implement of digital twin model is proposed. Through four layers of design and module development, the interconnection and communication scheme between layers is formed. A case study of logistics scheduling is provided with the implement of the proposed digital twin modeling framework. The AGV intelligent scheduling algorithm based on genetic algorithm is used to realize AGV visual scheduling and workshop logistics optimization strategies. The entire digital twin frame has the capabilities of logistics scheduling, virtual-real mapping, multi-level interconnection and intelligent decision-making. It is a new workshop operation mode for production and optimal management and control in Industry 4.0 environment.

## Acknowledgment

The research is funded by the National Key R&D Program of China (2022ZD0115402).

## References

[1] Tao F, Zhang M. Digital Twin Shop-Floor: A New Shop-Floor Paradigm Towards Smart Manufacturing. in IEEE Access, vol. 5, pp. 20418–20427, 2017, doi: 10.1109/ACCESS.2017.2756069.

[2] He YC, Zhang NS, Wang AM. Digital twin process and simulation operation control technology for intelligent manufacturing unit. IOP Conference Series: Materials Science and Engineering, Volume 836, 4th International Conference on Reliability Engineering (ICRE 2019) 20-22 November 2019, Rome, Italy. doi:10.1088/1757-899X/836/1/012010.

[3] Ostrosi E, Fougères A. Intelligent virtual manufacturing cell formation in cloud-based design and manufacturing. Engineering Applications of Artificial Intelligence, Volume 76, 2018, Pages 80-95, doi: https://doi.org/10.1016/j.engappai.2018.08.012.

[4] Zhang JY, Li PZ, Luo L. Digital twin-based smart manufacturing cell: Application Case, System Architecture and Implementation. Journal of Physics: Conference Series, Volume 1884, 2021 International Conference on Intelligent Manufacturing and Industrial Automation (CIMIA 2021) 26-28 March 2021, Guilin, China. doi: 10.1088/1742-6596/1884/1/012017.

[5] Forghani K, Ghomi S.M.T.F, Kia R, Concurrent scheduling and layout of virtual manufacturing cells considering assembly aspects. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture. 2021;235(6-7):1036–1049. doi:10.1177/0954405420980685.

[6] Miyamoto T, Inoue K. Local and random searches for dispatch and conflict-free routing problem of capacitated AGV systems. Computers & Industrial Engineering, Volume 91, 2016, Pages 1–9, doi: https://doi.org/10.1016/j.cie.2015.10.017.

[7] Rashidi H, Tsang E. P.K. A complete and an incomplete algorithm for automated guided vehicle scheduling in container terminals. Computers & Mathematics with Applications, Volume 61, Issue 3, 2011, Pages 630–641, doi: https://doi.org/10.1016/j.camwa.2010.12.009.

[8] Sahin C, Demirtas M, Erol R, Baykasoğlu A, Kaplanoğlu V. A multi-agent based approach to dynamic scheduling with flexible processing capabilities. J Intell Manuf 28, 1827–1845 (2017). doi: https://doi.org/10.1007/s10845-015-1069-x.

[9] Kaoud E, EI-Sharief MA, EI-Sebaie MG. Scheduling problems of automated guided vehicles in job shop, flow shop, and container terminals. 4th International Conference on Industrial Engineering and Applications (ICIEA), IEEE, Nagoya, Japan, April 21-23, 2017, pp.60–65.

[10] Kamoshida R. Concurrent optimization of job shop scheduling and dynamic and flexible facility layout planning. 5th International Conference on Industrial Engineering and Applications (ICIEA), IEEE, Natl Univ Singapore, Shaw Fdn Alumni House, Singapore, APR 26-28, 2018, pp.289–293.