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Factory Simulation Construction Method and Implementation of Intelligent Manufacturing

Zheng Bin[1], Bai Yan[2*], Yang Soo Siang[3], Tan Ming Keng[4], Zhang Jing Song[5]

[1,3,4,5]*Faculty of Engineering, University Malaysia Sabah, Kota Kinabalu, Sabah,88400, Malaysia.*
[2*]*Faculty of Mechanical Engineering, Beihua University, Jilin, 132013, China.*

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ABSTRACT

Construction methods and implementation of factory simulation of intelligent manufacturing discusses the key construction methods and realization ways of factory simulation in the field of intelligent manufacturing. As the core of the digital twin industry, it plays an important role in optimizing production and improving resource utilization. This paper expounds the construction method of factory simulation, including digital modeling, simulation parameter setting, advanced algorithm application and real-time data fusion. At the same time, it points out the challenges of model complexity and data accuracy in the simulation construction process and proposes corresponding solutions. This paper also takes Plant Simulation software as an example to analyze the implementation steps of factory simulation, such as model building, parameter configuration and process planning, emphasizing its value in optimizing factory layout, improving production process, and enhancing the scientific nature of decision-making. This paper comprehensively shows the key technical points and future development trend of factory simulation and provides theoretical support and practical guidance for the technological progress and industrial upgrading of intelligent manufacturing industry.

1. INTRODUCTION

With the rapid development of science and technology, intelligent manufacturing technology has become an indispensable part of industrial production (Tao et al., 2018). The use of automation, the Internet of things, artificial intelligence and other technologies can realize the production automation and intelligence, reduce human interference, and then improve the production efficiency and product quality (Li et al., 2017; Chander et al., 2022; Soori et al., 2023). As an important component of intelligent manufacturing, the construction method and implementation of digital twin factory involve a number of key fields, including digital modeling, virtual simulation, real-time monitoring, data analysis and optimization, cross-system integration and other (Liu et al., 2024; Segovia & Garcia-Alfaro, 2022). Through the digital modeling technology in this paper, the actual factory parts of the accurate digital processing, including production equipment, logistics system, personnel operation, etc., to establish a complete digital twin model. In the

[2*] Corresponding author. *E-mail address*: baiyan@beihua.edu.cn
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digital twin model, the production process of the factory is simulated through the simulation technology, including the operation of the production equipment, product manufacturing and logistics and other links. At the same time, through the analysis and processing of the collected data, the digital twin model is optimized and adjusted to improve the production efficiency and product quality of the factory. This paper aims to improve the production efficiency of manufacturing industry, reduce operating costs, and optimize the allocation of resources. Therefore, the construction and development of intelligent digital twin factories promotes the transformation of industrial manufacturing to intelligent and digital, helps to enhance the core competitiveness of enterprises and accelerate the development process of industrial intelligence (Li et al., 2022; Wang & Luo, 2021).

2. INTELLIGENT PRODUCTION LINE OVERALL SCHEME DESIGN

2.1 Process design

This paper studies the firebrick detection line of an enterprise in Dalian, China. The firebrick detection line has realized the production operation, which covers the whole life cycle of firebrick from warehouse to finished products (Wahab, 2022). In order to meet the requirements of the product production process, the overall process includes the raw material delivery, transportation, mold release and cutting, steam maintenance, palletizing packaging and other links. Its complete operation process is shown in Fig. 1.

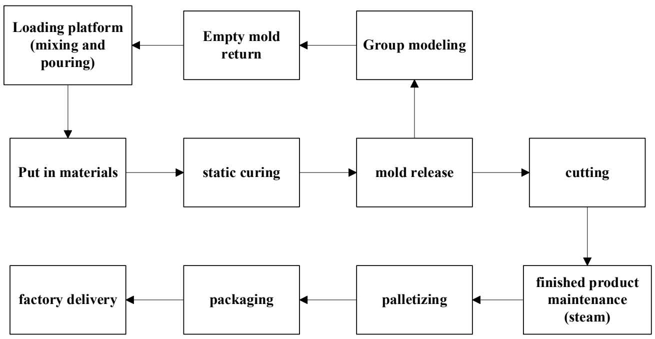

Fig. 1. Production line operation flow diagram

2.2 Intelligent production line planning scheme

The intelligent production line planning scheme is composed of layered design of equipment control layer, network layer, industrial cloud platform layer and application system layer (Qu et al., 2016; Wu et al., 2022). The equipment control layer is responsible for the overall planning, such as raw material control, valve monitoring, and data collection and remote control. The network layer is divided according to the hierarchical mode of the communication Internet industry, including the design of network, communication, cloud, and key basic capabilities (Peng et al., 2015). Network infrastructure mainly includes extranet, equipment, logistics tracking and energy monitoring. In terms of network form, it scientifically coordinates the planning of high-speed fiber network, wireless network and Iot sensing network; in the regional dimension level, the construction of high-speed fiber network and 4G / 4G + mobile communication network always follows the principle of comprehensive coverage of one network, and continuously promotes the commercial construction of 5G network (Stallings, 2015; Wen et al., 2021). The flow block diagram of the intelligent factory is shown in Fig. 2.

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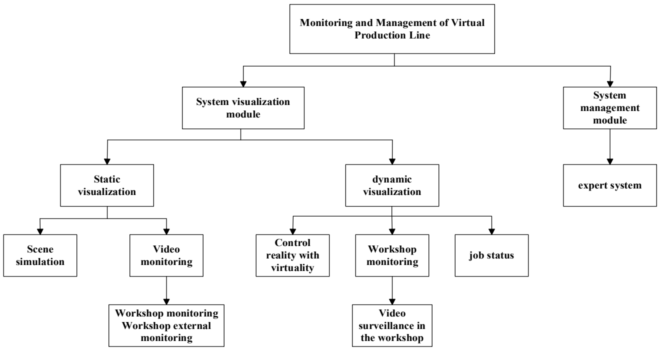

Fig. 2. Smart factory flow block diagram

3. HARDWARE STRUCTURE DESIGN OF INTELLIGENT PRODUCTION LINE

According to the required functions, the automatic detection line is designed for conveying system, central alignment system, separation system, 3D online measuring system, unloading system, marking and printing system, cardboard coating and installation system, and control system. As shown in Fig. 3. Overall design scheme diagram is the preliminary composition of firebrick automatic detection line. The delivery direction is shown in the arrow direction in Fig. 3.

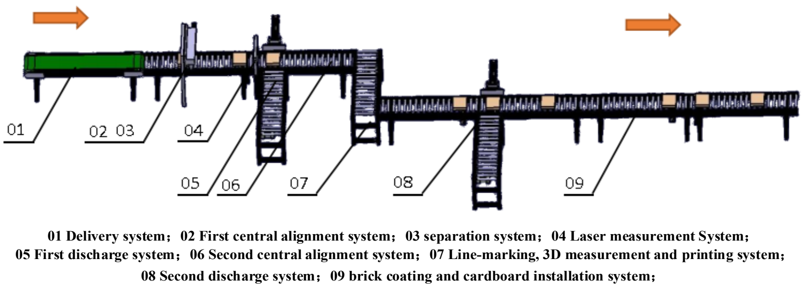

Fig. 3. Overall design scheme diagram

3.1 Conveying system

The conveying system runs through the whole brick detection line, which is the basis for all functional requirements of refractory bricks in the whole testing process. The conveying system mainly includes two types: the belt conveyor at the front end of the automatic detection line and the roller conveyor. As shown in Fig. 4 belt conveyor diagram and 5 roller conveyor diagrams are belt conveyor and roller conveyor respectively.

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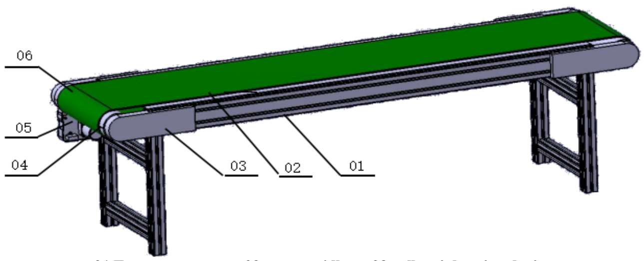
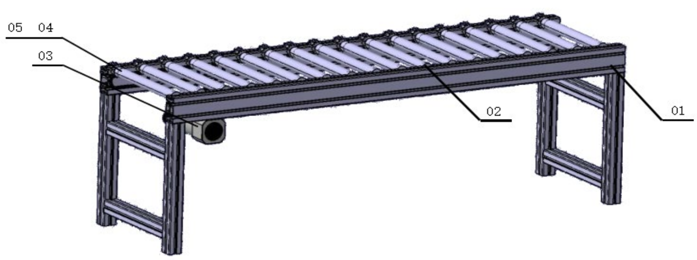


**01 Frame structure；02 support idler；03 roller tightening device；
04 moving roller；05 driving part；06 transmission part**

Fig. 4. Schematic diagram of the belt conveyor



**01 Frame structure；02 roller tightening device；03 driving part；
04 power idler；05 transmission part**

Fig. 5. Schematic diagram of the roller conveyor

3.2 Central alignment system, laser measurement system, separation system and unloading system

Fig. 6 central alignment system, laser measuring system, separation system and unloading system mechanical diagram, know the belt conveyor will brick into roller conveyor, into the central alignment system, by the system of the deviation of the brick, the mechanical alignment of the function of the motor gear, driven by the gear two relative rack movement, continue to transport forward into the separation system, the separation system is in a fixed position out baffle, let the brick stay, the function of the cylinder drive linear slide reciprocating movement (The diagram of the central alignment system structure and the separation system structure shown in Fig. 7) continue to move forward to the laser measurement system for data measurement and comparison. In the discharge system, the expansion cylinder will push out the unqualified refractory brick; the qualified one for alignment and separation will continue to be transported forward to the next station.

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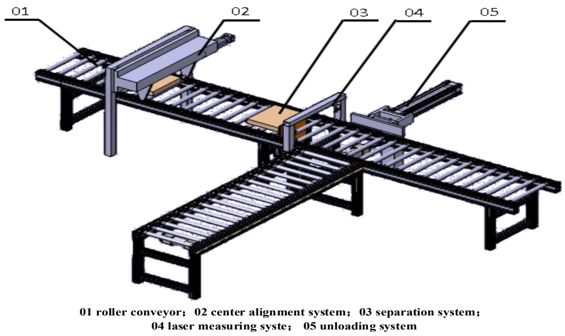

Fig. 6. Mechanical diagram of central alignment system, laser measuring system, separation system and unloading system

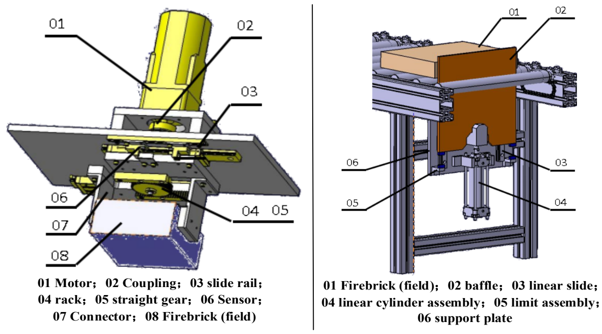

Fig. 7. Structure diagram of central alignment system and brief diagram of separation system

3.3 Line-marking, 3D online measurement and printing system

As shown in the schematic diagram of the marking, measurement and printing system in Fig. 8, the refractory brick qualified by laser measurement enters the second central alignment system, and the central alignment system pairs again. Then enter the marking, 3D online measurement and printing system.

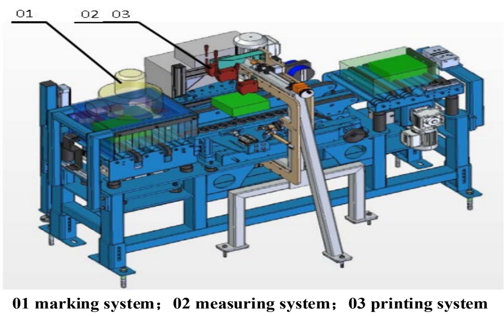

Fig. 8. Line-marking, measuring, and printing system

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3.4 Brick bonding and cardboard mounting system

As shown in Fig. 9, the printed refractory brick is transported to the brick coating system by the roller conveyor, and the automatic coating equipment in the brick coating system is coated. The coating position and printing position are vertical end surface. the position relationship of brick printing and glue coating. The graphic arrow shows the direction of delivery. The finished bricks continue to the sticker system, attaching standard cardboard to the end of the bricks.

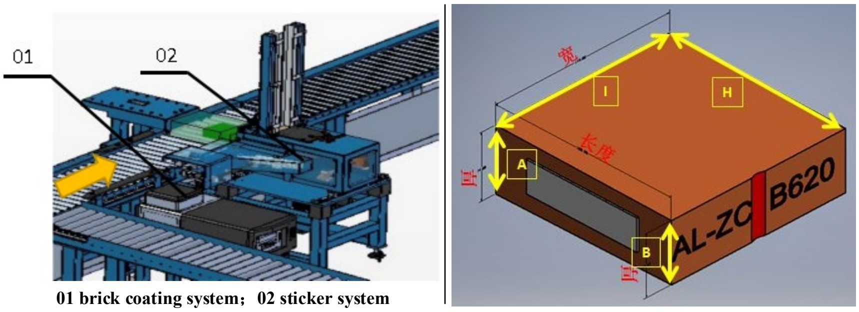

Fig. 9. Cardboard coating and installation and brick printing and coating position relationship

4. SOFTWARE PRODUCTION LINE SYSTEM DESIGN

This chapter studies two main parts: sorting and storage. First, the construction of the factory simulation environment based on Plant simulation software, then the design and construction of the raw material production unit and the raw material processing unit, and finally, the construction of the raw material storage unit.

4.1 Factory simulation environment construction based on plant simulation

4.1.1 The idea of the scene building

Before designing the production line model of the intelligent factory, the digital twin scene of the production line must be built according to the actual production process. The production line studied in this study needs to meet the sorting and transportation functions. Select the required model equipment from the digital twin model library and set up the production line in the Plant simulation 3 D modeling and simulation platform.

4.1.2 Scene building platform

Plant Simulation Is a software platform for the development of 3 D modeling and simulation display of digital twin systems, which can be used for the simulation and optimization of factories, production lines and production logistics processes. As part of the Siemens digital software Tecnomatix, it includes tools such as Process Designer, Process Simulation, and Plant Simulation. It is one of the key points of Siemens' digital manufacturing strategy. As a software that can simulate factories, production lines and logistics, Plant Simulation can quantify and verify all aspects of the production system, such as workshop layout, production logistics design and production capacity, and explore the optimization direction according to the simulation results, which can verify the effect of the implementation of the program before the implementation of the plan.

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4.2 Simulation module design

4.2.1 Overall module design

The 2D / 3D layout diagram of the simulation model is as follows:

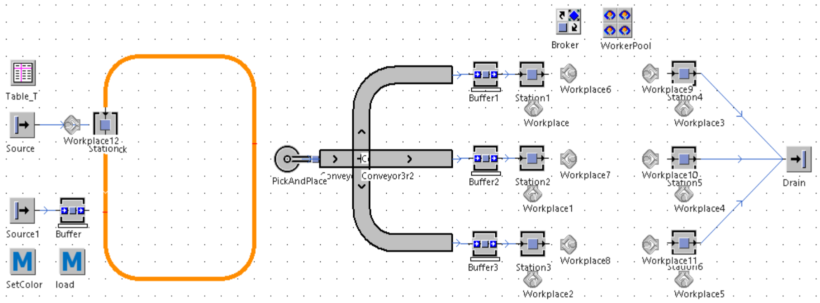

Fig. 10. Simulation model 2D layout diagram

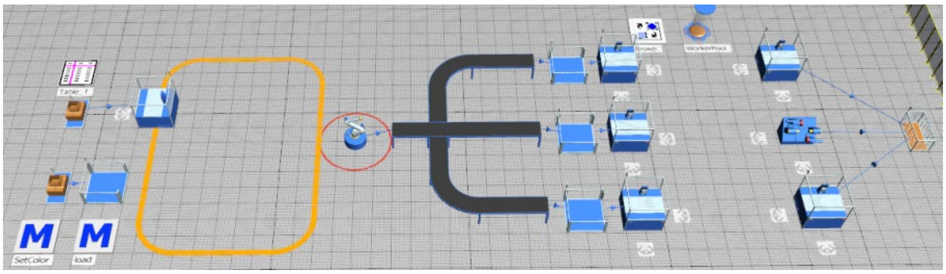

Fig. 11. Simulation model 3D layout diagram

In this model, the AGV trolley is generated from the Source on the left, and a buffer Buffer connects with the rail Track of the transport robot PickAndPlace, with two sensors on the rail Track. At the buffer zone Buffer, when the AGV car triggers the sensor, the car stops and loads the material, and the car continues to move when reaching the cargo capacity.

```
param SensorID: integer, Front: boolean, BookPos: boolean

@.stopped := true

while not @.full
    waituntil not Buffer.empty
    Buffer.cont.move(@)
end

@.stopped := false
```

Fig. 12. buffer Sensor controls

At the transport robot PickAndPlace, when the AGV car triggers the sensor, the car stops, the transport robot transfers the material to the production line from the AGV car, and the AGV car material is empty when the car continues to move.

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```
param SensorID: integer, Front: boolean

@.stopped := true

var Destination:object := PickAndPlace

while not @.Empty
    var mu: object := @.cont
    if not mu.move(Destination)
        stopuntil mu.location /= @ and not Destination.isLoading
    end
end

@.stopped := false
```

Fig. 13. PickAndPlace Sensor controls

4.2.2 Design of the transport and sorting area module

A transport robot PickAndPlace is placed on the right side of the AGV track, and a sensor is set at the AGV track. The function is to stop when the car triggers the sensor, and the transport robot transfers the material. When the material carried by the car is empty, the car continues to move along the track.

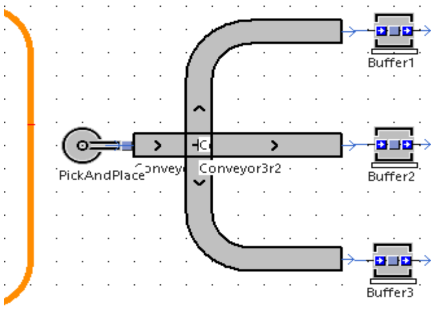

Fig. 14. Model layout

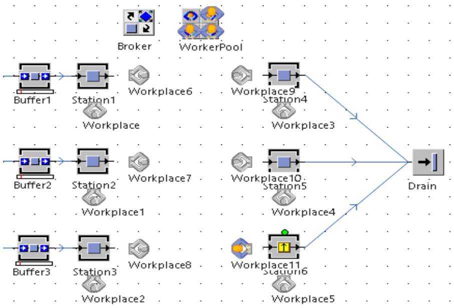

Fig. 15. Manufacturing zone model layout

A conveyor belt is placed next to the transport robot, and then a conveyor belt that can distinguish different materials and has a sorting function. The conveyor belts are connected to the other three ends.

4.2.3 Design of the raw material processing unit

Place a buffer behind each conveyor to prevent material from piling up on the belt. Two stations are placed after each buffer for material processing, with a distance between the two stations. A pool of workers is placed, in which ordinary workers and skilled workers with yellow circles are set up. The function of ordinary workers is to transfer materials from the first station to the next station.

One ordinary worker is set between each two stations, and a total of three ordinary workers are required in this model. Ordinary worker A1 transfers material from Station1 to Station4; ordinary worker A2 transfers material from Station2 to Station5, and ordinary worker A3 transfers material from Station3 to Station6. The technical workers with the yellow circle are responsible for the maintenance of the smart factory.

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.Models.Model.WorkerPool.CreationTable

*.Resources.Worker

	Worker	Amount	Shift	Speed	Efficiency	Additional Services
1	*.Resources.Worker	1				A1
2	*.Resources.Worker	5				A2
3	*.Resources.Worker	1				A3
4	*.Resources.WORKER1	2				A0

Fig. 16. Worker pool creation table

Changing the value in the table above can change the number of workers and setting the Capacity (yield) value in WorkerSpace can carry multiple human jobs in a Workspace, that is, the number of Worker that can stay on the specified Workplace at any time.

4.3 Raw material storage unit design

The HBW (High Bay Warehouse) elevated cargo stereo warehouse in the Plant simulation toolbox is used to simulate the logistics and storage facilities in the actual factory. There are three components in this library object, namely WMS, roadway stacker and library location addressing control. These three components need to be used together to be effective. That is, each library component must be dragged to the modeling window to realize the operation and debugging of the three-dimensional warehouse.

Fig. 17. Components in the HBW library

Under the interface of management, some very simple warehousing and warehousing strategies can be implemented, namely one by one, Random, Predefined rocks and XYZ ranges. The key control information is the userSetTarget, which enables the scheduling of material storage. The important thing is a word, rooot.WMS.placeIntoStock, let WMS decide to put a material into the three-dimensional warehouse. This is the starting method of the stereo library, by which all other actions are triggered.

```
var foundFreePlace : boolean := root.WMS.placeIntoStock(@)

if not foundFreePlace
    self.openDialog
    messageBox("Could not find any free place in the racklanes", 1, 1)
    root.Eventcontroller.stop
end
```

Fig. 18. userSetTarget the algorithm

There are four warehousing and warehousing strategies in plant simulation software:

One by one: One place after another. Store the material from low to high, from left to right.

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```
// Method Tasks:
// fill the rack lanes one by one
// Racklane is void if there was no free place found
//------------------------------------------------------------------------------
param Pallet: object,
    byRef Racklane: object, byRef Side: string, byRef Column, Row: integer,
    product: string

var found: boolean    := false
var finished: boolean := false

// just to make sure all racklanes have same utilization
var index: integer := lastIndex + 1
var count: integer := 1

if index > RackLanes.Dim then
    index := 1
end
```

Fig. 19. One by one source code

Random: That is, the randomly ground. Store the material in the stereo.

```
// Method Tasks:
// random search for a free place in the warehouse
//------------------------------------------------------------------------------

param Pallet: object,
    byRef Racklane: object, byRef Side: string, byRef Column, Row: integer,
    product: string

var occupiedPlaces: integer

for var i := 1 to RackLanes.Dim
    Racklane := RackLanes[i]
    occupiedPlaces += RackLane.OccupancyLeft.sum
    occupiedPlaces += RackLane.OccupancyRight.sum
next

var totalPlaces: integer
for var i := 1 to RackLanes.Dim
    Racklane := RackLanes[i]
    totalPlaces += RackLane.NumberOfColumns*RackLane.NumberOfRows*2
next

var emptyPlaces: integer := totalPlaces - occupiedPlaces
```

Fig. 20. Random source code

Predefined: That is, the predefined. Store the material in an empty position close to the shortest path of the palletizing.

```
// Method Tasks:
// search for a free place in the predefined racks
//------------------------------------------------------------------------------

param Pallet: object,
    byRef Racklane: object, byRef Side: string, byRef Column, Row: integer,
    product: string

var frame: object  := current.~
var found: boolean := false

// get all predefined racks of the product
var PredefinedRacks: string[] := getPredefinedRack(Product)

if PredefinedRacks.dim>0 then
    // predefined rack found
    // check if there is a free place in one of the racks
    var index: integer := 1
    repeat
        Racklane:= frame.extendPath(PredefinedRacks[index])

        // get the first free place of the left rack
        var rack: object := Racklane.OccupancyLeft

        rack.setCursor(1,1)
        if rack.find(0) then
            var cLeft: integer := Rack.CursorX
            var rLeft: integer := Rack.CursorY
        end

        // get the first free place of the right rack
        rack := Racklane.OccupancyRight

        rack.setCursor(1,1)
        if rack.find(0) then
            var cRight: integer := Rack.CursorX
            var rRight: integer := Rack.CursorY
        end
```

Fig. 21. Predefined source code

XYZ ranges, namely the XYZ range. Store an item in the first free position in all the rack channels.

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```
// Method Tasks:
// search for a free place in the warehouse
//----------------------------------------------------------------------------
param Pallet: object,
    byRef Racklane: object, byRef Side: string, byRef Column, Row: integer,
    product: string

// get the range for the columns where the product will be stored
var Ranges: table  := getProductRanges(product)
var frame: object  := current.~
var found: boolean := false

if Ranges.YDim > 0 then
    // in this table we will store the first free place of all rack lanes
    var temp: table[object, string, integer, integer]
    temp.create

    for var i := 1 to Ranges.YDIm loop
        Racklane := frame.extendPath(Ranges[1, i])

        var leftbound: integer  := Ranges[2, i]
        var rightbound: integer := Ranges[3, i]

        // get the first free place of the left rack
        var rack: object := Racklane.OccupancyLeft

        rack.setCursor(1,1)
        if rack.find({leftbound, 1}..{rightbound, *}, 0) then
            temp.writerow(1, temp.YDIm+1, Racklane, "left", Rack.CursorX, Rack.CursorY)
        end

        //get the frist free place of the right rack
        rack := Racklane.OccupancyRight

        rack.setCursor(1,1)
        if rack.find({leftbound, 1}..{rightbound, *}, 0) then
            temp.writerow(1, temp.YDIm+1, Racklane, "right", Rack.CursorX, Rack.CursorY)
        end
    next
```

Fig. 22. XYZ ranges source code

5. FACTORY SIMULATION OPERATION RESULTS

5.1 Overall factory simulation

The overall 3D diagram is shown in the figure below:

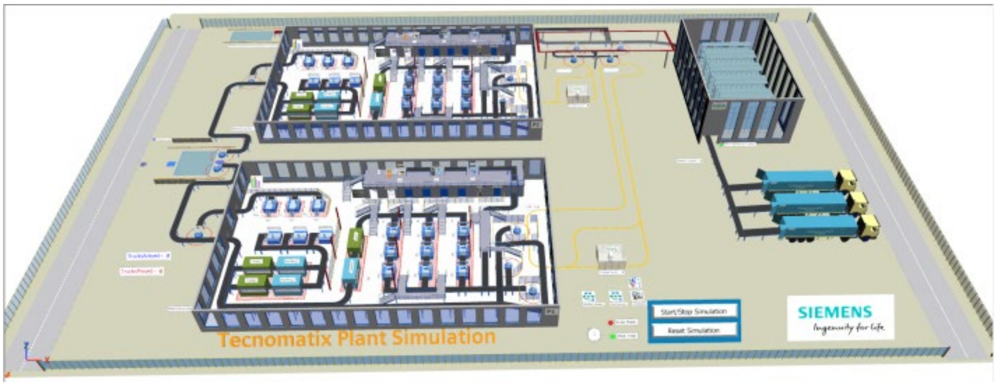

Fig. 23. Factory simulation overall 3D diagram

5.2 Raw material production unit

Fire brick raw materials through the conveyor belt transport to raw materials station for processing, processing by ordinary workers to the next station processing, processing through the conveyor belt successively through the spray machine and dryer spraying and drying, then by the conveyor belt transport successively successively through the paint machine and dryer for coating and drying.

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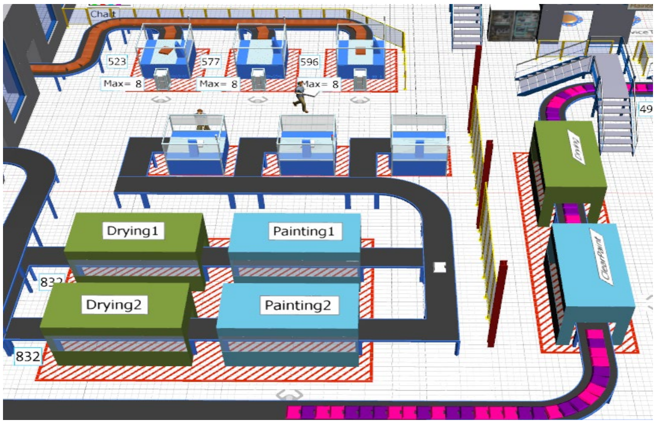

Fig. 24. Raw material production unit

5.3 Raw material processing unit

After the raw materials of refractory brick are sprayed with code and coating, they are transported by the conveyor belt to each station step by step. After the processing is completed, it will be transported to the transfer and sorting unit for packaging. Before the packaging, the workers will conduct manual sampling inspection on the processed raw materials to ensure the product quality.

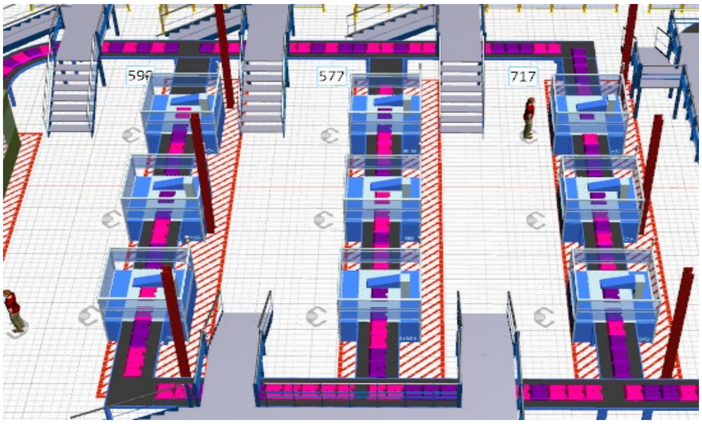

Fig. 25. Raw material processing unit

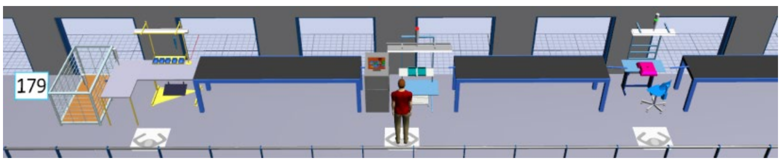

Fig. 26. Manual sampling inspection

5.4 Raw material storage unit

After packing the refractory bricks for stacking, they are transported to the three-dimensional warehouse for storage and transportation.

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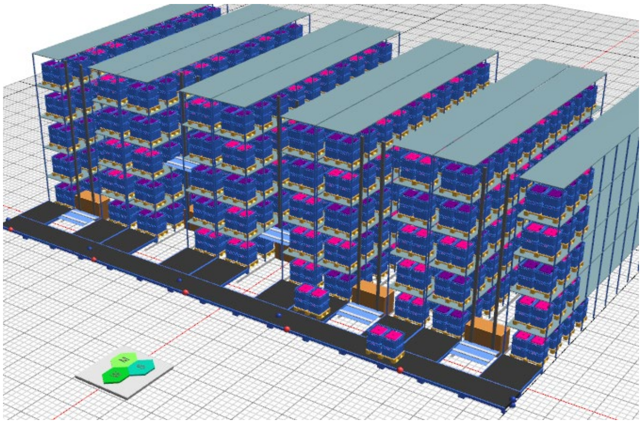

Fig. 27. Raw material storage unit

5.5 Computational results

Through the operation of the factory simulation, the conditions in the factory simulation, such as the processing situation, the station failure and maintenance situation of each station, are drawn into a diagram, and each part of the factory simulation is directly displayed.

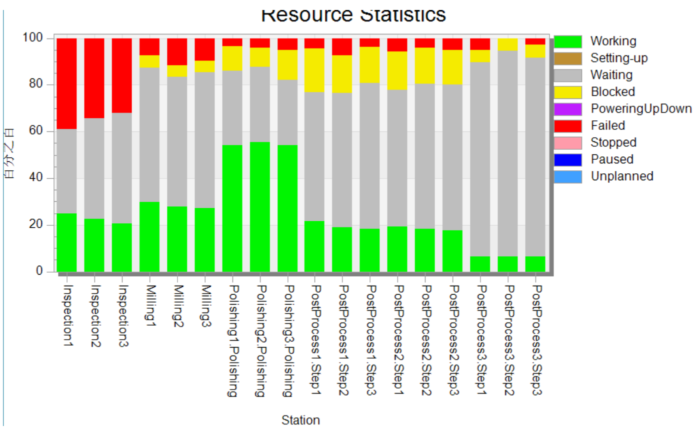

Fig. 28. Workplace diagram

6. CONCLUSIONS

Through simulation operation and debugging, the paper further optimizes the factory production line model, and the functions of material processing quantity, resource statistics and worker service statistics are added to make the simulation results closer to the actual operation of the factory. At the same time, this paper also verifies the advantages of three-dimensional warehouse in material storage and scheduling through the results of three-dimensional warehouse operation.

Despite the achievements made in this paper, there are still some improvements. First, the model should be further optimized to improve the accuracy and real-time performance of the simulation. Secondly, more simulation application scenarios should be explored, such as production line balance, equipment fault simulation, etc., to more comprehensively evaluate and optimize the production efficiency of the plant. In the future research, it is expected to further expand the application scope of simulation technology and

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provide more support and help for industrial production. At the same time, we also hope to make more breakthroughs in the research and innovation of simulation technology and contribute more strength to the intelligence and automation of industrial production.

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8. CONFLICT OF INTEREST STATEMENT

The authors agree that this research was conducted in the absence of any self-benefits, commercial or financial conflicts and declare the absence of conflicting interests with the funders.

9. AUTHORS' CONTRIBUTIONS

Zheng Bin: System design, development and conduct testing; **Bai Yan** and **Yang Soo Siang**: Analysis of testing, supervision, paper review and editing; **Tan Min Ken** and **Zhang Jing Song**: Industrial expertise advisor.

10. REFERENCES

Chander, B., Pal, S., De, D., & Buyya, R. (2022). Artificial intelligence-based internet of things for industry 5.0. In: Pal, S., De, D., Buyya, R. (Eds), *Artificial intelligence-based internet of things systems* (pp. 3-45). Springer. https://doi.org/10.1007/978-3-030-87059-1_1

Li, B. H., Hou, B. C., Yu, W. T., Lu, X. B., & Yang, C. W. (2017). Applications of artificial intelligence in intelligent manufacturing: A review. *Frontiers of Information Technology & Electronic Engineering*, 18(1), 86-96. https://doi.org/10.1631/FITEE.1601885

Li, L., Lei, B., & Mao, C. (2022). Digital twin in smart manufacturing. *Journal of Industrial Information Integration*, 26, 100289. https://doi.org/10.1016/j.jii.2021.100289

Liu, Y., Feng, J., Lu, J., & Zhou, S. (2024). A review of digital twin capabilities, technologies, and applications based on the maturity model. *Advanced Engineering Informatics*, 62, 102592. https://doi.org/10.1016/j.aei.2024.102592

Peng, M., Li, Y., Zhao, Z., & Wang, C. (2015). System architecture and key technologies for 5G heterogeneous cloud radio access networks. *IEEE network*, 29(2), 6-14. https://doi.org/10.1109/MNET.2015.7064897

Qu, T., Lei, S. P., Wang, Z. Z., Nie, D. X., Chen, X., & Huang, G. Q. (2016). IoT-based real-time production logistics synchronization system under smart cloud manufacturing. *The International Journal of Advanced Manufacturing Technology*, 84, 147-164. https://doi.org/10.1007/s00170-015-7220-1

Segovia, M., & Garcia-Alfaro, J. (2022). Design, modeling and implementation of digital twins. *Sensors*, 22(14), 5396. https://doi.org/10.3390/s22145396

Soori, M., Arezoo, B., & Dastres, R. (2023). Internet of things for smart factories in industry 4.0, a review.

Internet of Things and Cyber-Physical Systems, 3, 192-204. https://doi.org/10.1016/j.iotcps.2023.04.006

Stallings, W. (2015). Foundations of modern networking: SDN, NFV, QoE, IoT, and Cloud. *Addison-Wesley Professional*.

Tao, F., Qi, Q., Liu, A., & Kusiak, A. (2018). Data-driven smart manufacturing. *Journal of manufacturing systems*, 48, 157-169. https://doi.org/10.1016/j.jmsy.2018.01.006

Wang, P., & Luo, M. (2021). A digital twin-based big data virtual and real fusion learning reference framework supported by industrial internet towards smart manufacturing. *Journal of manufacturing systems*, 58, 16-32. https://doi.org/10.1016/j.jmsy.2020.11.012

Wahab, H. A. *Numerical study of brick using hybrid genetic algorithm*. chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://cdnx.uobabylon.edu.iq/undergrad_projs/D9MwvDloV0qWV1mXgRGyg.pdf

Wen, M., Li, Q., Kim, K. J., López-Pérez, D., Dobre, O. A., Poor, H. V., ... & Tsiftsis, T. A. (2021). Private 5G networks: Concepts, architectures, and research landscape. *IEEE Journal of Selected Topics in Signal Processing*, 16(1), 7-25. https://doi.org/10.1109/JSTSP.2021.3137669

Wu, Y., Dai, H. N., Wang, H., Xiong, Z., & Guo, S. (2022). A survey of intelligent network slicing management for industrial IoT: Integrated approaches for smart transportation, smart energy, and smart factory. *IEEE Communications Surveys & Tutorials*, 24(2), 1175-1211. https://doi.org/10.1109/COMST.2022.3158270