Digital-twin-based implementation framework of production service system for highly dynamic production logistics operation

Hongfei Jiang\textsuperscript{1,2}, Ting Qu\textsuperscript{2,3}, Ming Wan\textsuperscript{1,2}, Liangru Tang\textsuperscript{1,2}, George Q. Huang\textsuperscript{3,4}

\textsuperscript{1}School of Management, Jinan University, No.601 Huangpu Avenue West, Guangzhou, People's Republic of China
\textsuperscript{2}Institute of Physical Internet, Jinan University (Zhuhai Campus), No. 206 Qianshan Road, Zhuhai, People's Republic of China
\textsuperscript{3}School of Intelligent Systems Science and Engineering, Jinan University (Zhuhai Campus), No. 206 Qianshan Road, Zhuhai, People's Republic of China
\textsuperscript{4}Department Industrial and Manufacturing Systems Engineering, The University of Hong Kong, Pokfulam Road, Hong Kong, People's Republic of China
\textsuperscript{5}E-mail: quting@jnu.edu.cn

Abstract: In the customised production mode, production and logistics are required to operate in synchronisation under the high dynamic interference, to realise the rapid response to the personalised demand of high-frequency changes. Facing high dynamic interference, how to realise the efficient synchronised operation of production and logistics by integrating external service resources has become a major challenge for manufacturing manufacturers. This study proposes a digital-twin-based implementation framework of production service system (DTIF-PnSS) for highly dynamic production logistics operations. The framework realises online collaborative operation and autonomous decision-making control of production logistics under high dynamic interference by providing smart services for real-time dynamic capture, operational precision mapping, dynamic virtual simulation and iterative decision optimisation. At last, the effectiveness of the DTIF-PnSS is verified by an application case of a coating chemical enterprise. It provides a feasible way to support the production logistics synchronised operation under high dynamic interference.

1 Introduction

With the improvement of living standard, the customer requirement is shifting towards the pursuit of individualised demands. To meet the individual demands and improve their competitive advantages, the production mode of manufacturing manufacturers gradually shifting to a customised production mode [1]. Under the customised production mode, the production logistics operation is vulnerable to high dynamic interference because of the characteristics of customised demand are small batch, multi-variety and large randomness [2].

To cope with the high dynamic interference, production and logistics are required to operate synchronously to achieve a rapid response to the individualised demands of high-frequency changes [3, 4]. However, the production logistics system is faced with synchronised difficulties such as the real-time perception of dynamic operation difficulties, online synchronised optimisation difficulties, and large synchronised operation costs, which makes it difficult for manufacturing companies to independently support the efficient synchronised of production and logistics under dynamic interference. Facing random dynamic interference, how to realise the efficient synchronised operation of production and logistics by integrating external service resources has become a major challenge [5].

Product service systems (PSSs) are an effective integration model of services and products. It supports manufacturers to meet personalised needs by providing integrated solutions that include personalised products and value-added services [6]. PSS has been successfully applied in product design [7], after-sales service [8] and sustainable development [9]. This advantageous service concept of PSS is further extended to the production service system (PnSS) at the product manufacturing stage [10]. PnSS allows manufacturers to acquire manufacturing resources in the form of continuous production services instead of resource entities, which helps manufacturers reduce the setup costs and technical risks of manufacturing resources.

The production-logistics synchronisation is that one subsystem triggers other subsystems to establish a dynamic collaborative relationship based on random dynamics, then these subsystems make dynamic collaborative optimisation and autonomous decision control to generate a global optimal operation plan. Therefore, the efficient synchronisation of production and logistics not only needs to obtain the real-time operation dynamic of the whole process of production and logistics, but also needs to realise the coordinated decision-making of all stages of production-logistics under the real-time data-driven.

Digital twin (DT) meets the monitoring, simulation, and optimisation of unknown customer needs and the operating environment through virtual interaction feedback, data fusion analysis and decision iteration optimisation [11]. Facing the whole life cycle of the product, DT plays a role of the bridge between the physical world and the information world, which provides more real-time, efficient and smart services [12]. As a smart technology, DT can accurately map the real-time operation status of production-logistics in the physical world to the information world. Through the coordinated operation and iterative optimisation of production and logistics based on dynamic interference, the dynamic smart operation of production logistics is realised.

For the whole process of high dynamic production logistics operation, this paper proposes a DT-based implementation framework of production service system (DTIF-PnSS). It provides a solution for the smart synchronised operation of large production-logistics systems with multiple stages in a complex and frequent changing operating environment.

This paper addresses three research questions: (i) How does DTIF-PnSS manage hardware resources, software resources, and data collection resources to capture real-time operational data? (ii) How does DTIF-PnSS use real-time operational data to support the online optimisation of production and logistics? (iii) How can DTIF-PnSS achieve collaborative decision-making and autonomous control of production and logistics through online optimisation to cope with high dynamic interference?
This paper has two main research challenges: (i) How to expand the DT mapping framework into an implementation framework that is compatible with the characteristics of production and logistics synchronised operations? (ii) How to combine the service concept of the PnSS with DT technology to support the high dynamic production logistics synchronised operation?

This paper is organised as follows: Section 2 reviews some previous studies relevant to the proposed DTIF-PnSS. Section 3 analyses the problems of synchronised operation of production and logistics under high dynamic interference. Section 4 discusses the details about DTIF-PnSS. In Section 5, presents a case study to test the effectiveness of DTIF-PnSS. Finally conclusions are summarised in Section 6.

2 Literature review

2.1 Product-service systems

In the customised production environment, it is difficult for a single manufacturer to independently respond to random dynamic interference with its limited production and logistics resources. It is necessary to cooperate with external service resources to meet personalised needs. PSS is an innovative business model that combines products and services in a certain percentage and delivers them to customers through sale, lease even mix both ways [13]. PSS is the main development direction of transformation and upgrading of traditional manufacturers, which provides many companies with competitive opportunities and is successfully applied in many fields [14].

Lee et al. [15] researched PSS application on public bicycle systems to effectively measure the sustainability of PSS. Gelbmann and Hammert [16] explored the use of PSS in waste recovery, which effectively reducing waste and increasing resource productivity. Song and Sakao [17] verified the feasibility and potential of the PSS design framework in the industry by conducted a case study of elevator PSS design. Li et al. [18, 19] presented a PSS modular design framework for large-scale personalisation to achieve large-scale, personalised, low-cost and fast delivery of customer needs.

With the development of smart technologies such as the Internet of Things (IoT), DT, and cloud manufacturing, scholars are beginning to study the integration of PSS with smart technology. Zancul et al. [20] combined IoT technology with PSS to minimise potential product failures. Zheng et al. [21] presented an innovative system design framework for smartaggable system services that provide valuable insights to manufacturers.

This advantageous service concept of PSS is further extended to the PnSS at the product manufacturing stage [10]. This new model helps reduce the setup costs and technical risks of production resources while ensuring their lifecycle service levels. Zhang further expanded PnSS based on IOT and cloud, and proposed a PnSS enabled by cloud-based smart resource hierarchy to provide hardware and software resources for product manufacturing [22]. With the rapid increase of personalised demand, it is difficult to make decisions and control in the manufacturing stage, which increases the demand of manufacturers for precise decision-making and autonomous control services. At present, there are few studies considering PnSS that can provide online collaborative optimisation and autonomous decision control services to meet the personalised needs of high-frequency changes.

2.2 Smart enabling technology

The use of PnSS to achieve online collaborative operation and autonomous decision-making in the product manufacturing stage is inseparable from the support of smart enabling technology. DT is a smart technology with real-time synchronisation, faithful mapping, and high fidelity, which can realise the interaction and fusion of the physical world and the information world [23]. It has been applied to all stages of the product life cycle, including design [24], manufacturing [25], and maintenance [26].

Scholars have done some valuable research around DT. Canedo proposed to use of DT for full life-cycle control of physical devices [27]. Coronado et al. [28] built DT workshops for production control and optimisation. Banerjee et al. [29] combined knowledge learning with DT to develop a knowledge of extracting and reasoning from large-scale production line data, which improved manufacturing process management. Schleich et al. [30] presented a DT reference model, which solves the representation and application of DT model in the product life cycle, improves product performance and shortens the time to market.

Although DT provides an effective management model and technical framework for the physical integration, interaction, and collaboration of information. However, its application is limited to independent object. There is very little research to provide online collaborative decision-making services for complex operating systems composed of multiple stages.

3 Problem formulation

3.1 Production logistics operation process

As shown in Fig. 1, production-logistics operation is a complex operation process composed of multiple stages of production, warehousing and distribution. The operation process can be described as follows.

Firstly, the customer service of the manufacturers receives and integrates customer requirements to make production orders, and releases production orders to various production workshops. Secondly, according to the requirements of the production order, the workshop completes the production of different types by arranging the production time, production sequence, production

Fig. 1 Production logistics operation process
quantity and production equipment of the products. After the production is finished, it will be temporarily stored at the offline point of each production workshop. Next, a forklift directly delivers the products temporarily stored in the off-line point to the warehouse, which avoids affecting the production continuity. Then, the warehouses allocate cargos according to the storage rules to meet the storage needs of finished products that have been offline. Finally, the third-party logistics companies deliver products to customers by arranging delivery vehicles, distribution routes and delivery times in accordance with established loading principles.

The traditional production and logistics operation process are closely related and operate independently. Each stage has its own decision objectives and decision constraints. The actual situation of other related stages is not taken into account when a single-stage makes decisions, which makes the decision-making is difficult to achieve the overall optimisation. For example, the goal of decision-making in the production process is to make a production scheduling plan considering the personnel, material and equipment resources of the workshop. It is not considered whether the resources of the logistics stage can meet the requirements of the production plan.

### 3.2 Dynamics analysis

There are many types of dynamics in the whole process of production logistics. Each dynamic may have an impact on the execution of the production logistics plan. Dynamic refers to the uncertainty caused by the lack of accurate knowledge or prediction of a process or parameter, which may come from the lack of information, the complexity of the information, and the errors caused by the measurement [31].

Dynamic can be divided into four types: system inherent uncertainty, process uncertainty, external uncertainty and discrete uncertainty. The system inherent uncertainty includes relevant parameters obtained from the factory, such as dynamic constants, physical characteristics etc. The process uncertainty refers to data obtained from measurements or predictions, such as task processing time and speed, yield, and temperature etc. The external uncertainties are uncertain factors caused by changes in technology, processes, and market conditions, such as the increase or decrease of parts required for the original order etc. The discrete uncertainty mainly refers to production equipment failure, vehicle failure etc.

### 3.3 Challenge analysis

From the above analysis, it can be seen that the production-logistics operation is susceptible to random high dynamic interference. In the actual operation process, the strong correlation of all stages of production and logistics makes the random uncertainty of any stage affect the effective operation of other stages, and then affect the efficient operation of the whole production-logistics operation. The high dynamic has brought adverse effects to the production-logistics operation.

High dynamic interference results in poor execution of the initial plan of production and logistics. In the actual operation of production and logistics, all stages are strictly in accordance with the pre-established plan. However, due to the change of operation environment caused by random high dynamics, it is difficult for the initial plan to meet the actual dynamic operation requirements. As a result, the initial plan execution efficiency is low.

In addition, high dynamic interference leads to low utilisation resources and high operating costs of production and logistics resources. Random high dynamic interference makes the production completion time and quantity have great uncertainty. Meanwhile, due to lack of dynamic coordination mechanism, the logistics stage cannot dynamically adjust the plan according to the operation of the production stage, which makes a lot of waste of resources caused by waiting and the increase of the overall operating cost of the system.

To cope with the high dynamic interference, to realise the improvement of overall operation efficiency and the reduction of operating cost, production and logistics are required to operate synchronously. Due to the high dynamic adverse interference, the synchronised operation of production and logistics has the following three challenges:

- **The difficulty of perceiving real-time operational data**: The whole process of production-logistics produces a large amount of multi-source heterogeneous real-time data such as people, machines, materials, processes and environment. The acquisition of real-time data is the basic support of the synchronised operation of production and logistics. Therefore, an effective real-time operation data perception method is needed, which can provide data support for synchronised operation.

- **The difficulty of real-time data-driven online synchronised optimisation**: The synchronised operation of production and logistics with high dynamic interference is the dynamic coordination optimisation process of many related stages. The individual demand with the characteristics of small-batch, multi-variety and randomness improves the difficulty, precision and speed of production-logistics synchronised optimisation. Therefore, an effective and fast online synchronised optimisation method that can be driven by real-time full-process operation data is needed to realise the autonomous decision-making and dynamic control of production and logistics.

- **High cost of synchronised operation under random dynamic interference**: The synchronised operation of production and logistics under random dynamic interference needs the support of many kinds of resources. Self-built synchronised resources usually have the investment risk of high cost, long cycle and poor adaptability. Therefore, a simple, efficient and low-cost external synchronised service is needed to help manufacturers to realise the synchronised operation under dynamic interference.

### 4 Digital-twin-based implementation framework of PnSS

To realise the synchronised operation of production and logistics, not only require the synchronised resources of production logistics and the real-time acquisition of the operation data of production and logistics, but also need a synchronised method that can realise online iteration and optimisation of production and logistics driven by real-time data.

DT is used to solve problems in manufacturing by using IT technology and traditional modelling technology. Based on the real-time interaction of cyber-physics, DT can capture the real-time and comprehensive disturbance factors (e.g. sudden equipment failure, emergency insertion, extended processing time etc.) that occur during the execution of production and logistics. The optimal operation strategy is generated by virtual simulation, which realises autonomous decision-making and dynamic management of production and logistics.

Based on the above analysis, a DTIF-PnSS is proposed. DTIF-PnSS inherits the DT framework proposed by Tao et al. [32]. As shown in Fig. 2, DTIF-PnSS includes four layers: physical resource layer, resource management layer, smart synchronised service layer and smart synchronised application layer. By providing smart services for real-time dynamic capture, operational precision mapping, dynamic virtual simulation and iterative decision optimisation, online collaborative operation and autonomous decision-making control of complex production-logistics systems under random dynamic interference are realised.

#### 4.1 Physical resource layer

The physical resource layer is the bottom of DTIF-PnSS. The role of this layer is to provide a variety of resources to specific
production and logistics tasks, which can effectively solve the shortage of resources caused by the dynamic demands.

This layer contains four types of production and logistics operational resources, such as traditional hardware resources (e.g. machine, truck, warehouse etc.), software resources (e.g. MES, WMS, TMS etc.), and data collection resources (e.g. RFID reader, RFID tags, PDA etc.). These resources may be provided by different manufacturers or operators and registered with DTIF-PnSS through a standard registration format.

### 4.2 Resource management layer

The main function of the smart resource management layer is to realise the virtualisation of physical resources. This layer provides visual real-time resource data to the smart synchronised service layer through management measures such as registration, search, monitoring and visualisation of physical resources. Meanwhile, the smart synchronised service layer calls the resources of this layer to realise the effective synchronised operation of production and logistics. This layer contains four functions: resource registration, resource searching, resource monitoring and resource virtualisation.

- **Resource registration**: This function provides resource registration services for physical resource providers. Improve resource registration efficiency by providing a standard resource registration format and simple registration steps. It is also convenient for resource users to understand the related situation of resources.
- **Resource searching**: The resource provider searches the registered resource information through this function to reasonably determine the resource information such as the price, equipment capabilities and constraints of its own resources. Similarly, resource users search for resources based on specific production and logistics synchronised needs to obtain the optimal synchronised resources.
- **Resource monitoring**: This function obtains the real-time operating status of resources by collection data equipment to monitor the entire process of resource operations. Through the real-time monitoring of resources, the abnormal situation of resource operation is detected in time, which avoids adverse effects on production-logistics operations. Meanwhile, resource monitoring provides data support for the formulation of optimal resource plans, which can improve the optimisation of resource use.
- **Resource virtualisation**: This function is to manage the registered resource information, and display parameter information of the resource through various charts. Resource information includes two parts: basic parameters and capability constraints. For example, the registration information of production equipment includes the basic parameters of the equipment (e.g. equipment model, types of processable products, rated power etc.) and the processing capacity of the equipment (e.g. maximum production capacity, output power etc.).

### 4.3 Synchronised service layer

The smart synchronised service layer is driven by real-time operation data of physical objects to provide smart services for specific synchronised tasks. It enables each stage of production and logistics to achieve coordination in resource allocation, operation plan, operation mode and control parameters according to random dynamic interference, and realises adaptive decision-making and control of production and logistics.

- **Real-time dynamic capture**: This service uses specific intelligent data collection equipment to capture the real-time operation status of production and logistics, and provides accurate real-time dynamic data for the coordinated operation and synchronised decision of production and logistics units.
- **Operational precision mapping**: This service faithfully maps the production and logistics operation status in the computer information world by integrating real-time operation data of personnel, equipment, materials, processes and environment of the entire production and logistics operation, which realises accurate virtual display of production and logistics operations.
- **Dynamic virtual simulation**: Based on real-time fusion and interactive information physical data, the service generates optimal operation strategy for virtual simulation according to the decision objectives and constraints in the computer information world, and finally realises the collaborative decision-making and autonomous control of production and logistics.
• Iterative decision optimisation: Based on historical operational data and dynamic operational data, this service continuously optimises in the computer information world, which achieves the optimal operation of production and logistics under dynamic interference.

4.4 Synchronised application layer
The smart synchronised application layer provides the application needs for production and logistics synchronised operations. This layer contains three applications: synchronised configuration, synchronised decision and synchronised control. Manufacturers select one or more of these applications for the online synchronised operation to reduce the negative impact of dynamics on production systems.

• Synchronised configuration: For the specific operational tasks of production and logistics synchronisation, this application cooperates with each stage of production and logistics to optimise the allocation of resources. Because the synchronised resource allocation is performed from the perspective of global optimisation, the resource utilisation rate is greatly improved.

• Synchronised decision: Faced with the problem of inconsistent decision-making in production and logistics caused by dynamic customer demand, this application implements dynamic decision-making and adaptive adjustment of the composition structure and execution plan of the production system to achieve the optimal response to dynamic demand.

• Synchronised control: Facing the dynamic interference of production and logistics operations, this application controls the entire process of production and logistics operations to the optimal and feasible operation state by evaluating the control environment, selecting control timing, and adopting control behaviour.

5 Case study
This section describes the application of DTIF-PnSS by a large coating chemical manufacturer located in the Pearl River Delta of China, which verifies the effectiveness of the DTIF-PnSS proposed in this paper. It also provides a certain reference value for enterprise managers.

5.1 Operational analysis
This company is a well-known paint manufacturer in China, which has been focusing on the R&D, production and sales of coatings for a long time. This company has many kinds of products. Due to seasonal changes, the market demand of products usually fluctuates significantly. To effectively avoid operational risks, the company adopts a make-to-order (MTO) production method to organise production.

Although the company adopted the MTO production method to meet customer demands and reduce inventory levels. However, the personalised demand with the characteristics of small-batch, multi-variety and high randomness makes the production and logistics operation of the company vulnerable to high dynamic interference, which brings many problems to the company. At present, dynamic customer demand is a common dynamic with a large scale of influence during the implementation of production-logistics of this company. Dynamic customer demand has caused three aspects of production and logistics operation problems, as follows:

• Product offline time is uncertain: The production and logistics operation are vulnerable to dynamic interference from orders, resources, quality and so on, which causes the product offline time and quantity has a greater uncertainty. If products go offline early, it is easy to cause congestion at the workshop offline point and the warehouse. If products go offline late, the product may not be delivered to the customer on time.

• Inefficient implementation of initial plan: Random dynamics make it difficult for the initial production and logistics plan to meet the operational requirements of actual execution.

Meanwhile, due to the lack of an effective coordination mechanism between the various aspects of the production and logistics of this company. As a result, the implementation of production logistics plan is inefficient.

• High operating costs: The decision-making units of production and logistics of this company cannot dynamically and quickly adjust the operation plan according to the execution situation, which causes a lot of waste of resources. At the same time, dynamic interference greatly increases the difficulty of decision-making, which increases the overall operating cost of the production logistics system.

To solve the problem of production and logistics operation caused by dynamic interference, DTIF-PnSS is applied. Based on DTIF-PnSS, the company makes online collaborative decisions and dynamic joint optimisation for all stages of production and logistics, which enables optimal response to dynamic interference.

5.2 Implementation environment deployment
The synchronisation of production and logistics is a dynamic and collaborative process driven by real-time data. Therefore, to achieve effective synchronisation of production and logistics, the company needs to deploy an implementation environment of DTIF-PnSS. Real-time acquisition of production and logistics data is achieved by deploying IoT sensing equipment at key nodes in the entire process of the production logistics operation. The related IoT hardware deployment method has been introduced by Qu et al. [4]. This paper directly references it. The specific deployment details are shown in Fig. 3.

As shown in Fig. 3, the deployment environment includes four parts: the deployment of a communication network, the deployment of RFID readers, the deployment of tags, and the deployment of smart terminals.

The communication network is deployed in the workshop and warehouse to ensure that real-time data of production and logistics operations are transmitted to the DTIF-PnSS service layer in real-time. By deploying tags on pallets to record production and logistics operations data. After comprehensively considering the use environment and cost of the tag, the company uses ‘RFID/QR code tag. The deployment of RFID reader can read the production and logistics data so that the staff can make relevant decisions based on the data. After comprehensively considering the use environment, convenience and cost, the company uses explosion-proof handheld reading devices. Deploying smart terminal deployments in production workshops, fleets and warehouses can make managers to grasp the real-time execution status of timely production logistics operations.

5.3 System demonstration
DTIF-PnSS provides a solution for the company to online decision-making and dynamic control under dynamic interference. The main process of the solution includes six steps: order real-time acquisition, reasonable allocation resources, develop a static initial plan, real-time operation monitoring, dynamic correction optimisation and real-time coordination and control. Some important interfaces corresponding to each process is shown in Fig. 4.

(i) Order real-time acquisition: After a customer submits a purchasing order to the company, the company's customer service quickly receives the order to improve customer satisfaction.

(ii) Reasonable allocation resources: According to customer order requirements, the company searches for available production and logistics resources on DTIF-PnSS. Then, DTIF-PnSS formulates optimal resource allocation for customer orders to maximise resource utilisation and minimise costs.

(iii) Develop a static initial plan: Before the production starts, the company uses real-time dynamic capture service to collect real-time data such as personnel, equipment, materials, methods and environment in the production logistics operation process. Driven by real-time converged data, the initial plan is made through
synchronised decision between multiple units with heterogeneous
decision structure and independent decision objective.
(iv) Real time operation monitoring: In the process of production
and logistics execution, the precise image of the entire process of
production and logistics operations are performed in the computer
information world, so that the production execution dynamics can
be found in time.
(v) Dynamic correction optimisation: In the execution process of
production logistics, driven by real-time dynamics, the company
performs dynamic virtual simulation and iterative decision-making
optimisation of production and logistics operations. Through
continuous iterative revision and optimisation of the initial
production and logistics plan, the optimal operation plan that meets
the actual operation situation is obtained. This step eliminates the
bad interference of dynamics on production logistics operations.
(vi) Real time coordination and control: Through the real-time
feedback of the dynamic correction and optimisation results to the
production and logistics units, the online collaborative adjustment
of production and logistics operations is achieved. This step
controls the whole process of production and logistics in a feasible
and optimal state under dynamic effects, and realises the
coordinated management and control of the entire life cycle of
production and logistics.

5.4 Benefits
DTIF-PnSS provides basic operational data and synchronised
service support for efficient collaborative operation and
autonomous decision-making control of production and logistics,
which improves the management and control ability of production
and logistics to respond to dynamic interference. This company
benefits from DTIF-PnSS in three aspects relating to visualisation
and decision-making and cost.
For visualisation, the company used DTIF-PnSS to increase the
transparency of production and logistics operations. Before
applying DTIF-PnSS, workers need to go to the execution site to
obtain production logistics operation data. The actual operation of
all stages of production logistics is not transparent. After applying
DTIF-PnSS, Workers can know the real-time execution status of
production and logistics on smart terminals.

Fig. 3 IOT equipment deployment [4]
Fig. 4 Important interfaces of the DTIF-PnSS
For decision-making, the company improved its decision-making ability by applying DTIF-PnSS. Before applying the DTIF-PnSS, the company mainly made decisions through manual historical experience. Its decision-making speed is slow and difficult. After applying the DTIF-PnSS, the company generates optimised strategies through dynamic virtual simulation and iterative decision optimisation services, which improves the accuracy of decisions and reduces the risk caused by decision errors.

For cost, the company reduced production and logistics operations costs. After using the DTIF-PnSS, production and logistics can be collaboratively optimised based on random dynamic interference, which reduces the waste of resources caused by waiting. As a result, the overall operating cost of the company is reduced.

After the application of the DTIF-PnSS, the average time spent in warehouses was reduced from 45 to 36 h, which decreased by 25%. The timely rate of product stocking increased from 78 to 93%, which increased by 15%. Daily production increased from 275 kg per capita to 298 kg per capita.

6 Conclusion

In the customised production mode, to solve the difficulties of production logistics synchronisation such as real-time perception of operation dynamics difficult, online synchronisation optimisation difficult, and high synchronisation operation cost, this paper proposes a DTIF-PnSS. By providing smart synchronisation services for real-time dynamic capture, operational precision mapping, dynamic virtual simulation and iterative decision optimisation, DTIF-PnSS realises online collaborative operation and autonomous decision-making control of production logistics under high dynamic interference.

The contributions of this paper are fourfold. First, this paper proposes an effective service solution for the synchronised operation of production logistics under dynamic interference. It not only enriches the theoretical research on the collaborative operation of production logistics, but also helps manufacturing enterprises to quickly respond to high-frequency customer needs. Secondly, this paper extends the classic DT mapping framework to a digital-twin-based implementation framework of the PnSS that supports the synchronised operation of production logistics. It provides a research method for the relevant scholars to provide online collaborative decision-making services for complex multi-unit operation systems. Thirdly, this paper proposes DTIF-PnSS for DT smart technology and PnSS model, which provides a way for related scholars to design a personalised PnSS based on DT. The future works of this research could be summarised as follows. First, this research focuses on the basic framework of DTIF-PnSS. This research needs to further design the operational model of DTIF-PnSS to attract more stakeholders to use it. Second, the DTIF-PnSS proposed in this paper is a personalised PnSS for the synchronisation problem of production logistics under high dynamic interference. The research also needs to be extended to a general DTIF-PnSS, which addresses more problems.

7 Acknowledgments

This paper was financially supported by the National Natural Science Foundation of China (51875251), Guangdong Special Support Talent Program – Innovation and Entrepreneurship Leading Team (2019BT02S593), 2018 Guangzhou Leading Innovation Team Program (China) (201909010006), Blue Fire Project (Huizhou) Industry-University-Research Joint Innovation Fund of the Ministry of Education (China) (CXXZH2201722), Natural Science Foundation of Guangdong Province of China (Key program 2016A030311041), and the Fundamental Research Funds for the Central Universities (11618401).

8 References

[1] Fogliatto, F.S., Silveira, G.J.C.D., Borenstein, D.: ‘The mass customization decade: an updated review of the literature’, Int. J. Prod. Econ., 2012, 138, (1), pp. 14-25

[2] Luo, H., Wang, K., Kong, X.T.R., et al.: ‘Synchronized production and logistics via ubiquitous computing technology’, Robot. Comput. Integr. Manuf., 2017, 45, (1), pp. 135-145

[3] Qu, T., Pan, Y.H., Liu, X., et al.: ‘2016: IoT-based real-time production logistics synchronized mechanism and method toward customer order dynamics’, Trans. Inst. Meas. Control, 2017, 39, (4), pp. 429-445

[4] Qu, T., Lei, S.P., Wang, Z.Z., et al.: ‘IoT-based logistics synchronized system under smart cloud manufacturing’, Int. J. Adv. Manuf. Technol., 2016, 84, (1-4), pp. 147-164

[5] Yang, C., Lan, S., Shen, N., et al.: ‘Towards product customization and personalization in IoT-enabled cloud manufacturing’, Cluster Comput., 2017, 20, (2), pp. 1717-1730

[6] Zhang, Z., Chu, X.: ‘A new approach for conceptual design of product and maintenance’, Int. J. Comput. Integr. Manuf., 2016, 23, (7), pp. 603-618

[7] Sundin, E., Lindahl, M., Ijomah, W.: ‘Product design for product/service systems: design experiences from Swedish industry’, J. Manuf. Technol. Manag., 2009, 20, (5), pp. 233-253

[8] Szweczyzews, M., Goﬁn, K., Anagnostopoulos, Z.: ‘Product service systems after-sales service and new product development’, Int. J. Prod. Res., 2015, 53, (17), pp. 5334-5353

[9] Ding, K., Jiang, P., Zheng, M.: ‘Environmental and economic sustainability aware resource service scheduling for industrial product service systems’, J. Intell. Manuf., 2015, 26, (6), pp. 1303-1316

[10] Qu, T., Chen, X.D., Zhu, M., et al.: ‘Analytical target cascading-enabled optimal conﬁguration platform for production service systems’, Int. J. Comput. Integr. Manuf., 2011, 24, (5), pp. 457-470

[11] Tao, F., Cheng, T.J., Qi, Q., et al.: ‘Digital twin-driven product design, manufacturing and service with big data’, Int. J. Adv. Manuf. Technol., 2018, 94, (9-12), pp. 3563-3576

[12] Tao, F., Sui, F., Li, A., et al.: ‘Digital twin-driven product design framework’, Int. J. Prod. Res., 2019, 57, (12), pp. 3935-3953

[13] Mont, O.K.: ‘Clarifying the concept of product–service system’, J. Clean Prod., 2002, 10, (3), pp. 237-247

[14] Beuren, F.H., Ferreira, M.G.G., Miguel, P.A.C.: ‘Product-service systems: a literature review on integrated products and services’, J. Clean Prod., 2013, 47, pp. 222-231

[15] Lee, S., Geum, Y., Lee, H., et al.: ‘Dynamic and multidimensional measurement of product-service system (PSS) sustainability: a triple bottom line (TBL)-based system dynamics approach’, J. Clean Prod., 2012, 32, pp. 173-182

[16] Greßmann, U., Hammerl, B.: ‘Integrative re-use systems as innovative business models for devising sustainable product-service-systems’, J. Clean Prod., 2015, 97, pp. 50-60

[17] Song, W., Sakao, M.: ‘Customization-oriented framework for design of sustainable product/service system’, J. Clean Prod., 2017, 149, pp. 1672-1685

[18] Li, H., Ji, Y., Gu, X., et al.: ‘Module partition process model and method of integrated service product’, Comput. Ind., 2012, 63, (4), pp. 298-308

[19] Li, H., Tang, F., Wen, X., et al.: ‘Modular design of product-service system oriented to mass personalization’, China: Mech. Eng., 2018, 29, pp. 2204-2214

[20] Zanuy, E.S., Takey, M., Barquet, A.P.B., et al.: ‘Business process support for IoT based product-service systems (PSS)’, Bus. Process Manag. J., 2016, 22, (2), pp. 305-323

[21] Zheng, P., Lin, T.J., Chen, C.H., et al.: ‘A systematic design approach for service innovation of smart product-service systems’, J. Clean Prod., 2018, 201, pp. 657-666

[22] Zhang, K., Wan, M., Qu, T., et al.: ‘Production service system enabled by cloud-based smart resource hierarchy for a highly dynamic synchronized production process’, Adv. Eng. Info., 2019, 42, p. 100995

[23] Tao, F., Zhang, M.: ‘Digital twin shop-floor: a new shop-floor paradigm towards smart manufacturing’, Access, 2017, 5, (99), pp. 20418-20427

[24] Hao, L.I., Fei, T., Haoqi, W., et al.: ‘Integration and key technologies of complex product design-manufacturing based on digital twin’, Comput. Integ. Manuf. Syst., 2019, 25, (6), pp. 1320-1336

[25] Uhlenm, T.H.J., Schock, C., Lehmann, C., et al.: ‘The digital twin: demonstrating the potential of real time data acquisition in production systems’, Procedia Manuf., 2017, 9, pp. 113-120

[26] Aivaliotis, P., Georgoulias, K., Arkouli, Z., et al.: ‘Methodology for enabling digital twin using advanced physics-based modelling in predictive maintenance’, Procedia CIRP, 2019, 81, pp. 417-422

[27] Canedo, A.: ‘Industrial IoT lifecycle via digital twins’, Proc. of the Eleventh IEEE/ACM/IFIP Int. Conf. on Hardware/Software Codesign and System Synthesis. ACM, Pittsburgh, USA, 2016, p. 29

[28] Corrales, P.D.U., Leyva, R., Lauthch, N., et al.: ‘Part data integration in the shop floor digital twin: Mobile and cloud technologies to enable a manufacturing execution system’, J. Manuf. Syst., 2018, 48, pp. 25-33

[29] Banerjee, A., Dalal, R., Mittal, S., et al.: ‘Generating digital twin models using knowledge graphs for industrial production lines’, UbMIC Information Systems Department, New York, USA, 2017

[30] Schleich, B., Anwer, N., Mathieu, L., et al.: ‘Shaping the digital twin for design and production engineering’, CIRP Ann., 2017, 66, (1), pp. 141-144

[31] Zimmermann, H.J.: ‘An application-oriented view of modeling un-certainty’, Eur. J. Oper. Res., 2000, 122, (2), pp. 190-198

[32] Tao, F., Cheng, Y., Cheng, J., et al.: ‘Theories and technologies for cyber-physical fusion in digital twin shop-floor’, Comput. Integ. Manuf. Syst., 2017, 23, (8), pp. 1603-1611