Achieving Manufacturing Excellence through the Integration of Process Planning Change and Data-driven Simulation

Xiaogang Wang¹*, Yiqun Liu¹, Yang He², Li, Nie¹, Hua Mu³, and Yuewei Bai¹

¹School of Intelligent Manufacturing and Control Engineering, Shanghai Polytechnic University, Shanghai, 201029, P. R. of China
²China Tobacco Guizhou Industrial Co., Ltd, Guizhou, 550001, P. R. of China
³Wuhan KM Information Technology Co., Ltd., Hubei, 430076, P. R. of China

*Corresponding author’s e-mail: xgwang@sspu.edu.cn

Abstract. In this paper, a data-driven simulation framework with the integration of process planning change is proposed. It solves the problems of insufficient throughput and unbalanced resource utilization caused by the extremely unbalanced working time, improper resources allocation. Integration with Flexsim using a 3D graphical user interface is designed to meet the needs of complex data management. Experiments were tested, and the results show that the proposed approach combines the real-time rescheduling and quickly changing.

1. Introduction

In recent increasingly fierce global manufacturing competition, enterprises are required to constantly tap production potential, make full use of the existing productive resources in the workshop, in order to reduce production costs and quickly respond to market changes[1-2]. More and more scenarios require enterprises to have the characteristics of low cost, low energy consumption, fast response, and the ability to flexibly produce single-batch or small-batch, highly customized products, which proposes changes in factory layout and rapid adjustment of process flow New requirements. In the past, rapid layout of production lines was mainly used in RMS (Reconfiguration Manufacturing System)[3], which can quickly adapt to changes in market demand by quickly reorganizing existing Manufacturing resources. However, considering that the layout of the workshop directly affects the material handling cost of the workshop and the operation efficiency of the production system; in the production lines of workshop, there are constraints such as the number of shift personnel and equipment, fixed layout constraints, process priority constraints, man-hour constraints, as well as workshop space, capital investment and other constraints [4]. And technical factors, resources change, assembly process operation time of randomness, key equipment maintenance rules, rules of re-entry and staff scheduling rule change will bring the change of system efficiency, some changes may even cause the changes of physical layout in the workshop. The large-scale and traditional workshop layout adjustment is often a huge time-consuming scene, which is not easy to evaluate various rapid evaluation schemes, and to study a data-driven process and simulation interactive workshop process changes and workshop layout schemes to achieve quick response is particularly important in production planning.
2. Data-driven Simulation for Process Planning Change

2.1. The State of the Art

At present, the domestic enterprises gradually are adopted the advanced assembly equipment and technology, but they still use the traditional assembly line planning model to design the production line. Engineers need more experience to validate the feasibility of the assembly line planning, and lack of quantitative evaluation and analysis method to validate plans ahead. A lot of planning problems were found just in practical operation, and the changes in the production process and not prompt field assembly planning[6-7]. Changes are not easy to make quickly. The discrete event modelling tool is utilized to simulate the production line with simulation model. However, due to the uncertain influencing factors in the assembly site, including the labour efficiency of workers and the state of machinery and equipment, the simulation model and the actual assembly process are seriously "distorted", resulting in the "bottleneck drift" on the assembly line[8], which seriously affects the assembly line productivity and efficiency. In addition, some foreign institutions and scholars mainly focus on how to make the material handling cost lowest and the efficiency highest in the layout optimization research, such as solving the layout scheme through systematic layout planning [4] and artificial intelligence evolutionary algorithm. Improving the utilization rate of production units is part of the effective means for enterprises to improve production efficiency and reduce production cost. However, production units are often subject to various constraints in work, such as: fault and maintenance of production units, cleaning of production units, operators' rest and so on. These constraints make it difficult calculate the effective working time of the processing unit and increase the difficulty of material supply. If the material supply speed is too slow, the processing unit will wait for the material and the equipment utilization rate will be low. If the supply speed of material is too fast, the queue of material to be treated is too long. At present, a large number of researchers have applied virtual manufacturing system modelling and simulation technology to solve the layout problem. The data-driven approach leads to the emergence of rapid modelling, simulation and reconstruction technologies. G. Poptics propose a real-time data-driven simulation model modelling framework based on PLC and MES data. In addition, NIST and NNSA respectively completed the application of database-based rapid modelling technology in Quest and Flexsim of DES platform[9-10].

2.2. Typical Constrains of Production Unit & Problem formulation

2.2.1 Typical Constrains of Production Unit to Simulation Model

For example, a machining production unit model is: the workpiece is carried to an infinite capacity waiting area for processing at a constant speed of 10 min. Machine tools can only process one piece at a time. The processing time of a single work piece is subject to the standard normal distribution $\mu=7.5$ min, $\sigma=20s$. Considering the actual situation of drilling machine processing, the following constraints are added: (1) the time interval of machine fault is distributed exponentially with an average of 3h, the maintenance time of failure is distributed exponentially with an average of 15 min. (2) Drill press state inspection interval is 1h, the examination time was distributed exponentially with a mean of 2 min. (3) The interval of cutting debris cleaning time is normally distributed $\mu=2h$, $\sigma=10$ min, and the cleaning time was constant 5mins. The production and processing model is presented in Fig.1.
2.2.2 Problem formulation

Assuming that each assembly unit contains N station types, Ni refers to stations i. For a specific assembly unit, if the number of stations increases, the utilization rate decreases, causing resources and personnel to be idle; on the contrary, if the number of stations decreases, the utilization rate can be increased, but excessive utilization rate will increase or decrease the load of workers, or even create a new bottleneck assembly unit.

Given the constraints of assembly process content, workshop layout, logistics path, etc., determine the optimal number of stations under different assembly units, so that the station utilization rate meets certain requirements, the assembly line smoothness index is minimum; at the same time, the equipment failure rate, and the effect of personnel learning curve on assembly time.

The mathematical model of the problem is described as:

\[
\text{Min } S_I = f(N_1, N_2, \ldots N_n) \tag{1}
\]

s.t.

\[
N_i, \text{ min } \leq N_i \leq N_i, \text{ max } \tag{1-1}
\]

\[
\min(\eta_i, j) \eta_i \text{ min } \tag{1-2}
\]

\[
P(N_1, N_2, \ldots N_n) \leq 0 \tag{1-3}
\]

\[
L(N_1, N_2, \ldots N_n) \leq 0 \tag{1-4}
\]

\[
R(N_1, N_2, \ldots N_n) \leq 0 \tag{1-5}
\]

\[
F(N_1, N_2, \ldots N_n) \leq 0 \tag{1-6}
\]

Where, SI is the smoothness index; Formula (1) shows that the smoothing index value is minimized as the objective function; Equation (1-1) represents the boundary value of the number of available stations after considering the space size and assembly process. \(N_{i,\text{min}}\) and \(N_{i,\text{Max}}\) represents the minimum and maximum number of No.i station respectively. Equation (1-2) represents the requirement that the workstation utilization rate meets, wherein \(I_j\) is in the workstation of the second type The utilization rate of the \(i_{th}\) station, where the minimum requirement of \(i_{\text{min}}\) is ensured; Equations (1-3)-(1-6) represent process constraints, workshop layout constraints, path constraints and equipment failure rate constraints. Where, \(P(*)\) represents the process constraints that the key equipment must meet; \(L(*)\) represents the workshop layout constraints that key equipment must meet; \(R(*)\) represents the path constraint that the critical device must satisfy; \(F(*)\) represents the equipment failure rate constraint that critical equipment must meet. Because of the particularity of these constraints, traditional mathematical models are sometimes difficult to express accurately. The emergence of simulation modeling method provides a new way to implement these constraints, which can not only describe these constraints, but also accurately reflects the logical constraints of the assembly line.
3. Framework of the integration of Process Planning Change and Data-driven Simulation

A data-driven simulation framework with the real process data is proposed. The process planning change will influence the simulation in a near real-time state as to response the change and to solve the flexible scheduling problem.

3.1. Data-driven Simulation Framework

The data-driven rescheduling and simulation policy is used and the critical events that trigger the rescheduling procedure are defined as a machine breakdown. In other word, once a machine breakdown occurs, the rescheduling and simulation procedure begins. And the data-driven simulation framework is based on manufacturing process parameters and constrains. Real-time update from product manufacturing lines will call the change of the simulation model.

Fig. 2 shows the main phases:

3.1.1. Data Gathering

For the production line or a plant floor system, the modeling and simulation objectives will be specified first, for example, the layout data, constrains of the machines, can be identified and classified. The information gathering is used to describe the complex relationship among the data objects of the whole shop floor system.

3.1.2. Generating Model

During this phase, production logics for the production line or the shop floor will be defined from a sets of templates and be checked to assure its correctness. In Flexsim, C++ codes will be introduced for generating the simulation modules, a sets of inner APIs of the commercial simulation software are powerful. Therefore, the simulation can reflect the production dynamic status and expected changes.

3.1.3. Validating Model

Model verification and validation (V&V) is extremely important in simulation practice. It provides a base for further analysis and scenario studies. Model validation affirms that the simulation model is an accurate representation of the system. And in the framework of data driven production modeling and simulation, simulation analysis is conducted with different sample production data from the plant floor in order to ensure the correctness of the simulation models.

![Fig.2 Framework of Data-driven Modelling & Simulation from Engineering Process Change](image-url)
3.2. Data Definition from Product Process Planning to Simulation Model

The data model from product process planning to simulation model in the framework is shown as Fig. 3. Data consistency and normalization are more conducive to the transformation of defined logical models into physical models. Fig. 3 describes the 8 types of basic data for simulating the final assembly line. The relationships and organizational structure of true data, as well as the relationships between entities, attributes, and entities.

The ID identifies the entity in the figure: 1) Simulation model: the current data-driven or reconstructed simulation model. 2) Simulation experiment: Various parameters of simulation experiment contained in the simulation model are provided for automatic simulation operation parameters. 3) Final assembly line: The final assembly line is the main part of the simulation model, which is composed of multiple operational areas. 4) Working area: It is comprised of work stations and contains various parameters related to rapid visual layout. 5) Working Station: Operate the corresponding process, and generate parts distribution request and worker scheduling request before the process. After completing the corresponding process, the product transfer request is generated. The interior contains fast visualization layout pose parameters and reentrant operation Rules and simulation statistics. 6) Process: The process constitutes the process flow, which includes operators, man-hour data, parts requirements, etc. 7) Process flow: The process flow belongs to the assembly product and is comprised of the process and its priority constraints. 8) Final assembly product: Simulation research objects, mainly including product name and model information.

3.3. Interoperability of Simulation-Process and Quick Response in Flexsim

The data-driven modelling, simulation and reconstruction of process interaction are illustrated in the Fig 4. Firstly, data-driven modelling and simulation are performed. Through ADO/ODBC and other data access technology to read the modelling data in the data model, and through the model generator to call the relevant model library file, so as to automatically drive the model generation, and run the simulation. Secondly, the reconstruction scheme of the simulation model is designed. If the current simulation output is not satisfactory, the alternative scheme is redesigned and simulation model parameters are reset, and the data-driven modelling and simulation module are called again. At last, after repeated iteration, the modelling, simulation and reconstruction process will be completed until the evaluated simulation results meet the expected requirements.
Fig. 4 Interoperability of Simulation- Process and Quick Response in Flexsim

The main interaction objects are:

3.3.1. Basic modelling objects
Basic modelling objects contain resource class objects, entity class objects, information class objects and user interface class objects for the model. For example, discrete event simulation software Flexsim provides rich basic object classes, which can meet various requirements of data-driven modeling. The details will not be dealt with in this paper.

3.3.2. Model library
The model library includes the virtual workstation device model library. In addition, a data-driven template library, model generator templates, is included. The model builder template calls files in the model library and instantiates them to complete the modelling or refractory process.

3.3.3. Quick response from Process Planning
Process route planning usually contains: 1. 3D resource management, factory structure maintenance and other auxiliary functions provide data basis for process planning; 2. Process route rapid planning and division of labour based on 3D model and assembly process BOM; 3. Multi-process route editing and process view analysis; 4. Built-in typical process route, custom process route knowledge base. In the framework, we store templates in Flexsim and use the process flow module to response the change immediately.

4. Conclusion and future work
In this paper the framework of data-driven simulation with real-time process change was proposed. An integration framework was applied and the integration method is proposed. Simulation results showed that the framework responds to the changes in the shop floor immediately. The dynamic simulation model was rapidly customized with layout, modeling, simulation and reconstruction technology, which significantly improved the model. To develop a plugin toolkits which incorporated the advantage of pre-rescheduling approach and the reactive approach for manufacturing system (especially in 3D CAPP) deserves to further research.

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