Modeling and Simulation of Auto Parts Production Line Based on Petri Net

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Abstract. The production efficiency of small and medium auto parts manufacturing enterprises has been restricted by unreasonable production processes arrangement, high equipment load rate, high quantity of work in process (WIP), etc. To cope with these problems, this paper proposes a novel modeling method to analyze production line. The production line model is established by the method that combination of object-oriented Petri net (OOPN) and time transitions. Then the proposed model is validated based on incidence matrix and state equation analysis method, by which the bottleneck of the production line is identified. Simulation results are provided to validate that the proposed method can accurately reflect the production process and the bottleneck.

Keywords: Production line modeling · OOPN · Incidence matrix · Production bottleneck

1 Introduction

The production line is the core of manufacturing, and the manufacturing competitiveness is affected by production cycle, quality and cost of the products. So in order to produce better quality products with lower cost in a short time, modeling is necessary.

At present, there are many methods for manufacturing process modeling, such as IDEF, object-oriented, queuing theory [1–5]. But they have obvious deficiencies in system calculation and performance analysis. Meanwhile, computer simulation software from the earliest common programming language, to the text mode simulation software, to the graphical construction model [6], has been well applied to the manufacturing process simulation [7–9]. However, they lack theoretical analysis.

This paper has both theoretical calculation and simulation verification. It proposes a novel modeling method, then the established model is theoretically analyzed. Finally, the analysis results are verified by simulation.

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2 Petri Net

2.1 Basic Petri Net

A basic Petri net system is a triad [2],

$$PN = (P, T, F) \tag{1}$$

where P and T are respectively the place set and the transition set. $F \subseteq (P \times T) \cup (T \times P)$ is a directed arc set to represent the flow of resources in the net.

2.2 Object-Oriented Petri Net

Object-oriented Petri net system is a multivariate group,

$$OOPN = (P, T, F, OP, \&, W, M_0) \tag{2}$$

where OP represents the object net; and represents the relationship between the basic net and the object net; W is the set of weights, M_0 is the initial state identity.

Because we just focus on the number of the objects, so for OOPN model, we can use the number to descript the observed objects.

3 OOPN Modeling and Analysis

3.1 Introduction of Camshaft Production Line

The production process about the camshaft production line is shown in Fig. 1.

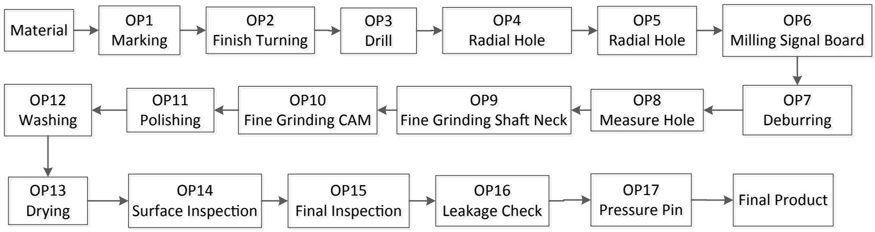

Fig. 1. Production process of camshaft

3.2 Establishing of OOPN Model

According to the production process of the camshaft, the whole process is divided into three stages: the rough machining stage, the finishing stage, and the detection stage. OOPN models of whole and each stage are shown in Figs. 2, 3, 4 and 5. In Fig. 2, P_{01} and P_{02} represent the material place and product place respectively.

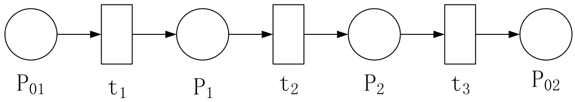

Fig. 2. Whole OOPN model

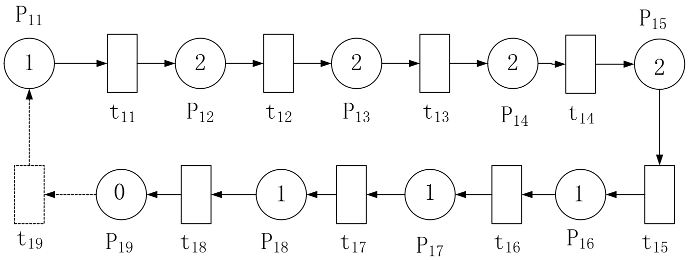

Fig. 3. OOPN model of rouge machining stage

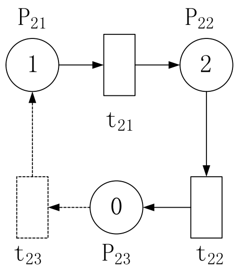

Fig. 4. OOPN model of finish machining stage

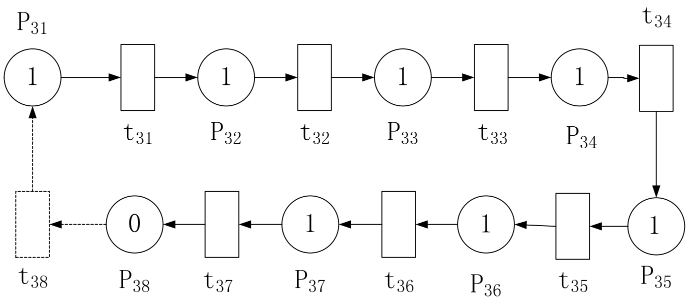

Fig. 5. OOPN model of detection stage

3.3 Validation of OOPN Model

The state equation of the established OOPN model is

$$M = M_0 + A^T X \tag{3}$$

where, A, X, and M represent incidence matrix, transition vector, and the state vectors respectively. If the established OOPN model is suitability, the production system can be returned to the initial state:

$$A^T X = 0 \tag{4}$$

Based on the incidence matrix, the basic solutions of the three stages of camshaft production line are calculated by Eq. (4):

$$x_1 = (1, 1, 1, 1, 1, 1, 1, 1, 1)^T \tag{5}$$

$$x_2 = (1, 1, 1)^T \tag{6}$$

$$x_3 = (1, 1, 1, 1, 1, 1, 1, 1)^T \tag{7}$$

According to the calculation, there are nonzero solutions in the three processing stages, so the OOPN model is suitable, the established models are able to run from the beginning of the production to finish and return to the initial state, which can realize repetitive production cycle.

3.4 Bottleneck Analysis

The production cycle is the time after a series of transitions to return to the initial state, namely,

$$\tau \geq y^T (A^-)^T Dx / y^T M_0 \tag{8}$$

where x satisfies the formula (4), is called T invariant, y satisfies Ay = 0, is called S invariant, $D = \text{diag}(d_j)$ is the diagonal matrix of each transition time.

According to formula (8), the production cycle of the rough machining stage, the finishing stage, and the detection stage is: τ_1 = 31 s, τ_2 = 26 s, τ_3 = 23 s, respectively. As we can see, the production cycle of rough machining stage is the longest, and the subsequent production stages are impacted, so it is the bottleneck of the system and affects the production efficiency of the whole production line.

To take full advantage of process time, output and tack time data, and to more intuitively understand the working state of equipment on the production line, the next chapter maps the OOPN model to Plant Simulation software.

4 Simulation and Analysis

The places and directed arcs in OOPN model are converted into entity and line of Plant Simulation respectively and set the parameters of entities to represent the transition process. Then simulation time is set to one month. Finally, the statistical results of the working status of each device are shown in Fig. 6.

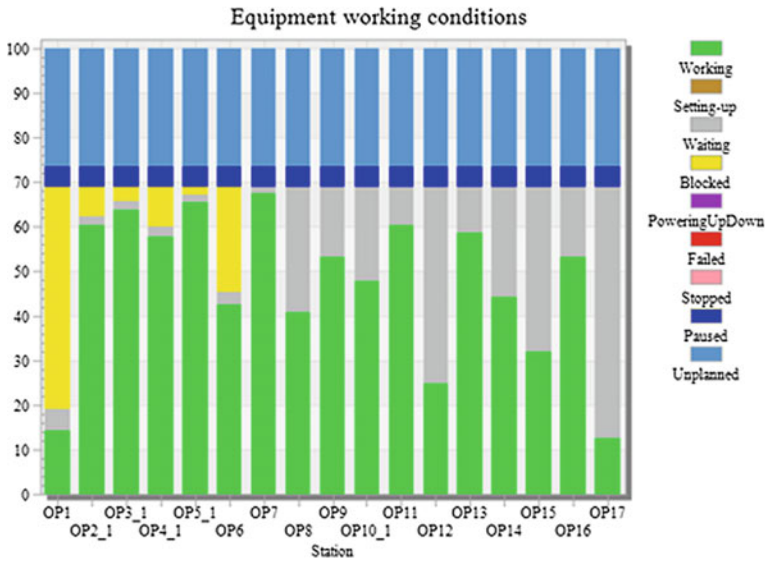

Fig. 6. Working status of each device

As evidently shown in Fig. 6, the load rate of OP7, OP5_1 and OP3_1 is as high as 67.18%, 65.42%, and 67.18% respectively. And for the first six workstations, there are obvious blocking phenomena, particularly the blocking rate of the OP1 process is up to 49.86%. The result indicated that the bottleneck of the whole production line appeared in the rough machining stage.

The result of simulation analysis is the same as that of the modeling analysis, which indicates that the proposed method that integrating OOPN hierarchical modeling with time transition can describe the actual production process well and can find the bottleneck of the production line accurately.

5 Conclusion

In the process of producing auto parts, there is a large difference in the load degree of different equipment, so the production line is imbalanced. In order to solve the problem, this paper takes the camshaft production line as an example, proposing the OOPN hierarchical model method and adding time in transitions. Then use the incidence matrix and state equation analysis method to prove the accessibility of established OOPN model and to determine the bottleneck of the production line. Finally, the theoretical analysis results of OOPN model verified through simulation analysis. It provides a theoretical basis for improving the production line.

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