Chapter 124
Modeling and Simulation of a Just-in-Time Flexible Manufacturing System Using Petri Nets

Yue Cui and Yan-hong Wang

Abstract The modeling and simulation issues of the flexible manufacturing system under Just-in-Time environment is addressed in this paper. A typical flexible manufacturing system has been used as the study case, and its Petri nets model with Kanban has been presented. Since bottleneck or hunger resources in the manufacturing system usually have bad influence on the production process, more attentions were paid to the bottleneck identification and digestion in support of the proposed modeling and simulation mechanism in this paper. The machine utilization, under the premise of meeting custom needs just-in-time, is used as the main measure, while the trigger priority and the kanban numbers are two main adjusted artifices. Therewith, a large number of numerical simulations are investigated and detail discussions are proposed further. The simulation results show that the proposed Petri nets based modeling technique, as while as the bottleneck identification and digestion strategies, are feasible and effective.

Keywords FMS · JIT · Modeling · Petri nets · Simulation

124.1 Introduction

FMS is a manufacturing mode that combines computer information control system and material automatic storage and transportation system (Du 2010). JIT approach to production was originated by Toyota in 1970s in their car assembly plants and the core content is eliminating manufacturing wastes by producing only the right amount and combination of parts at the right place at the right time (Araz et al. 2006; Zhang et al. 2012). The advantage of JIT flexible manufacturing system is

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not only embodies the JIT ideology but also enhances the flexibility of production systems. However, flexible manufacturing system is an extremely complex discrete event dynamic system; it is difficult to be described with traditional mathematical models.

Petri nets with its perfect mathematical theory as the foundation, has strong modeling capabilities to describe the parallel, synchronous, conflict relations and plays an important role in the system modeling and simulation. It has also been applied in the modeling of flexible manufacturing systems (Colombo et al. 1997; Mao and Han 2010). On the other hand, with the manufacturing system has become increasingly complex, especially under today's challenge environments, the auxiliary analysis software becomes a prerequisite for the application of Petri nets. ExSpect (Voorhoeve 1998), the Executable Specification Tool, is a powerful modeling and analysis of language and software tools based on timed colored Petri nets. It is widely used in transportation systems, workflow modeling and maintenance support system (Qu et al. 2009; van der Aalst and Waltmans 1991; Vanit-Anunchai 2010; University of Aarhus 2005).

This paper addresses the modeling and simulation issues of the flexible manufacturing system under Just-in-Time environment basing Petri nets and ExSpect, a common simulation software platform. A typical flexible manufacturing system has been used as the study case, and its Petri nets model with Kanban has been built. Since bottleneck or hunger resources in the production process are commonly occurred cases, and they often have bad influence on the production process of JIT flexible manufacturing system (Zhang and Wu 2009), more attentions were paid on the bottleneck identification and digestion in support of the proposed model and simulation mechanism. The machine utilization, under the premise of meeting custom needs just-in-time, is the main measure of the problem, while the trigger priority and the kanban numbers are two main adjusted artifices. At the end of the paper, a large number of numerical simulations are investigated to verify the effective of the proposed model and detail discussions are proposed further.

124.2 Petri Nets Model of the Single-Kanban System

One of the major elements of JIT philosophy is the kanban system (Al-Tahat et al. 2009). The kanban system is an information system which controls the production quantities in every process. Figure 124.1 shows a Petri nets model of the single-kanban system (Di Mascolo et al. 1991) and describes the production process of three adjacent processing units. In a single kanban system, a production line could be divided into several stages and there are a fixed number of kanbans at every stage. The production of a part cannot start until a kanban indicates that this part is needed by the following downstream station (Matzka et al. 2012).

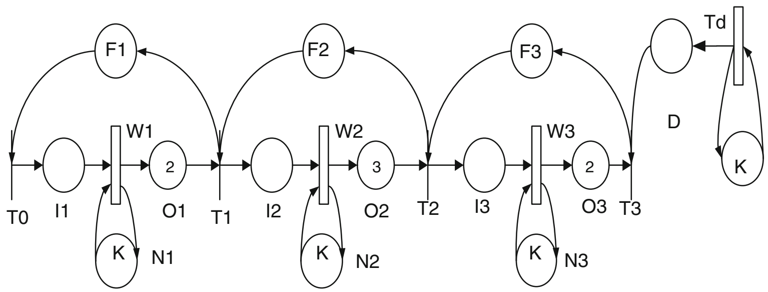


Fig. 124.1 Petri nets model of the single-kanban system

124.3 Modeling of JIT Flexible Manufacturing System

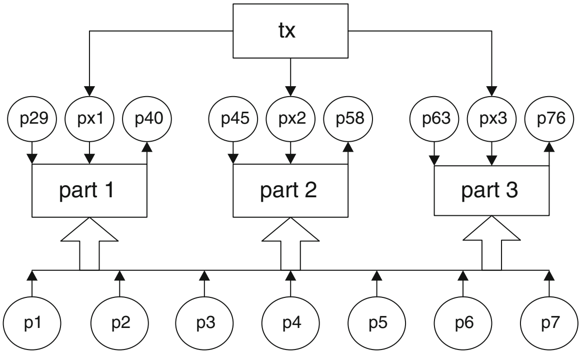
124.3.1 A JIT Flexible Manufacturing System Case

This paper takes a typical JIT flexible manufacturing system given in (Raju et al. 1997) as a case for addressing the modeling and simulation problem. The JIT flexible manufacturing system consists of five machining centers (from M1 to M5) and a load/unloads station (LUS), and they were connected by automatic guided vehicles (AGV) network. It caters to a variety of part types. In this paper, three part types are processed in this JIT flexible manufacturing system.

124.3.2 Petri Net Model of JIT Flexible Manufacturing System

The proposed JIT flexible manufacturing system modeling strategy adopted a hierarchical modeling methodology. First, The Petri net model of each part type is made separately. Then, these three models are linked by merging the common

Fig. 124.2 The JIT flexible manufacturing system model



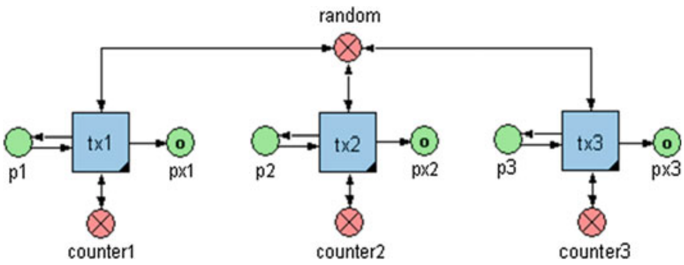


Fig. 124.3 User demands subsystem model

resource places to yield the system net. The interpretations of places and transitions are given in (Raju et al. 1997). Figure 124.2 shows the model.

Here main elements in the system are defined as:

px1, px2, px3: num, //Input requirements

p29, p45, p63: num, //Input of raw materials

p40, p58, p76: num, //Output products

p1, p2, p3, p4, p5: num, //Machines

p6: num, //Fixture

p7: num, //AGV

This Petri net model contains four sub-system, they are named as tx, part1, part2 and part3, respectively representing user demands subsystem, part1 processing subsystem, part2 processing subsystem and part3 processing subsystem. Among them, tx randomly generates user demands. A Poisson arrival pattern with a different mean arrival time for each part variety is considered in the present study. Each part has 10 demands as example in this paper, as an example for the system modeling, the tx model shown in Fig. 124.3.

This paper takes part1 as an example to introduce the processing subsystem, its model shown in Fig. 124.4. Being a demand-driven system, the functioning of the JIT flexible manufacturing system starts with the arrival of a demand. When a demand arrives, the system directly delivered the part to the user from output buffer. Then, the system begins to produce the same number of semi-finished or finished products to compensate for output buffer.

124.4 Simulation and Results

This paper use ExSpect as the simulation platform for our JIT flexible manufacturing system to illustrate the performance of the proposed modeling mechanism. Since bottleneck or hunger resources in the production process are commonly occurred cases, and they often have bad influence on the production process of JIT flexible manufacturing system, more attentions were paid on the bottleneck identification and digestion in support of the proposed model and simulation mechanism. The machine utilization, under the premise of meeting custom needs

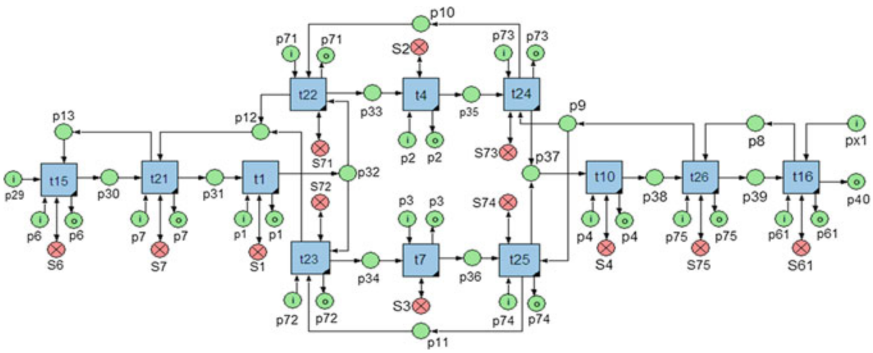


Fig. 124.4 The processing subsystem model for Part1

just-in-time, is the main measure of the problem, while the trigger priority and the kanban numbers are two main adjusted artifices. The simulation is running by the concurrent execution of the system net. A large number of simulations have been done, and the results data are recorded.

124.4.1 Initial Settings

The initial conditions of the system include the number of resources place token is one, the number of output buffer token is one, kanban number is zero, raw material is infinite and the average arrival time of the three part type demands are 10, 12 and 15 s respectively.

Simulation data include that the processing time of three parts, the difference of takt time, the total time, the machines utilization and the machines average utilization.

124.4.2 Simulation Results

Among them, takt time is an important factor in simulation. In order to produce only what the customers need just-in-time, the supplier has to adapt his production quantity to the customers' orders and produce to the takt time. The takt time is used to synchronize the pace of production with the pace of sales.

Takt time = Available working time per day/Customer demand rate per day (Matzka et al. 2012).

The difference of takt time is the difference between largest takt time of the part type and minimum takt time of the part type. The difference is smaller, the synchronization is better. However, because of bottleneck resources and hunger resources in the production process often impact the synchronization of

Table 124.1 Simulation Data

Performance Index	Simulation					
	1	2	3	4	5	6
P40 (s)	6052	5077	3872	3655	3670	3620
P58 (s)	3167	2517	3562	3170	3410	4200
P76 (s)	3797	3407	3142	3440	3470	3390
Difference of takt time	288.5	249	73	48.5	26	81
Total time	6632	5457	4892	4960	5290	5515
P1 (%)	61.37	69.27	83.20	94.35	94.52	91.21
P2 (%)	46.97	81.82	96.48	86.69	76.08	95.19
P3 (%)	33.47	51.31	52.33	76.81	93.01	81.41
P4 (%)	84.74	96.11	93.93	91.94	90.08	87.04
P5 (%)	49.00	73.30	91.99	90.73	85.07	90.66
P6 (%)	27.14	32.99	36.79	38.10	37.43	37.53
P7 (%)	78.71	47.42	52.59	54.39	53.36	52.63
Average utilization	55.11	74.36	83.59	88.10	87.75	89.10

production, it must eliminate bottlenecks and hunger issues. So this paper gives the definitions of bottleneck resources and hunger resources. Bottleneck resources refer to the machine resources that utilization exceed 10 % of the machines average utilization, and hunger resources refer to the machine resources that utilization below 10 % of the machines average utilization.

Simulation results were shown in Table 124.1 and the detail analysis were given bellow.

(1) Simulation 1. The simulation is run in the initial conditions; data show that the difference of takt time is too large; it means that the production synchronization is too weak. By comparing machines utilization and machines average utilization, it can obtain hunger resource is P3, bottleneck resources are P4 and P7 respectively.
(2) Simulation 2. In JIT flexible manufacturing system, resources are divided into two classes: fixed resources (P1–P5) and variable resources (P6, P7). Because of the former is the machine resource with high cost, it is not allowed to increase arbitrarily the number of resources. While the latter resource cost is low, it allowed be added properly its resources quantity. This paper adds one token in P7 for eliminating the influence of the bottleneck P7. The simulation results show the difference of takt time is decreased and bottleneck P7 is eliminated, it means that the production synchronization is improved. But there are still bottleneck resource P4 and hunger resource P3.
(3) Simulation 3. In JIT flexible manufacturing system, priority is divided into two kinds: resources priority and processing subsystem priority. Application simulation 1 utilization to set resources priority, (P1–P7): 0.61, 0.47, 0.33, 0.85, 0.49, 0.27, and 0.79. Through respectively calculating the ratio of three parts production time and the total time to set three processing subsystem priority, they are 0.91, 0.48, and 0.57. Resources priority can be set in the corresponding transitions, processing subsystem priority is set in all

transitions. When two kinds of priority will be set in the same transition, they should be added together. The priority is greater, the transition to be inspired more early. Results show that the difference of takt time are decreased, utilization are increased. But there are still bottleneck resources P2, P4, and hunger resource P3.

(4) Simulation 4. Increasing one kanban of P3, results show that synchronization continues to strengthen. By analyzing the data, it can obtain bottleneck affect has been eliminated, but there are still hunger resource P3.
(5) Simulation 5. Increase two kanbans of P3, results show that the synchronization is best, hunger resource P3 has been eliminated, but hunger resource P2 is appeared again.
(6) Simulation 6. The above conditions remain unchanged, increase one kanban of P2, results show that synchronization has been weakened, but the basic elimination of bottlenecks and hunger problem.

Through simulation and analysis of the simulation data, the bottleneck resources and hunger resources can be identified. Via adjust the number of kanban and the system priority, the system can effectively solve the bottleneck and the hunger problems, and optimize the performance indicators.

124.5 Conclusion

The main trend of the system simulation is the integration of modeling and simulation. Petri nets give a convenient method for the flexible manufacturing system modeling and simulation. This paper presents our modeling and simulation mechanism of the flexible manufacturing system under Just-in-Time environment.

By virtue of strong modeling capabilities of timed Petri nets, the model of the JIT flexible manufacturing system can describe the complex production process completely. In support of ExSpect environment, through simulation and data analysis, it can identify bottleneck resources and hunger resources. By setting the system priority and the number of kanban, the bottlenecks or hunger facilities are settled, and performance of the system is thereby improved by ameliorating the machine utilization and takt time in manufacturing processes. Therefore, the manufacturing process can run as a smooth and orderly mode with the premise of meeting custom needs in just-in-time manner.

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