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Production Process Scheduling Based on Simulation with Global Optimization Strategy: A Case Study

Yang Peng and Yue-Chao Jiang
School of Computer and Information Engineering,
Zhejiang Gongshang Universtiy, China

Abstract: In a production system, assembly line is a very important part. Some process should be improved, so the efficiency could get boosted. A simulation method is adopted to solve the production scheduling problem in this study. Illustrated by a practical example, the model and parameters, especially, the random allocation optimization and global task allocation have been put forward. Simulated by FlexSim, the optimization solution of the scheduling problem has been found, the simulation analysis shows the effectiveness of the proposed method.

Key words: Simulation, production scheduling, global task allocation, FlexSim, process modeling

INTRODUCTION

Human and material resources are allocated to the different tasks in a production scheduling problem (Guyon *et al*., 2010). Heuristic approach based on mathematical model and the computer simulation methods are the common ways to solve the scheduling problem. Moslehi and Mahnam (2011) presented particle swarm optimization and local search method to flexible job-shop scheduling problem, Li *et al*. (2011) adopted hybrid tabu search algorithm with an efficient neighborhood structure to solve such problem. An accurate mathematical operational model is hard to build and solve, a simulation method is adopted here.

Simulation provides a quick way to observe and study the operational patterns. Simulation is generally a computer technique to imitate the real-world facilities or processes. The process imitates a practical case with mathematical formula and the computer is to generate a simulation model to describe the interactions among the components of the systems (Smith, 2003; Tewoldeberhan *et al*., 2002; Fan *et al*., 2010).

Simulation software makes it visualized and easier to analyze the production scheduling problem. Sun *et al*. (2012) introduced a general simulation platform to evaluate the operational capability and efficiency of different designs of seaport container terminals. Yuan (2012) gave the simulation system of a dynamic management method for fast manufacturing resource reconfiguration by FlexSim software. Kuo and Yang (2011) imitated and analysis the assembly line with FlexSim as an assist. Purgstaller and Missbauer (2011) presented a simulation study that compares multi-period models for order release optimization.

This study adopted simulation method to deal with the production schedule problem, illuminated by practical instance, built the simulation model with FlexSim software, especially gave the random allocation optimization and global task allocation dynamic scheduling strategy in simulation mechanism, to analyse and get the relatively optimized solution.

PRODUCTION SCHEDULE PROBLEM AND THE MATHEMATICAL MODEL

Characters of the problem: The production schedule is a complex problem in manufacturing process, it has the following characteristics:

- The relationship among the various procedures is complicated
- High degree of uncertainty
- Vast manufacturing resources (teams and groups/equipment), complex supporting relationships among the processes, the existence of the many-to-many relationships
- The orders belongs to small lot/unit production, short delivery cycle, enterprises usually use the order oriented way to organize production, then supply according to the downstream business inventory

Because of manufacturing process characteristics, scheduling strategy and the current market competition environment, it is decided that the following questions exist in the production process:

Corresponding Author: Yang Peng, School of Computer and Information Engineering, Zhejiang Gongshang Universtiy, China

- The scheduling staff usually assigns the tasks by experience and intuition in team application for processing tasks, lacking global allocation optimization
- The teams always select and apply the tasks from their local interests, instead of the whole manufacturing process of interests, there are excessive applicants and negative applications. The scheduling center can't effectively control the specific production process
- Along with the economic recovery and developing market, increasing customer orders, contradiction of production and marketing is increasingly outstanding. Meanwhile, under the globalized dynamic market environment, the customer demand is increasing, and the order delivery circle is becoming shorter and shorter

Under the constraints of the existing manufacturing resources, the enterprises are in urgent demand to optimize the production process through scientific methods(shorten the manufacturing circle, improve the productivity, respond rapidly to the customer).

Research hypothesis: The processes studied here belong to the production and management process. This study mainly included the structured business process of good normative logic structure.

The following hypothesis was made based on the above research work:

- Activities are like atoms, i.e., the resource type that an activity instance/task execution needs to support is not more than 1 and the execution can not be interrupted
- In the business process, resources are exclusive

The process is divided into three parts: data collection and simulation model establishment, parameter setup, and results analysis.

The data is easy to get from the BPMS (business process management system) and WfMS (workflow management system). This study establishes simulation model in the manufacturing and supply process, to describe the relations among the activities, processes, resources and the logical structure, etc. Next, the related parameters shall be setup. In the end, the study proves that the production maximization oriented and execution time minimization oriented task allocation method works efficiently.

Mathematical model: The objective of the production scheduling is to get the start time and end time of each processes and make the time shortest and processing cost lowest. Due to the shorter production time does good to production capacity, this study selects the execution time minimization as the indicator:

$$\min T = \sum_{\substack{j=\mu+1 \\ j\in J}}^{n} (S_{jm} + P_{jm} - S_{j1}) + \max_{\substack{i=1,2,\ldots,\mu \\ i\in I}} \{S_{im} + P_{im} - S_{i1}\}$$

s.t.

$$\begin{cases} S_{aq} \geq S_{pq} + P_{pq} & (a, p \in \{I, J\}, q \in N) \\ E_{pq} = S_{pq} + P_{pq} & (p \in \{I, J\}, q \in N) \\ 0 \leq S_{p,q+1} - E_{pq} \leq T_{p,q+1} & (p \in \{I, J\}, q, q+1 \in N) \end{cases}$$

The definition of the variable:

i, j	:	Processes number.
I, J	:	Processes set, I = {I|i∈[1, μ]}, J = {j|j∈[μ+1, n]}, set I belongs to the paratactic logical structure, set J belongs to the tandem logical structure:
q	:	Activities number
N	:	The activities set in the production, N = {b|b∈[1, m]}, m is the last activity in each process
q+1	:	The process behind q process
S_{pq}	:	The starting time of process i, activities j
E_{pq}	:	The ending time of process i, activities j
P_{pq}	:	The production time of process i, activities j
T_{pq}	:	In process i, the allowed max waiting time before activities j comes to production
S_{aq}	:	The activity next to S_{pq} in the same process

SIMULATION METHOD AND THE CASE STUDY

In the boiler manufacturing process, the integrated scheduling of production and supply are difficult problems for decision-making. As descript above, simulation method is effective in many similar problem, we use FlexSim software to simulate and try to get the solution. Firstly, the simulation model must be design and parameters next.

The simulation models

Boiler production process modeling: Production process can be divided several activities and the smallest task allocation team is modeled as resources, the 'a' in Table 1 means activities and in Table 2, 'r' means resources. the 'c' in Fig. 1 stands for the logic nodes. e.g., 'c1' means logical relation 'and'. 'c5' means 'or', the detail activities are listed as Table 1 to help to study each process.

Table 1: The relatives between the actives and processes

Cone manufacturing	Liner manufacturing	Smoke-box and Interface manufacturing	Upper and lower cover manufacturing	Assembling
a1: Cone blanking	a6: Liner blanking	a12: Smoke-box and Interface blanking	a17: Upper and lower cover blanking	a19: Girth welding
a2: Cone rolling	a7: Liner rolling	a13: Smoke-box and interface rolling	a18: Upper and lower cover borehole	a20: Testing
a3: Cone longitudinal welding	a8: Inner longitudinal welding	a14: Smoke-box and interface welding		a21: Rework
a4: Cone NDT	a9: Liner NDT	a15: Smoke-box and interface NDT		
a5: Cone rework	a10: Liner rework	a16: Smoke-box and interface rework		
	a11: Liner forming			

Table 2: The relations between the resources and groups

Team	Resources	Quantity
Automatic blanking team	r1	1
Manual blanking team	r2	1
Rolling team 1	r3	1
Rolling team 2	r4	1
Manual welding team	r5	5
Automatic welding team	r6	2
Forming team	r7	1
Borehole team	r8	1

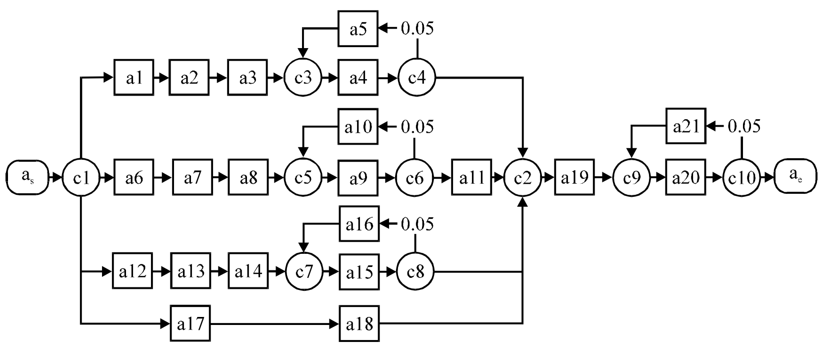

Fig. 1: Boiler manufacturing logic structure

In the table, each process includes several activities in the same column and the blanks show that no activities exist. If there are more blanks in a column, then the related process is more simple and the links among the team, resources and quantity are shown in Table 2.

The logic structure is necessary, the manufacturing system is divided into paratactic logical structures, which is important in the optimization, the relations among the components in the system are shown in Fig. 1.

As displayed in Fig. 1, a1, a2, a3, a4, a5 make up the process, cone manufacturing. a6, a7, a8, a9, a10, a11 make up the process, liner manufacturing. a12, a13, a14, a15, a16 make up the smoke-box and interface manufacturing. a17, a18 make up the upper and lower cover manufacturing. a19, a20, a21 make up the process, assembling. c1, c2 stand for logic nodes ‘and’, the rest ‘c’ for ‘or ’. namely, assembling should start after all the other processes finished. And the probability of c4-a5 is 0.05, c4-c2 is 0.95, which means after cone NDT, the probability to rework is 0.05.

In the Fig. 1, a_i(i = s, 1, 2, 3 ... 21, e) stands for the activities related to Table 1. c_i(i = 1, 2, 3..., 20) stands for the connection nodes, c1, c2 stand for the logic relationship ‘AND’, c3, c4, c5, c6, c7, c8, c9, c10 stand for logic relationship ‘OR’.

The scheduling relations between the resources and activities are listed in (Fig. 2) (a) Automatic blanking team and manual blanking team are required by activities a1, a6, a12, a17, which corresponds to cone blanking, liner blanking, smoke-box and interface blanking and upper and lower cover blanking in Table 1. (b) Rolling team 1 and team 2 are required by cone rolling, liner rolling and smoke-box and interface rolling. (c) Manual and automatic welding team are required by activities cone longitudinal welding, cone rework, inner longitudinal welding, liner rework, smoke-box and interface welding, smoke-box and interface rework, girth welding and rework. (d) Forming team is required by liner forming. (e) Borehole team is required by upper and lower cover borehole.

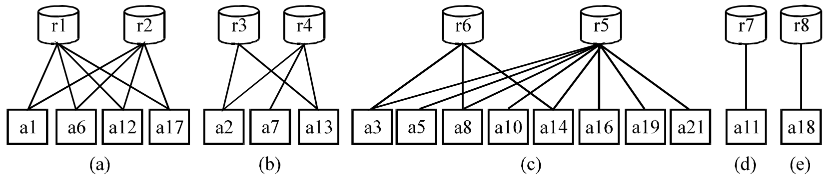

Fig. 2: Resources scheduling graph

Table 3: The average time that the resource processing takes (unit: min)

	Cone manufacturing					Liner manufacturing				Smoke-box and interface manufacturing							Upper and lower cover manufacturing		Assembling		
	a1	a2	a3	a4	a5	a6	a7	a8	a9	a10	a11	a12	a13	a14	a15	a16	a17	a18	a19	a20	a21
r1	35					40						20					30				
r2	40					90						40					30				
r3		60											40								
r4		40					60						30								
r5			80		20			160		25				60		15			320		30
r6			60					80						40							
r7											60										
r8																		80			
--				480					480						480				480		

In the Fig. 2, a_i is as displayed in Fig. 1., r_j stands for resources related to Table 2.

The origin efficiency in resources processing is listed In Table 3.

In the Table 3, the numbers mean the resource processing time of each activities and the blanks mean the resource is not required by the activity. Especially, there are no resource limit for a4, a9, a15 and a20.

Boiler supply process modeling: The boiler enterprises supply according to the downstream business orders, the downstream business make the boiler in storage decreased in the process of the daily transport, sales and so on. When the boiler in the merchants' warehouse reduced to a certain number, the businesses began to send out order to the boiler enterprises, notify the boiler production enterprises to deliver goods, the experiment perform a simulation design on the supply process. the supply lines are shown in Fig. 3.

Experiments on merchant cargo supply are successively transport process, all the downstream business warehouse to a minimum capacity began to deliver boiler manufacturing enterprise orders when the capacity in the warehouse is reduced to minimum.

Parameter analysis

Boiler production process parameter analysis: Some parameters in the simulation of above manufacturing process scheduling are design as follows:

- **The instance of the boiler manufacturing process (boiler need):** Φ.dt = Exp(85) min, among which Exp(a) stand a random variable whose mean value submit to exponential allocation, the arrival rate of the boiler manufacturing process is:

$$\varphi = 1/E(\Phi.dt) = \frac{1}{85}/\min$$

- **Activities:** $\{a_i, i = s, 1, 2, 3 ..., 20, 21, e\}$, a_s and a_e are the artificial starting and ending time whose inherent execution time are 0, bringing in a_s and a_e in the business process is to make the business process model qualified for the rules raised in the second chapter, ensure the correct logic structure without the support of any resources; there are no limit in the execution of activities a_4, a_9, a_{15}, a_{20}, their inherent execution time is a.tm = Exp(480) min, mean value a.tm = Exp(480) min; except for the a_4, a_9, a_{15}, a_{20}, the inherent time of the other activities is 0

- **Connections:** Connection nodes set $c = \{c_i, i = 1, 2, 3,..., 10\}$; type $\tau(c_i)$ = And, I = 1, 2, $\tau(c_j)$ = Or, j = 3, 4, 5...,8

- **Resources:** $R = \{r_i, i = 1, 2, 3...,8\}$; the quantity of the resources: r5.rq = 5, r6.rq = 2; besides, the quantity of all the resources is 1, namely: ri.rq = 1, i = 1, 2, 3, 4, 7, 8

- **Linkarc:** The linkarcs are shown in the Fig. 1, the execution probability of the linkarc: $\eta(\langle c4, a5\rangle) = 0.05$, $\eta(\langle c4, c2\rangle) = 0.95$, $\eta(\langle c6, a10\rangle) = 0.05$, $\eta(\langle c6, a11\rangle) = 0.95$, $\eta(\langle c8, a16\rangle) = 0.05$, $\eta(\langle c8, c2\rangle) = 0.95$, $\eta(\langle c10, a21\rangle) = 0.05$, $\eta(\langle c10, a_e\rangle) = 0.95$, the probability of all the other linkarc is 1

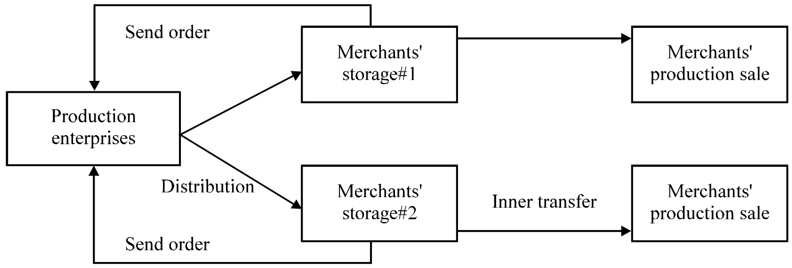

Fig. 3: Supply flow chart

Supporting relations of the activities and resources: The supporting relations are shown in the Table 3, if the value in the grid is not null, then supporting relation exists between the row and the column. e.g., U(a1,r1). The corresponding processing rate (the quantity of the tasks you process each minutes) is the reciprocal of the value in the grid. e.g., $\mu(a1, r1) = 1/35$.

These formal, structured model data of the manufacturing process can be input through the tangible parameter setting interface in the established Flexsim model.

Boiler supply process parameter analysis: The setting of the streamline supply scheduling in the simulation is mainly on the downstream business warehouse parameter settings but in the actual production process, the basic set of the storage facilities may expanded many times according to the simulation model.

The parameters of businessman 1 are as follows:

- When the boiler storage volume in the storage area reached 6 or more than 6, manufacturing enterprises will stop the supply of goods to the merchant, until the orders reach again
- When the boiler storage volume in the storage area reached 3 or 3 below, business orders would be sent to manufacturing enterprises for expediting and the manufacturing enterprises would start to supply goods

The parameters of businessman 2 are as follows:

- When the boiler storage volume in the storage area reached 5 or more than 5, manufacturing enterprises will stop the supply of goods to the merchant, until the orders reach again
- When the boiler storage volume in the storage area reached 3 or 3 below, business orders would be sent to manufacturing enterprises for expediting and the manufacturing enterprises would start to supply goods. In addition, the business 1 and business 2 product sales process are set to 400 and 500

SIMULATION ANALYSIS

The display of simulation: Completing the parameter setting, we get the whole boiler scheduling assembly line. The simulation perspective model is shown as Fig. 4.

The analysis of simulation with common strategy: Commonly, the simulation strategy is processing capacity maximization oriented task allocation and then get the solutions of processing capacity maximization oriented random task allocation in the whole gall boiler manufacturing process, the data is shown in Table 4, the optimization of the objective function value is 0.0125, namely in the gall boiler manufacturing process, the theoretical maximum manufacturing capacity is 0.0125 per min.

In this Table 4, the strategy of the resource scheduling relations is showed and it is assumed that the sum of resource required by each activity is 1. And the ωi means the process capability. And the blanks show that the resources are not required by the activity, there are no resource limit for a4, a9, a15 and a20.

The improved strategy: The execution time minimization oriented random task allocation optimization strategy and the results are shown in Table 5. The optimization value of the objective function is 6671, namely the task allocation optimization (the task without the use of dynamic scheduling strategy based on the independent Queue shall be optimized by random allocation optimization) scheme theory execution time is 6671 min.

Comparison and analysis: Before the using of scheduling optimization methods, enterprises use the pull scheduling strategy in the manufacturing process, namely when the present task is completed by the teams and groups, the scheduling center (shared task queue) is informed and the

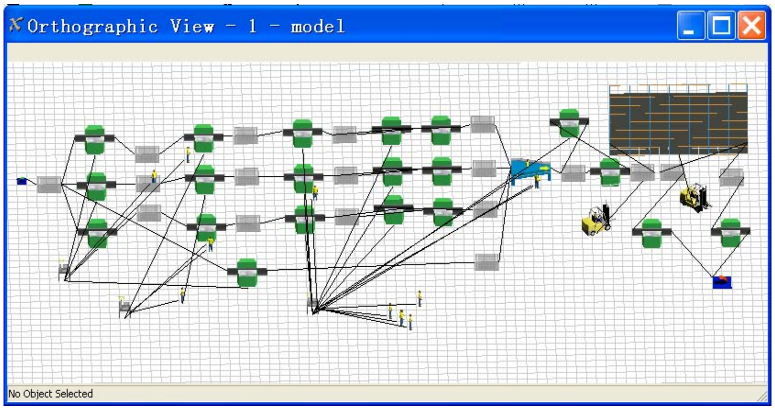

Fig. 4: The simulation perspective model of the case study

Table 4: Some simulation result of common strategy

	Cone manufacturing					Liner manufacturing						Smoke-box and interface manufacturing					Upper and lower cover manufacturing		Assembling		
	a1	a2	a3	a4	a5	a6	a7	a8	a9	a10	a11	a12	a13	a14	a15	a16	a17	a18	a19	a20	a21
r1	.133					1						1					0				
r2	.867					0						0					1				
r3		.600											1								
r4		.400					1						0								
r5			.545		1			0		1				0	1			1		1	
r6			.455					1						1							
r7											1										
r8																		1			
--				1					1						1					1	
1000ωi	155	132	136	--	136	155	132	136	--	136	167	155	132	136	--	136	155	125	136	--	136

Table 5: Some simulation results of improved strategy

	Cone manufacturing					Liner manufacturing						Smoke-box and interface manufacturing					Upper and lower cover manufacturing		Assembling		
	a1	a2	a3	a4	a5	a6	a7	a8	a9	a10	a11	a12	a13	a14	a15	a16	a17	a18	a19	a20	a21
r1	.135					1						1					0				
r2	.865					0						0					1				
r3		.586											1								
r4		.414					1						0								
r5			.436		1			0		1				0		1			1		1
r6			.564					1						1							
r7											1										
r8																		1			
--				1					1						1					1	

next task is applied from it. The processable tasks are distributed to the teams based on the experience and certain rules (such as the earliest due priority), so it is based on the traditional shared queue tasks allocation method (DR-SQ). Problems exist such as distributing tasks only by experience, lacking the overall optimization of tasks allocation, too much application and negative phenomenon in the team, planning and scheduling center can't effectively control the specific manufacturing process of the team/device, contradiction of produce and sale is increasingly outstanding, can't meet the customer need of shortening customer order delivery circle and so on.

In manufacturing process, when the presented task random allocation optimization of production capacity maximization and the execution time minimization based on the independent cohort (Table 4 and 5) combine with the dynamic task scheduling method of reallocation policy, which namely is DST_IQ and DSC_IQ, average execution time of boiler manufacturing process is (i.e., a boiler average manufacturing cycle): 3041 minutes and 2970 min, the max production/manufacturing capacity of the whole boiler manufacturing process is approximately: 0.0125 per min.

After using optimization method, the comparison between the average execution time of boiler

Table 6: The comparison before and after applying the optimization method

Performance index	AET (min)	Max production capability (min^{-1})
Before		
DR_SQ	3187	0.0118
After		
DST_IQ	3041	0.0125
DSC_IQ	2970	0.0125

manufacturing process (a boiler average manufacturing cycle) and the maximum production/manufacturing capacity of the gall boiler manufacturing process are shown in Table 6, it can be found that the maximum production/manufacturing capacity is improved by about 6% and the average manufacturing cycle can be shortened by more than 7%.

CONCLUSION

The establish of the scheduling oriented structured expand business process model ensures the reasonable logic structure and through applying the random allocation optimization and global task allocation dynamic scheduling strategy, It realizes the global allocation optimization, effectively controls the specific manufacturing process, eliminates excessive team application and negative application, improves the productivity, shortens the manufacturing cycle, accordingly effectively alleviates the contradiction of produce and sale, responds more quickly to customer needs.

Through the study of the production process in a manufacturing enterprise, the experiment test and verify the operability and validity of the process optimization method and the related supporting software system.

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