The Work in Process (WIP) Control

Model and Its Application Simulation

in Small-batch and Multi-varieties Production Mode

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Abstract

This paper aimed at the phenomena of the volume of work in process (WIP) great and uneven distribution, which is caused by small batches, various breeds, the complex scheduling, and long production cycle and so on in machine manufacturing industry. The machine manufacturing industry production workshop is taken as the research object in this paper. A work in process (WIP) control model based on the limited capacity is put forward by analyzing the characteristics of multi-varieties of small-batch production, the factors of the state of workshop equipment, equipment parameters (breakdown rate and maintenance rate), delivery deadline, product process similarity and so on. Taking a gear production line of a state-owned large-scale speed reducer's factory as an example, Witness2003 is used to simulate and optimize the work in process control model of the gear production line. The case study proves that in the manufacturing of small-batch and multi-varieties production mode, WIP volume control problems can be effectively solved by the WIP control model. And the WIP control model provides an effective, workable solution for small-batch and multi-varieties production under the control of the production mode.

Keywords: Machine manufacturing industry, Small-batch and multi-varieties, Work in process (WIP), Control model, WITNESS

1. Introduction

The four target criteria of delivery time, on-time delivery, WIP, and utilization determine the objectives of production logistics. They are not only easy to measure, but are also of strategic importance for commercial success. Empirical studies show that enterprises with short delivery times grow faster and earn higher profits than their slower competitors. With the widespread efforts to reduce the WIP level throughout the value chain, on-time delivery gains importance. At present, there are some generally characteristics exists in the mechanical manufacturing industry producing such as multi-varieties, small-batch, complexity of scheduling, long production cycle and so on, it leads to the phenomena of the accumulation of WIP in the process routs, uneven WIP distribution quantity, and extension of production cycles. So how to effectively control the enterprise WIP under the guarantee product delivery deadline becomes an important restriction factor which can enhance the benefit and the competitive ability of enterprise. Currently, the approach of this phenomenon is mainly built on the basis of experience, this paper take this situation as research object, a work in process (WIP) control model based on the limited capacity is put forward, powerful basis was provided by reducing production cycle, balancing physical distribution system, optimizing control physical distribution investment as well as the transporting batch by the control factors in WIP control mode.

2. Work in Process (WIP) Control Model

2.1 Production System Model

Some suppositions are proposed before production system model: Assuming workshop human resources are sufficient, the production system is only constrained by capacity of equipment and limited products inventory. There are N processes through the bottleneck equipment production, and M available equipments in each process. Each process has a part buffer, products from out of a final process directly into the warehouse, production tasks with N processes as shown in figure 1, the production of the time structure shown in figure 2.

Supposition B_i represents buffer aggregate capacity which between i and i+1, I_i is the number of parts which in B_i, S_i is surplus spatial quantity in the B_i, so $B_i=I_i+S_i$. I_i and S_i is important attribute in WIP management. I_i decide the ability of

maintaining the regular production after machine i when machine i breakdown, S_i decide the ability of maintaining the regular production before machine i when machine i breakdown. Asuming equipment breakdown rate and repair rate obeys the exponential distribution, breakdown rate is P (t) $=1-e^{pt}$ (p- breakdown rate), repair rate is H (t) =1-e-ht (h-repair rate).The production carries on in batch, production process can't be interrupt. it is only considered the system influence of equipment work, machine breaks down, the number of buffer, investment batch and movement batch and so on batch behavior and so on, under the determination production task premise.

2.2 The Determination of Queuing Order in Work Shop

A reasonable working procedure plays an important role in controlling WIP. This paper uses the group technology to determine the product the similarity factor, if similar factor $S_k-S_{k-1}<h$ (h is precision), parts which components k and k-1 as a part family, P_j (j<=k) is part family. Queuing order determined by heuristic algorithm.

2.3 The Construction of WIP Control Model

The optimal state in working procedure is smallest WIP, and stable continuously production. The objective function is $S_i(t)=B_i-I_i(t)$ $0<B_i<R$, $I_i>0$, L_i is the distance between machine i and WIP zone; The V_m is the speed of movement; S_k is similar factor of part k; P_j is part family; V_i is work time of machine i, P_i is investment batch of product i, P_{0i} is turnover batch of product i; T is the production cycle. The maintenance time of machine j which appears the breakdown in working procedure i is t (t<T): $t=\int_0^T tdH(t)=\int_0^T td(1-e-h(t))=\frac{1}{h}(1-e^{hT})-le^{-hT}$ (1), Their consecutive breakdown time of machine j is u(u<T): $u=\int_0^T tdP(t)==\int_0^T td(1-e^{p(t)})=\frac{1}{p}(1-e^{-pT})-le^{-pT}$ (2), Before Machine j is restoring, the breakdown probability of other machines is:

$$F_2(t)'=1-(1-F_j(t)(1-F_1(t))(1-F_2(t))\cdots(1-F_{n*m}(t))=1-e^{-\sum_{k=1}^{m*n}f_kt}$$ (3)

Before Machine j is restoring, the normal work probability of other machines is:

$$F_2(t)'=F_j(t)(1-F_1(t))(1-F_2(t))\cdots(1-F_{n*m}(t))=e^{-\sum_{k=1}^{j-1}f_kt-\sum_{k=j+1}^{m}f_kt}-e^{-\sum_{k=1}^{m}f_kt}$$ (4)

$$=e^{-\sum_{k=1}^{j-1}f_kt-\sum_{k=j+1}^{m}f_kt}(1-f_jt)$$

Transporting time: $T_{Bi}=V_m*L_i$; the speed of parts enter machine: $v_1=\frac{p}{(t+t_{si})}$;the speed of Components output buffer: $v_2=\frac{P_0}{T_{Bi}}$; v_3 is the difference between the input and output: $v_3=v_1-v_2$;and the number of parts in buffer is: $v_3\times(T-T_i)$;the number of parts which the machine is processing is: $v_0\times(t+t_{si})$; NO. of parts in WIP = NO. of parts in transporting + NO. of parts in buffer + NO. of parts which is processing: $I_i(t)=v_i\times T_{Bi}+(\frac{P}{(t+t_{si})}-\frac{P_0}{T_{Bi}})+v_0\times(t+t_{si})$ (5);

If the paper seeks to minimize the volume of WIP, at the same time the surplus of WIP must be maximum: $\max\sum F_i(t)=\sum B_i-\min\sum I_i(t)$.

3. An Example

Taking a gear production line of a state-owned large-scale speed reducer's factory as an example, there are 256 kinds of gear in this gear production line, the production batch reach from 1 to 300, and the production mode tends to small-batch and multi-varieties production. The complex scheduling is caused by above characteristics, the equipments are old, and abilities of product are limited, so the phenomenon of WIP accumulation becomes more and more serious. At present, percent 3 productions can't be delivery on time.

Take the cyclical gear from 2 to 8 whose ratio between 11 and 87 from March 2007 production plan as an example, the product processes main routs are: drilling, boring machine, gear milling, dill chamfering, coarsely flat surface grinding, accurate flat surface grinding, grind bearing hole, grinding, cyclical, and so on. According to the urgency of product delivery time, production of this product can be divided into three categories: abnormal emergency, the general emergency, forecast invest. The paper use group technology which take the parts in production process don't need to be replaced with clamping fixture but only need to be adjusted with precision products as a part family. according to the N\1 schedule problem ,this paper use SPT(shortest processing time), And according to the N\M(M>3) schedule problem ,this paper use PALMER algorithm. WITNESS2003 is used to simulate the gear production, simulation interface shown in Figure 3, according to the above WIP control model, an objective function wipfun() is establish in the simulation model.

This paper uses annealing algorithm to optimize the objective function, when the objective functions in the smallest the

value of the various variables shown in Table 1. Optimize value re-put into the model, average WIP, and the variety of production cycle is go before and after the optimization, comparing situation as shown in Table 2: Products in the average of WIP volume reduce 0.1-27 units and production cycle shortened 3 -300 hours can be found in chat through the optimization.

4. Conclusions

This paper presented a WIP control model for small-batch and multi-varieties production mode. The control model is mainly decided by the following nine factors: investment batch, delivers the batch, movement speed between working procedure, movement speed between working procedure, maintenance rate of machine, breakdown rate of machine, setup time, the capacity size of WIP, workshop scheduling. In addition, the application simulation experiments provided some insight into the impact of sequencing rules on WIP, throughput and production cycle. As a future study, a distributed learning method will be developed to improve coordination among controllers in the Machine manufacturing industry. One of the possible scenarios to be studied is to adjust the sequencing decisions of the controller to reduce set-ups or accelerate batch operations at the succeeding product steps. In short, if management can learn to minimize the level of WIP inventory effectively, it can increase throughput and reduce lead-time requirements.

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Table 1. The Optimize of Output Batch And Input Batch

Part	p_i	p_{0i}	Part	p_i	p_{0i}	Part	p_i	p_{0i}	Part	p_i	p_{0i}
P223	30	15	443	200	100	P587	30	30	P747	30	30
P311	25	25	459	200	100	P59	50	50	P759	30	30
P325	50	50	487	100	50	P611	30	30	P771	20	10
P329	50	50	49	60	30	P643	40	20	P811	30	10
P417	50	30	511	50	50	P66	20	10	P817	40	20
P423	25	20	517	50	50	P711	20	20	P823	20	20
P425	15	15	523	40	20	P725	20	10	P829	30	15
P435	25	25	525	20	20	P735	30	20	P847	20	10
P859	30	10	887	30	10						

Table 2. Average WIP (AvgWIP) and Average Production Cycle (AvgTime) before and after Optimization

Name	B opt Avg-WIP	A opt Avg-Time	B opt Avg-WIP	A opt Avg-Time	Name	B opt Avg-WIP	A opt Avg-Time	B opt Avg-WIP	A opt Avg-Time
p223	1.97	78.72	1.54	75.33	p725	2.51	150.43	2.64	194.08
p311	9.23	221.55	7.76	228.24	p735	25.53	1021.29	22.24	1089.73
p325	13.2	316.86	10.11	297.09	p743	25.73	1029.3	23.86	1169.18
p329	16.12	386.77	15.15	445.45	p747	27.72	1108.77	25.75	1261.52
p417	79.44	1124.9	93.74	1167.8	p759	28.16	1126.5	27.73	1358.71
p423	24.53	588.73	41.24	1212.3	p771	15.89	953.25	18.12	1332.08
p425	2.68	107.16	4.57	224.05	p811	11.33	453.12	8.36	409.5
p435	38.2	916.71	43.85	1289.3	p817	26.74	802.2	16.87	620.08
p443	125.26	751.54	135.7	997.72	p823	4.02	241.03	9.07	666.42
p459	179.39	1076.3	193.4	1421.5	p829	15.93	637.33	16.58	812.23
p487	96.45	1157.3	95.97	1410.8	p847	5.85	350.71	11.78	865.68
p49	40.05	961.26	49.92	1467.5	p859	20.66	826.59	20.75	1016.59
p517	14.21	340.99	13.02	382.65	p523	11.86	355.74	14.01	514.96
p525	2.05	122.89	8.12	596.86	p587	10.9	436.11	12.12	594.07
p711	14.47	868.11	18.73	1376.5	p59	26.72	641.38	35.73	1050.37

Figure 1. Production Tasks with N Processes

Figure 2. The Production of The Time Structure

Figure 3. The Simulation Interface of Gear Production Line