Determining the number of cards for a lean production system of an extrusion process based on resource selection criteria

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Resumen

Este trabajo presenta un sistema de producción esbelto basado en reglas de asignación de recursos. El procedimiento adoptado controla el número de unidades (inventario en proceso) que pasan por el proceso productivo y selecciona el recurso que tiene la capacidad potencial de despachar el producto (después de procesamiento) en el tiempo esperado más próximo. Para explicar mejor el proceso y el procedimiento de programación/control se desarrolló un modelo de simulación de un sistema real. El sistema productivo consta de 5 recursos en paralelo y 4 (cuatro) diferentes tipos de producto, cada uno con diferentes características de procesamiento.

Palabras claves: Reglas de asignación de recursos, producción esbelta, tiempo de proceso más corto, simulación.

Abstrac

This paper focuses on the planning of a lean production system based on resource allocation rules. The procedure controls the number of units (work in process) that undergo production and chooses the resource that has the capacity to deliver the product (after processing) in the shortest expected time. To better explain the process and the control/scheduling procedure, a simulation model of the real system has been developed. The production system consists of 5 resources in parallel and produces 4 different types of products, each one with different production features.

Keywords: Allocation rules, lean production, parallel resources, shortest processing time first, simulation.

Fecha de recepción: 6 de abril de 2005
Fecha de aceptación: 10 de abril de 2006

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INGENIERÍA & DESARROLLO
Número 20
Julio-Diciembre, 2006
ISSN: 0122-3461

1. INTRODUCTION

Over the years, most industries have traditionally implemented push policies in their production systems, specially in non-developed countries. There is an increasing trend nowadays to implement control policies that make systems leaner and more agile. Many control policies have been thoroughly studied [3, 4], but not many real applications for control/scheduling procedures have been documented. Kanban and CONWIP policies are well explained in [1] and [2]. [3] and [4] compared several lean production policies trough an application in a manufacturing/assembly line with simulation, which allowed to know the characteristics, advantages and disadvantages of each one. Having a simulation model to represent the production systems so as to make better decision adds flexibility and simplicity to the evaluation of control and scheduling parameters. Scenario analysis of *what if?* decisions on lean multi-product settings can be seen in [5]. For a transition procedure from push production to pull production we recommend [6].

The priority rules SPT, LPT and modified Johnson are compared in [7] trough their application in a two-stage production system, where it is shown that LPT is superior when measuring the maximum delay. This advantage is clearer in low setup frequency scene.

The Shortest Processing Time (SPT) rule is the most similar to the proposed dispatching rule. This priority rule is applied by Peters [8] to a production system using a simulation model, working with two productive scenes with different complexity. There exists a great amount of priority rules in the literature, most of them well studied in [1] and [2]. Hunsucker and Shah [9] concluded that SPT rule brings better results than other rules (e.g. FCFS, LIFO, LPT, MWRF and LWRF) on special settings. It is important to say that this analysis did not take into account due dates. Also, Brah and Wheeler [10] concluded that SPT is the quickest strategy when the process complexity increases.

The problem under discussion studies the behavior of lean production methods with resource selection criteria versus the current push production system. We impose a practical constrain to make the system work with a minimum desired service level. A specific production curve is constructed based on the performance of the simulation model. In what follows, a brief description of the scheduling procedure is presented.

2. DESCRIPTION OF THE RESOURCE SELECTION RULE

The procedure chooses the resource with least expected delivery time. The simulation model takes into account production time and resource setup times (warming, accessory changes, fitting, etc.). The least expected delivery time includes the production time of the product that selects among all resources as well as those previously scheduled that are waiting in the resource inlet buffer to be processed. The allocation rule points out that the system must evaluate which resource brings the earlier delivery time before sending it to the selected resource. It is clear that it is not possible to find a priori the delivery time. Hence, we must use expected (standard) times.

For the model description the following nomenclature is used

- n : Number of products
- m : Number of resources
- TDI_i : Initiation time of the resource i
- TDP_{ijk} : Setup time of resource i from product j to product k
- $flag_i$: Availability for resource i
- NQ_{ij} : Number of type j products in the resource i queue
- μ_{ij} : Standard processing time in the resource i of the product j
- TC_i : Queue size in the resource i

Delivery time components

To include the initiation time the following expression is added

$$TDI_i * flag_i \qquad i = 1, 2, 3, \dots m$$

This expression is equal to 0 when the resource is available and equal to TDI_i when it is not.

On the other hand, processing time determination for products that are queued for processing in each resource is done two ways, (a) those resources that can handle only one kind of product and (b) those resources that are able to handle several kinds of products.

For those resources that can handle only one type of product the number of products that are queued for processing is used along with the standard processing time for that type of product in that exact machine, according to the following relationship:

$$NQ_{ij} * \mu_{ij} \qquad i = 1, 2, 3, \ldots m$$

For those resources that can handle several types of products, the procedure turns a bit more complex, since different types of products can be queued. A check of the whole queue is done, adding to the total processing time of the queue the corresponding time of each product.

This can be represented by the following expression:

$$\sum_{k=1}^{TC_i} \mu_{ijk} \qquad i = 1, 2, 3, \ldots m$$

The determination of the necessary time to make the accessory changes and adjustments on each resource to process the products on the queue is done only for those resources that can process several types of products. For this it is needed to know the order of the queued products. Now we determine if the product on the queue is the same as the last one. If it is, no change is needed; if not, change is needed.

For those resources that can only handle one type of product, the estimated time that will occur before product delivery is given by the following expression:

$$\text{Delivery time} = (TDI_i * flag_i) + (NQ_{ij} * \mu_{ij})$$

As with those resources that can process several kinds of products, the delivery time for any product can be calculated as described in figure 2.A.

```
counter = 0
while counter ≤ NQi
        if counter = 1 then
        cola i = μij
        else
        cola i = cola i + TDPi, produtcounter-1, productcounter + μij
        end if
        counter = counter + 1
end while
Delivery time = (TDIi * flagi) + cola i
```

Figura 2.A. Finishing time calculating algorithm of one product

Finally, a comparison is made between the delivery times of all possible resources and the least expected delivery time is chosen.

3. APPLICATION

A simulation model of the proposed procedure is developed and results obtained. A production system of an extrusion process for sanitary pipes is simulated using Arena® (Rockwell Software).

3.1. **System description**

The system consists of five resources in parallel, each having unique characteristics. Some machines can produce different types of products, but some can only process one type of product. There are four product references under study.

The measured process times are:

Initiation times

The initiation (start-up) times for each machine according to each kind of product to be processed are shown in the table 3.1.A. Notice that there are some blanks on the table, for the products that cannot be processed on these machines.

Production times

The production times can be seen in the table 3.1.B. Some of the times from tables 3.1.A and 3.1.B. are probabilistic, others could not be measured and it was necessary to use standard established times.

Table 3.1.A

Initiation time according to the machine and the product

	Time for product (min)			
	1	2	3	4
Machine 1	UNIF (86,220)			
Machine 2		UNIF (142,181)	UNIF (122,181)	
Machine 3	UNIF (122,181)			
Machine 4			UNIF (75,100)	UNIF (75,100)
Machine 5	75			

Table 3.1.B
Processing time according to the machine and the product

	Time for product (min)			
	1	2	3	4
Machine 1	NORM (0.8958,0.02)			
Machine 2		0.945	0.546	
Machine 3	NORM (0.92472,0.02)			
Machine 4			0.6423	0.8765
Machine 5	NORM (0.735,0.02)			

Table 3.1.C
Setup times between different products, minutes

	FROM PRODUCT																			
	Machine 1				Machine 2				Machine 3				Machine 4				Machine 5			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
To product:																				
1	-				-				-				-				-			
2		-				-	20			-				-				-		
3			-			20	-				-				-	25			-	
4				-				-				-			25	-				-

Setup times

The setup times are shown in the table 3.1.C. Demand orders could be adjusted to a normal distribution with these parameter, mean= 3 hours and standard deviation = 30 minutes. Each order may consist of anyone of the four types of products. The event probabilities for each product are shown in table 3.1.D. When an order requires a specific type of product the demanded quantity follows a uniform distribution with the parameters shown in the table 3.1.D. In the real system an order must be satisfied within the next 5 days. When this time expires, the demand is lost.

Table 3.1.D
Demand for product in each order

Product	Event probability in the order	Demanded quantity when it is ordered
1	0,75	UNIF(66,86)
2	1	UNIF(50,70)
3	0,6	UNIF(78,98)
4	0,5	UNIF(18,38)

The performance in production management is measured trough the service level indicator, that is at present approximately 85%. This situation must be improved as a response to market conditions. This industry has a 95% of service level for immediate delivery as a goal.

Information provided predicts a demand of 3042 units of product 1, 3224 of product 2, 2824 of 3 and 742 of the 4 in the next 6 months.

Due to its composition, the variable that is desired to be determined in this system is the level of work in process inventory that is needed to maintain the desired service level. This level is measured by the number of cards that are allowed to circulate (in the simulation model). So the main problem is "to determine the number of cards that the production control system must work with to guarantee a minimum performance service level requirement of 95%."

3.2. **Further considerations**

It is considered that:

- Partial dispatching does not occur
- Standard times supplied by the company are assumed correct
- There is no limit on raw material availability
- In-process transportation is not relevant
- Due to preventive maintenance machines do not fail
- Orders that stay more than five days in the system must be withdrawn

3.3. **Results**

For each number of cards experimented, 15 simulation runs were made, and each run had 6 months duration (20 working days per month and 24 hours per day).

The service level parameter for each one of the runs is shown in table 3.3.A, and its behavior is shown in figure 3.3.A. This same results for machine use is shown in table 3.3.B. The output for each product is shown in table 3.3.C.

Table 3.3.A
Service level for each number of cards

Number of cards	Service level	Number of cards	Service level
200	0,0374667	310	0,749409
210	0,0418693	320	0,850692
220	0,063694	330	0,893149
230	0,107452	340	0,919853
240	0,141671	350	0,950585
250	0,177082	360	0,969881
260	0,233534	370	0,991885
270	0,328935	380	0,992307
280	0,455361	390	0,991256
290	0,563271	400	0,991469
300	0,633011		

$$y = \begin{cases} 2.58643223 - 0.0253284x + 6.2972E - 05x^2, x \leq 300 \\ -24.9150852 + 0.19950989x - 0.00051272x^2 + 4.397E - 07x^3, x > 300 \end{cases}$$

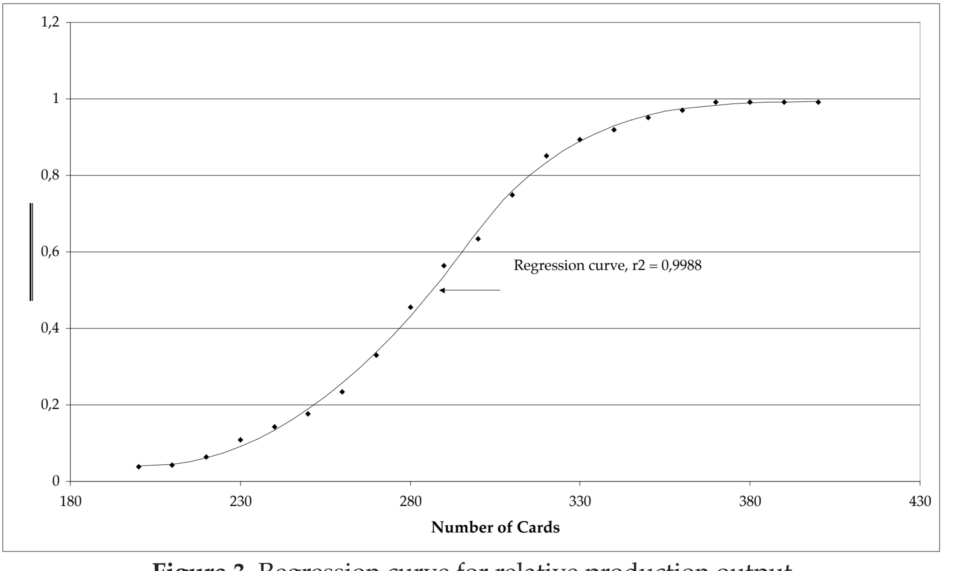

Figure 3. Regression curve for relative production output

Table 3.3.B
Machine utilization

Number of cards	Utilization		
	Machine 2	**Machine 4**	**Machine 5**
200	0,00370333	0,00040298	0,00025480
210	0,00419933	0,00077096	0,00026765
220	0,04389333	0,00068567	0,00117810
230	0,01138267	0,00099256	0,00565400
240	0,01497067	0,00156634	0,00720067
250	0,01857000	0,00186667	0,01038867
260	0,02486733	0,00647400	0,01563267
270	0,03610667	0,01015600	0,02362267
280	0,07831200	0,02246667	0,03557267
290	0,06363533	0,02739467	0,04394800
300	0,07223600	0,03449000	0,04933733
310	0,08596200	0,04533000	0,05881400
320	0,09842533	0,05708200	0,06503200
330	0,10358267	0,06217000	0,06993733
340	0,10687533	0,06522067	0,07177800
350	0,10997733	0,06801533	0,07413800
360	0,11293933	0,07117733	0,07691267
370	0,10842333	0,07314267	0,07365987
380	0,11552400	0,07306200	0,11915793
390	0,11539600	0,07327733	0,08423067
400	0,11518200	0,07327733	0,07840333

Note: Table 3.3.B. does not indicate the use of machine 1 and 3, because it was zero. For this table the initiation and preparation times of the machines was not considered.

Table 3.3.C
Production of the different kind of products for each number of cards considered

Number of cards	Type of product			
	1	**2**	**3**	**4**
200	0,00	603,20	0,00	33,07
210	0,00	690,87	0,00	32,47
220	211,20	1142,20	0,00	83,87
230	814,80	1996,80	0,00	136,87
240	1621,60	2648,27	0,00	254,07
250	2371,13	3314,27	0,00	313,33
260	3602,00	4394,33	462,80	471,80
270	5471,33	6241,60	2035,60	778,80
280	7798,53	8672,73	4134,20	1223,60
290	9498,47	10021,47	6042,53	1500,80
300	11315,23	11900,76	8121,70	1834,65
310	13739,33	14304,93	11109,47	2391,13
320	15321,80	16117,53	14279,00	3639,53
330	16356,93	17106,00	15225,20	3200,40
340	16778,80	17647,00	15656,40	3596,40
350	17341,80	18226,53	15872,33	3994,07
360	17975,13	18574,27	16643,73	4131,00
370	18307,20	17909,53	16854,07	4412,87
380	18225,87	19113,40	16835,60	4424,27
390	18030,93	19044,73	27783,93	4428,60
400	18339,20	19074,80	16657,27	4511,07

3.4. **Analysis of results**

It can be seen from the level of service result graphics that while the number of cards varies the curve is very similar to that of a second order polynomial distribution. This is verified by the obtained correlation coefficient of 0.9563.

Using this graphic and following the trend line, the required number of cards necessary to achieve the desired level of service(95%) was determined. The number of cards was determined to be approximately 360 cards. This number varies a bit if the curve obtained by the simulation is used (350 cards).

Using *Arena´s OptQuest®* optimization tool the suitable number of cards was determined (350 cards). The difference between this value with the ones that were mentioned before can be explained by errors in data location.

Table 3.4.A

Part of product satisfied by the estimated demand

Number of cards	**Types of product and its estimated demand**			
	1 (18252)	**2 (19344)**	**3 (16944)**	**4 (4452)**
200	0,00	0,03	0,00	0,01
210	0,00	0,04	0,00	0,01
220	0,01	0,06	0,00	0,02
230	0,04	0,10	0,00	0,03
240	0,09	0,14	0,00	0,06
250	0,13	0,17	0,00	0,07
260	0,20	0,23	0,03	0,11
270	0,30	0,32	0,12	0,17
280	0,43	0,45	0,24	0,27
290	0,52	0,52	0,36	0,34
300	0,62	0,62	0,48	0,41
310	0,75	0,74	0,66	0,54
320	0,84	0,83	0,84	0,82
330	0,90	0,88	0,90	0,72
340	0,92	0,91	0,92	0,81
350	0,95	0,94	0,94	0,90
360	0,98	0,96	0,98	0,93
370	1,00	0,93	0,99	0,99
380	1,00	0,99	0,99	0,99
390	0,99	0,98	1,64	0,99
400	1,00	0,99	0,98	1,01

Regarding the use of the resources, it can be seen that the bigger the number of cards, more orders are completed. For machines 1 and 3 no values were obtained, which is explained by the required machine initiation time, which is considerably large compared to the time required for the other machines.

For the optimal number of cards (assumed 350), it was found that total machine usage, including initiation and preparation time, for machine 2 is 41.2%, for machine 4 is 18.13% and for machine number 5 is 17.47%.

At first, a product output was estimated for six months. It can be seen in table 3.4A that the estimation was correct. It can also be confirmed that the bigger the number of cards gets, the greater is the fulfillment of the demand.

Using this model other kinds of data can be analyzed, like the number of machine adjustments or changes, how many times it is warmed up, average number of items that are kept in storage, among others, but they are not relevant for this study. They would have been relevant only if cost figures would have been known.

Another point to consider and that has been set aside due to its complexity is the required total utilization time of all machines, because they are also used to produce other products, therefore, the necessary accessory changes and adjustments should be made in order continue that production.

The recommended number of cards is 350, where 108 are of product 1, 115 of product 2, 101 of product 3 and 26 of product 4. With this amount of cards a service level of at least 95% is guaranteed.

It could also be seen that when only 4 products are considered, there is no need to use machines 1 and 3, but a 14.47% of the number 5 machine's capacity had to be used. Also, the usage of other machines is very high, 18.13% of machine 4 and 41.20% of machine 2; especially when the fact that this products do not have a large participation in the enterprise's total production. Therefore, machine usage would be sacrificed in order to obtain a better service level.

This sacrifice could be diminished when working with special considerations in the resource selection criteria so as to allow the production of groups of the same type so that setups and accessory changes necessary for production are diminished.

3.5. **Results validation**

The variance of the results obtained in the simulation was analyzed with the Anova table, shown in the table 3.5.A.

Table 3.5.A
Anova table

Variation source	SS	Fd	MSE	Fo	F
Treat	43,6878	20	2,18439	6749	1,61
Error	0,0951565	294	0,000323661		
Total	43,783	314			

The value F was found with an alpha of 0.05 and the values of the degrees of freedom. Therefore there is no reason to conclude that the number of cards that circulate in the system do not have an effect on the level of service that the system offers.

All runs covered the [200,400] cards range, in equal intervals of ten cards. The limits were included, for safer results. Each run time is enough to guarantee the settling of the variable in study, the level of service, as shown in figure 4.C.

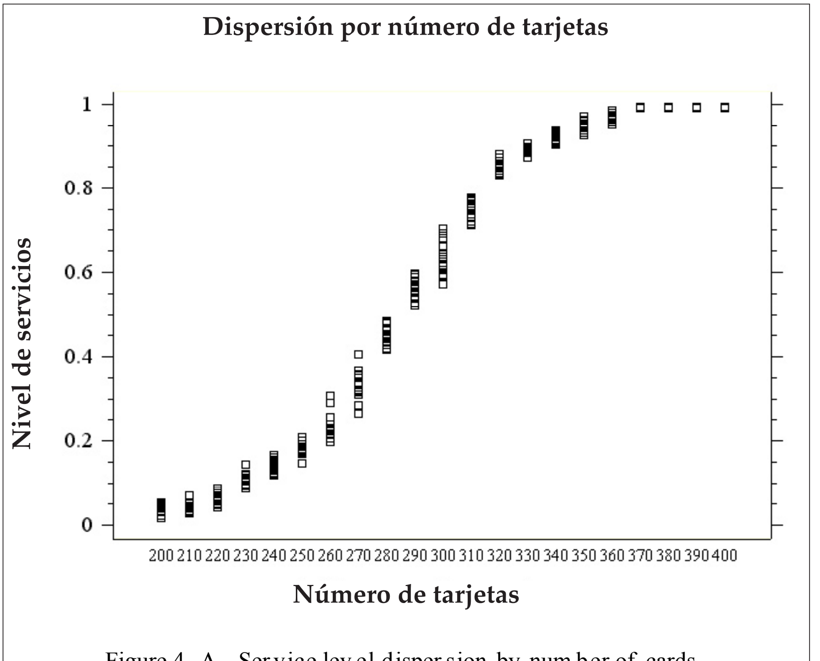

Figure 4 .A. Service level dispersion by number of cards

Figure 4.C. Corresponds to a run of approximately 5760 hours. The six months considered were sufficient to obtain stabilized values.

CONCLUSIONS

A modified resource selection criterion was described for a lean production system. The developed application shows a good performance, i.e. obtaining the goal of 95% service level with 350 cards. The model does not include costs due to lack of information. Therefore we considered costs proportional to time.

The results obtained outperform current system conditions for the four products under study. The resulting utilization of the machines gives a measure of sufficient available capacity in the system to other production settings.

Future studies are related with the comparison between the presented criteria and other dispatching rules, as well as spreading the procedure to all types of products and resources over the system. Also, we plan to validate the results obtained by simulation in the real system and compare to current system performance.

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