SELF ORGANIZATION SHOP FLOOR CONTROL

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Shop floor control in batch type manufacturing environment is regarded by the current research community as a very complex task This paper claims that the complexity is a result of the system approach were inflexible decisions are being made at a too early stage in the manufacturing process. It proposes a method that introduces flexibility and dynamics and thus simplifies the decision making in production planning. The SFC method, which is a module of production management system, proposes that in order to introduce flexibility routings should be regarded as a variable. Each expert will generate routine that meets his needs at the time of need thereby increase dramatically manufacturing efficiency.

1. INTRODUCTION

The turbulence introduced by changing market requirements and technology demands obliges industrial companies to search for new methods to manage operations, fulfil customer orders and meet performance objectives. The amount of data and the manner of processing them is a time critical factor for planning and operation of manufacturing system. (Cunha,2005)

The planning tasks involve the management of large amounts of dynamic data, which has to be analysed for decision-making, and has to deal with a range of existing options and uncertainty about the impact that some decisions can have on manufacturing systems performance. Thus, the objective of planning task is to make sure that the released jobs for a period will be completed on time and in the most economical way. In terms of shop floor the complexity (Halevi,2004) is caused by the thousands operations waiting for scheduling, jobs competing over resources, creating bottlenecks and on top of it disruptions occur such as resource breakdown, tool breakage and unexpected urgent orders. Employing a routing that was defined previously in time (e.g. several weeks/month/years ago) by a process planner which very easily is not a production planner expert, increases the complexity. Assuming that the routing was considered “optimum” by the process planner the efficiency of his work is doubtful. The routing might have been “optimum” at time of devising it with assumed quantity and available resources, however ignoring aspects like shop floor load it is not optimum for ever. Thus, the proposed shop floor control objective should be to employ the routing that will result in meeting planned product

mix with no bottlenecks or disruptions and at the least operation cost. Also, the proposed is that instead of scheduling at the level of routings that may not be carried out as planned, to schedule by objectives, which means: define a set of product mix that has to be manufactured at each period. Shop floor planning and control must meet this plan. In order to meet the plan, total flexibility must be providing in the form of network of possible routings, while deferring the decision of which routing to use, to a later stage, the stage of actual processing. Furthermore, the routing is allowed to be changed after each technological operation.
The method proposed in this paper for production scheduling it is in alternative to reduce the shop floor complexity (Guenov 2002; Wiendhal 1994) and disruptions through the use of priority rules or the development of a very complex planning program (Fitzgeraled 2000; Tinham 2000; Walker 2005; Wallace 2003). Instead it uses the strategy that we (human) do in our daily personal life. The decisions are taken and performance adjusted to the immediate conditions (disruptions), making the resources to search for a job, rather than jobs to be allocated to resources. This is done through a matrix of process alternatives (Table 1) that is created, instead of an additional work of process planning defining routings (Halevi 1999, 2003)..

Table 1 - Process plan matrix.

Op	**PR**	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**
10	00	3.12(*)	3.17	3.68	99	4.02	3.27
20	00	1.15	1.2	1.71	99	2.05	1.3
30	20	1.49	1.53	2.05	99	99	1.64
40	10	1.30	1.35	1.86	1.86	2.2	1.45
50	40	1.28	1.33	1.84	99	2.18	1.43
60	50	1.51	1.56	2.07	99	99	1.66

* - Time to process each operation on available resource.

PR - The priority of sequencing the operations.
n0 - Operation that can be processed only after processing operation n0 has finished ;
00 - Operation that may be processed at any time;
99 - Resource that is unable to process this operation

2. THE CONCEPT AND TERMINOLOGY

The proposed shop floor control approach is based on the concept that whenever resource is free, it searches for a free operation to perform. A ***free resource*** is defined as a resource that just finished an operation and the part was removed, or is idle and can be loaded at any instant. A ***free operation*** is defined as an operation that can be loaded for processing at any instant. An example would be the first operation of an item which the raw material and all the auxiliary jobs are available, and is within each of the resource operator. An intermittent operation is one for which the previous operation has been completed and the part has been unloaded from the resource that performed the previous operation, and is within each of the required resource. Example: Process planning of an item is given in table 1. As operations 10 and 20 have the priority of 00, they are both free operation and can be loaded whenever a resource is available. When operation 10 is done, then operation 40 becomes free. When operation 20 is done than operation 30 becomes free. When operation 30 is done, no operation becomes free. Therefore the sequence of operation may be: 20; 30; 10; 40; 50; 60 OR 10; 20; 30; 40; 50; 60; OR 10; 40; 50; 60; 20; 30 and several other combinations as indicated. This shows the flexibility of the system.

The term ***operation*** has different meaning in production management and scheduling and in technology. ***Production management operation*** considers an operation as a set of all the activities done on one resource, from the loading till unloading. It does not give any indication of what are the operations. Production management operations (routing) are used for production planning and scheduling, while the technological operations are used for resource set up, and preparing work instructions. ***Technological operation*** is an individual processing operation (the 6 operations in table 1). The term open operation in the proposed shop floor control approach refers to technological operation.

The scheduling cycle starts by scanning all resources in search for free resource. The free resources scan all free operations and lists those free operations. The best operation for resource can be based on performance objective, such as minimum processing time or cost. This scanning results with a list of candidates for scheduling.

If the list contains only one entry, than that operation is loaded on that resource.

If the list contains more than one entry, then the system allocates the operation with the biggest time gap of performing it on another resource.

If the list is empty, this means that there is no free operation available for processing on that resource. Hence the resource becomes idle, waiting for an appropriate operation. Idleness is a waste of time and such time may be used to process a free operation. Despite of increasing processing time, it might be economic. Therefore the system searches for a free operation that the idle resource can perform although not being the best resource for the job, but economically. One method to compute the economics of using an alternate resource is to compute the difference in time between the “best” and the alternate operation and comparing it to the time that the free resource will otherwise be idle. As an example: suppose that the quantity is 100 units, the best processing time is 5 minutes. The alternate resource processing time is 6 minutes and the waiting time is 150 minutes. Then the economic consideration is as follows: i) To produce the operation with the best resource it will take 5 x 100 = 500 minutes; ii) to produce the operation with the alternate resource it will take 6 x 100 = 600 minutes, which 150 out of them are replacing the waiting time. Therefore the actual processing time is 600-150 = 450. Hence using the alternate resource and working "inefficient" will save 500 - 450 = 50 minutes of elapsed time.

If this next operation is more economical or better in terms of performance for this resource than the following operation is allocated to that resource. Economical or better performance means that this resource is the best for this operation, or that its processing time (or cost) minus a transfer penalty is equivalent or lower then the best time of that operation. ***Transfer penalty*** is defined as the time/cost to transfer a job from one resource to another. It includes setup time, inspection, storage, material handling, etc.

In case of resource breakdown, no special treatment is needed. It will be marked as busy, hence no scanning cycle it will be regarded as a free resource.

In case of item being rejected the product structure is consulted to determine if it will hold assembly. If so all items required for that assembly are not needed and will be removed from the list of released jobs for the period.

The figure blows shows how the proposed Shop floor control method can be integrated within a production management system.

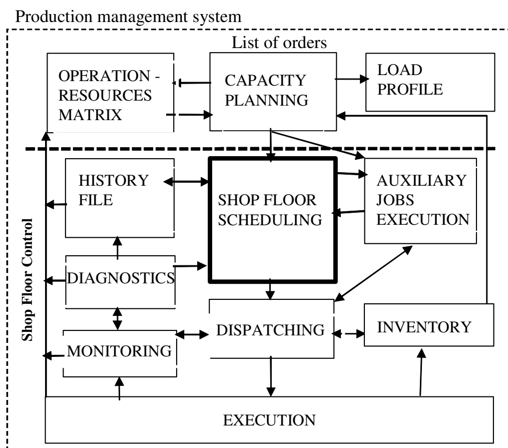

Figure 1 – Implementation of a SFC module in a production management system.

3. THE ALGORITHM AND TERMINOLOGY

Shop floor control starts with a list of jobs that should be processes in the relevant period. Such list may be compiling from the matrix production planning module, or from any other source. The list contains:

Job number and name; Quantity; Sequence priority; Bill of materials of the order.

These jobs are free for execution. However, before job execution can start some auxiliary jobs have to be performed. The auxiliary jobs are:

Fixture design and built; Tool preparation; NC program generation; Material preparation (inventory management and control); Material handling (transport); Quality control, (preparation of method and tools); Set up instructions; and Set Up Job instruction

Each of the free jobs retrieves from company database the two dimension process plan matrix (as shown in table 1) and construct a 3D matrix process plan as shown in table 2. (3D: Resources - Operations - Items)

The algorithm is based on the following records:

Resource status file keeps the status of the resource throughout of the scheduling period. The data stored is:

Resource number; The loaded item, item and operation; Quantity; A link to the bill of materials; Resource counter; Sequence number of entry in the History file.

Resource counter is a counter that indicates the remaining time for processing the item. When loaded it is set by multiplying the quantity by the processing time, as indicated by the 3D matrix, and it is updated at each scan cycle by the elapsed time from the last scanning cycle.

History File keeps track of the actual performance on shop floor. It keeps the following data:

Sequence number; Resource number; product, item and operation; Start time; Finished time

The objective of the history file is to store data for management and production control reports. It can be used to compare planning to actual performance. To arrive at actual item cost, resource load etc.

The scheduling module is based on a *sequence cycle* loop that examines all resources, listed in the *resource status file*, loads the free resources and updates the resource counter. The sequence cycle loop starts whenever processing an operation is finished. At this point the resource becomes idle and decision has to be made on the next assignment. ***Sequence cycle time*** is the elapsed time between present time and the previous sequence cycle loop. The time is retrieved from running clock that start at the beginning of the scheduling process and advances by the working time.

Shop floor control is based on the concept that whenever resource is free, it searches for a free operation to process. A free operation is identified by scanning the column of "PR" of 3D matrix process plan matrix. Any operation with PR = 0 is a free operation. A free resource is identified by the resource counter is equal to zero (0).

The sequence cycle loop scans all resources and checks the field resource counter.

If the counter is zero it means that it was idle in the last scanning cycle, and will be treated as such (see next case).

If the counter is not zero, the sequence cycle time is deducted from the resource counter. If the result becomes zero it means that the process of the present operation is finished. In this case the priority field (PR) of this operation is marked by X, and the priorities of all operations with this operation number are changed to 00.

Automatically the next operation on that item becomes free and gets priority in processing, if it is economical to do so. This means that this resource is the "BEST" for this operation or that its processing time/ cost minus a transfer penalty is equivalent or lower then the "BEST" time of that operation. The operation is allocated to that resource and its resource status file is updated and its counter is set to the new operating time. As an example: Table 2 represents the shop floor status at a certain time. Item #7 operation 20 was just finished, it was processed on R2, and operation 30 became free. The best resource for this operation is R4 with 7.23 minutes per item. A check is made if it is economical to process this operation on R2 in order to save transfer time. The time to process on R2 is 8.92. The increase in time is 8.92-7.23=1.79. Assume a transfer penalty of 25 minutes and a quantity of 40 units than the increase in time is 40*1.79=71.6 and the saving will only 25 minutes, then it not economical.

Another case: Item #9 operation 20 was just finished, it was processed on R3, thus operation 30 became free. The best resource for this operation is R4 with 11.4 minutes per item. A check is made if it is economical to process this operation on R3 in order to save transfer time. The time to process on R3 is 11.9 minutes. The increase in time is 11.9-11.4=0.4. Assume a transfer penalty of 25 minutes and a quantity of 40 units than the increase in time is 40*0.4=16 minutes and the saving will be 25 minutes, then it is economical and R3 will process operation 30.

If it is not economical to process the following operation on the previous resource, or if the resource was idle from the previous sequential cycle, then the system scans the matrices of all parts in this particular resource column, and lists all free operations with a best mark on them. This list includes all free operations that the specific resource can do best.

If the list contains only one entry, then this entry (operation) is allocated to the resource and its resource status file are updated and its counter is set to the new operating time

If the list contains more than one entry, then the system allocates the operation with the biggest time gap of performing it on another resource. This value is determined by scanning the operation row in the relevant matrix, and computing the processing time difference between the best resource and the processing time on different resources. Each free operation will be tagged by this difference value. The free operation with the highest tag value will be the one that will be allocated on this sequence cycle on the idle resource.
Table 2 demonstrates this algorithm.

Table 2 - 3D matrix status when R4 is idle

Op	**PR**	**R1**	**R2**	**R3**	**R4 IDLE**	**R5**	**R6**	**BEST**	**Δ**
	I	**T**	**E**	**M**		**#3**			
10	X	12.5	9.51	5.15	99	4.02	6.54	5	
20	X	5.04	3.93	2.55	99	99	2.82	3	
30	X	6.28	4.86	2.98	2.53	2.47	3.44	5	
40	**00**	6.38	6.12	7.05	5.78	5.93	6.83	4	1.27
50	40	8.24	6.33	3.67	2.96	2.62	4.42	5	
60	50	5.15	99	4.02	4.86	2.98	2.53	6	
	I	**T**	**E**	**M**		**#5**			
10	X	3.12	3.17	4.02	3.27	99	99	1	
20	**00**	13.9	10.3	10.8	9.95	12.5	99	4	3.95
30	20	4.86	2.98	2.53	4.86	2.98	2.53	3	
40	20	6.04	4.68	2.90	99	99	3.32	3	
50	40	5.76	4.47	2.8	99	99	3.18	3	
	I	**T**	**E**	**M**		**#7**			
10	X	3.12	3.17	4.02	3.27	99	99	1	
20	X	6.15	4.2	8.05	9.3	99	99	2	
30	**00**	8.34	8.92	7.58	7.23	8.76	8.12	4	1.69
40	30	2.06	2.11	2.96	2.21	99	99	1	
	I	**T**	**E**	**M**		**#9**			
10	X	4.6	3.60	2.39	99	2.05	2.60	5	
20	X	5.96	4.59	2.87	99	99	3.28	3	
30	**00**	11.5	12.8	11.9	11.4	13.1	99	4	1.7
40	30	99	99	99	99	1.45	1.72	5	

R4 is the idle resource and there are four free operations for which this resource is the best one. The system scans these operations across all resources and computes the difference between the minimum time (BEST) and the time on each resource. The maximum difference value is on the column marked by Δ. In this case the difference between the BEST resource and the resource processing time of item 5 operation 2 is the biggest (13.9 - 9.95 = 3.95). Therefore, this operation will be allocated to the R4 resource. Its resource status file is updated and its counter is set to the new operating time.

If the list is empty a "look ahead" feature is used to determine the "waiting time" for a best operation to become "free". This search is done by scanning the idle resource column for a search for a free operation. When such operation is encountered, (it is not the best for that resource) the BEST field of this raw indicates which resource is the best for that operation. The entry in the field *resource counter* of the *resource status file* indicates the waiting time of that resource. Example of this procedure is shown by table 3 which shows the status of the 3D matrix at this stage. R5 is idle and search for a free operation. The free operations (PR = 00). Scanning the "BEST" column of the table finds that none of the free operations calls for resource R5. The BEST for the free item #3 operation 40 is resource R4. Calling the *resource status file* in resource R4 raw indicates that operation 40 is in process and it will take another 25 minutes to end, which means that waiting time for operation 40 is 25 minutes.
The system checks if it will be economically to use the idle resource to process the free operation. One method is to compute the difference in time between the BEST and the alternate operation, and compare it to the time that the free resource would otherwise be idle. If the time spent is lower than the time gained it is economically to do so. The computation is as follows:

Table 3 - Status when R5 is idle

Op	PR	R1	R2	R3	R4	R5	R6	BES
	I	**T**	**E**	**M**		**#3**		
10	X	12.5	9.51	5.15	99	4.02	6.54	5
20	X	5.04	3.93	2.55	99	99	2.82	3
30	X	6.28	4.86	2.98	2.53	2.47	3.44	5
40	**00**	6.38	6.12	7.05	5.78	5.93	6.83	4
50	40	8.24	6.33	3.67	2.96	2.62	4.42	5
60	50	5.15	99	4.02	4.86	2.98	2.53	6
	I	**T**	**E**	**M**		**#5**		
10	X	3.12	3.17	4.02	3.27	99	99	1
20	**00**	13.9	10.3	10.8	9.95	12.5	99	4
30	20	4.86	2.98	2.53	4.86	2.98	2.53	3
40	20	6.04	4.68	2.90	99	99	3.32	3
50	40	5.76	4.47	2.8	99	99	3.18	3
	I	**T**	**E**	**M**		**#7**		
10	X	3.12	3.17	4.02	3.27	99	99	1
20	X	6.15	4.2	8.05	9.3	99	99	2
30	**00**	8.34	8.92	7.58	7.23	8.76	8.12	4
40	30	2.06	2.11	2.96	2.21	99	99	1
	I	**T**	**E**	**M**		**#9**		
10	X	4.6	3.60	2.39	99	2.05	2.60	5
20	X	5.96	4.59	2.87	99	99	3.28	3
30	**00**	11.5	12.8	11.9	11.2	13.1	99	4
40	30	99	99	99	99	1.45	1.72	5

Resource Status File

Res.	Item	Op.	Q	Link	Counter	Hist.
R4	**#2**	**40**	**60**	**22**	**25**	**66**
R1	**#7**	**03**	**100**	**23**	**87**	**68**

Processing the free operation, item #3 operations 40 is by resource R4, and it takes 5.78 minutes per unit. However resource R4 will become idle only after 25 minutes. Processing this operation on, the idle, resource R5 takes 5.93 minutes per unit. Suppose that the quantity is 100 units, than by working "inefficient" and increasing the processing time by (5.93-5.78) * 100 = 15 minutes gives a savings of (25-15) =10 minutes in throughput time.

Checking the other three open operations indicates that this is the best alternative. Therefore item #3 operation 40 is loaded on R5.

If the finished operation was the last one in processing an item, the data of that item is removed from the 3D matrix, calling the bill of material for another item. The new item data (item name and quantity) are recorded and its process plan from the two dimension matrix master file is introduced into the 3D matrix.

In case of disruption; the *finish time* on the *history file* will list the time of the interrupt, the *resource counter* of the *resource status file* will be set to 99, which will be set back to zero when the resource will be in working conditions again. A new job for that operation (item and operation number) is opened with the remaining quantity. This procedure is for a single or multi resource disruption.

4. SUMMARY

The job release stage was done in the office with stable conditions. However, conditions on the shop floor are dynamic. Therefore, the decisions on the shop floor must consider the immediate shop floor status, adding flexibility and dynamics in the shop floor control.

This paper proposes a shop floor control method that does not plan in advance the routine for each released job, therefore bottlenecks cannot be created and disruptions are solved automatically. It is allowed to alter the process when necessary.

The matrix (table 1) method is a tool that can generate a process, considering the immediate state of shop floor, and do it within a split of a second.

To validate the flexibility of the proposed system a demonstration program was prepared. For demonstration, 2 orders, 12 items, 35 operations, and 15 resources were considered. Simulation results are shown in table 4.

Table 4 - comparison of scheduling strategies

Optimization Criteria	No. periods to process	Unit cost
Maximum production	35	162
Minimum cost	32	76.2
Semi flexible	23	131
Outmost strategy	21	102

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