Dispatching Labor and Jobs to Work Cells

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Work cells are becoming increasingly common in manufacturing. Machines are typically arranged to perform work on a set of similar items. Studies have shown that this configuration leads to less material handling, less work-in-process, reduced setup times, and greater overall flexibility. Two aspects of scheduling work cell systems are considered in this study, (1) when to dispatch jobs to a work cell that is busy but has not received recent jobs and (2) when to dispatch both jobs and workers to idle cells. Two methods for determining mathematically how much time should elapse before jobs and workers are assigned are explored. One rule appears to reduce mean flow time in a simulation model. Another simpler rule can be used in some scheduling situations and performs almost as well in the simulation study. These two models are applied to an actual example from a southern California manufacturing facility.

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I. INTRODUCTION

Manufacturing work cells include groups of machines and related equipment, typically arranged in a U-shaped configuration, which process similar but not identical jobs. Cellular manufacturing is a hybrid layout, intermediate between an assembly line and a job shop. It was designed to combine the efficient one-way flow and lack of setups characteristic of assembly lines with the flexibility of job shops, able to produce a wide variety of jobs. Studies by Kaimann and Bechler (1983), Kannan and Ghosh (1995), Akturk and Turkcan (2000), and Miltenburg (2001) show that work cells reduce setups, in-process production times, queue lengths, and average job waiting time. Work cells are also the subject of this study.

Some cellular manufacturing systems include order release centers where dispatchers can hold or release jobs. Mahmoodi, Dooley, and Starr (1990) noted that such systems could yield beneficial results in practice. In their research the systems worked best under situations of tight due dates and low load. Other systems employ material-handling devices to release jobs. Lee, Wang, and Chu (1990) developed what they claim is an efficient dispatching algorithm for such devices. Al Kattan (2005) balanced workload in designing cellular systems. Celano (2008) focused on scheduling unrelated parallel cells with limited human resources. Dixit (2010) incorporated operation sequence in inter-cell movement calculations so that workload is uniform on the machines. All the systems described above are alike in that jobs are not instantly dispatched, which is also the case in this study.

II. OPTIMIZING DISPATCHING DELAYS

In this study delays in the dispatching of jobs are considered. Unlike previous studies, procedures are developed for attempting to optimize dispatching delays. These procedures can be applied to the release of (1) jobs for assignment to cells that are busy but have not received recent jobs and (2) jobs and workers for assignment to idle manufacturing cells. The latter case involves fewer workers than cells, a system that has been called dual-resource constrained (DRC) in the literature. Studies by Nelson (1967), Fryer (1974), Gunther (1981), Kher and Malhotra (1994), Jensen (2000), and Gunther and Johnson (2010) have demonstrated that DRC systems offer a degree of flexibility not found in non-DRC or machine-limited situations. This study also analyzes a DRC system. That is, delays can occur in both dispatching jobs *and* workers.

In both situations above optimizing the timing of assignment is crucial. If reassignments are too frequent, workers will often be forced to interrupt important work in other cells and waste productive time walking and performing setups. A strict SPT rule will not work well in this situation because it allows frequent reassignments. Alternately, if reassignments are too seldom, important work waits too long to get dispatched. Proper reassignment timing can optimize a firm's productivity. It can be mathematically determined how much time should elapse before the workload intended for a cell justifies its dispatch and, in some cases, the reassignment of workers. A probability distribution is derived by Gunther (1981) and modified for this study. The derivation follows.

Suppose n jobs intended for a given work cell have arrived at a dispatch center since the last job assignment. In this model the status of these jobs does not have to be known. Let

C_i = characteristic of job i (i=1, n). (1)

Characteristics are used to determine job priority. They can include process times, due dates, ratings, etc. In all cases jobs with the smallest C_i have priority. This is consistent with the shortest process time (SPT) and earliest due date priority dispatch rules used both in practice and in research. Then

$$F(c) = \text{probability } (C_i \leq c), \quad (2)$$

$$[1-F(c)] = \text{probability } (C_i > c), \quad (3)$$

and

$$[1-F(c)]^n = \text{probability n jobs have } C_i > c | n \text{ arrivals.} \quad (4)$$

so

$$G_n(c) = 1-[1-F(c)]^n, \quad (5)$$

where $G_n(c)$ is the probability at least one job has $C_i \leq c | n$ arrivals. The marginal probability of at least one job with a characteristic less than or equal to c is given by

$$G(c,t) = \sum_{n=0}^{\infty} \{1-[1-F(c)]^n\}\{P[N=n \text{ in } t]\}, \quad (6)$$

where

$$t = \text{time elapsed since last assignment}, \quad (7)$$

$$P[N=n \text{ in } t] = \text{probability of n arrivals in time t.} \quad (8)$$

Assume that the characteristics of jobs arriving at the dispatch center are exponentially distributed. This is not unreasonable since these characteristics represent process times or due dates. Further assume that arrivals into the dispatch center follow a Poisson process. Thus we have

$$F(c) = 1-e^{-\mu c}, \quad (9)$$

where $1/\mu$ is the mean job characteristic (i.e. process time) for all jobs arriving to the dispatch center.

$$P[N=n \text{ in } t] = [(\lambda t)^n e^{-\lambda t}]/n! \text{ for } n = 0,1,2, \ldots, \quad (10)$$

where λ is the mean arrival rate of jobs arriving in the dispatch center. Combining equations 6, 9, and 10 gives

$$G(c,t) = \sum_{n=0}^{\infty} [1-e^{-\mu cn}]\,[(\lambda t)^n e^{-\lambda t}/n!]. \qquad (11)$$

Simplifying terms

$$G(c,t) = \sum_{n=0}^{\infty} [(\lambda t)^n e^{-\lambda t}/n!] - \sum_{n=0}^{\infty} [(\lambda t)^n e^{-\lambda t} e^{-\mu cn}/n!] \qquad (12)$$

$$G(c,t) = 1 - [e^{-\lambda t}] \sum_{n=0}^{\infty} [(\lambda t e^{-\mu c})^n/n!]. \qquad (13)$$

Maclaurin's Theorem can be used to show

$$\sum_{n=0}^{\infty} [(\lambda t e^{-\mu c})^n/n!] = \exp(\lambda t e^{-\mu c}). \qquad (14)$$

Combining equations (11) and (12) and simplifying

$$G(c,t) = 1 - \exp[\lambda t(e^{-\mu c}-1)] \qquad (15)$$

G(c,t) gives the probability a job with a characteristic, such as a process time or slack, less than c has arrived at a dispatch center (or kanban rack) during the time t. Characteristics are related to job priorities, i.e. slacks are used if jobs are scheduled least slack first, a rule sometimes used when meeting due dates. A job with a sufficiently small characteristic c, such as a small slack or a short process time, is a high priority job. c is a parameter; large values of c increase G(c,t). This is because a large c implies a job with a smaller value of c has likely arrived at the dispatch center. The time elapsed since the last assignment is represented by t. t is another parameter; large values of t will also increase G(c,t). The more time that elapses increases the probability that a high priority job has arrived. Job arrivals are assumed to be Poisson with mean arrival rate λ and service times are assumed exponential with mean $1/\mu$.

Two methods for implementing equation (15) are explored in this study for the first time. One approach, denoted as Method A, is to set G(c,t) to some probability p and solve for c giving

$$c = -\ln\{1+[\ln(1-p)/\lambda t]\}/\mu. \qquad (16)$$

In equation (16) p is a parameter that represents a critical value of G(c,t). High values of p imply that a high-priority job has arrived. Simulation will be used to explore good performing values of p.

Once p is known, equation (2) can be solved numerically for c. If at time t all jobs at a work cell have characteristics greater than c, new jobs are dispatched or a worker can obtain new jobs, i.e. at a kanban rack. New jobs are obtained because there is a high probability (p) a high priority job has arrived and needs to be worked on. Method A is designed to reduce mean job flow time to a minimum since it incorporates information related to the arrival of high priority jobs.

Another approach, labeled Method B, is designed to be a practical, easier-to-use alternative to Method A. This will be shown in the implementation section below. For example, it can be used when a firm is basing its schedules on service time, i.e. shortest job first or SPT sequencing. In this case c is set equal to the typical or mean service time ($1/\mu$) of all jobs that have arrived during t. Thus,

$$1/\mu = c = -\ln\{1+[\ln(1-p)/\lambda t]\}/\mu. \qquad (17)$$

Solving equation (17) for t gives

$$t = [(e)\ln(1-p)] / [(\lambda)(1-e)]. \qquad (18)$$

With this rule new jobs are dispatched or a worker can obtain new jobs after a time of t has elapsed. Again, simulation will be used to explore good performing values of p. In equation

(4) note that t is a direct function of λ, the arrival rate. The more arrivals there are in a time period, the more often new jobs should be dispatched or obtained.

III. SIMULATION STUDY

Simulation was used to compare rules incorporating methods A and B with several simpler benchmark rules. It was also used to find the best performing values of p for various situations. In one such simulation, a sample of 30000 jobs was tested with the following parameters: two cells and one worker (DRC), process time characteristics (c is process time), shortest processing time (SPT) and first-come first-served (FCFS) job priorities, 75% utilization, and setups and transfers set at 0.3. Parameters were chosen which were comparable with previous studies and the case described below.

Table 1 shows the simulation results. The first two rows (0 delay) illustrate the extreme case of job and worker reassignments after every job, while the third and fourth rows (∞ delay) imply job and worker reassignments only when cell centers are idle. The next or fifth row, Method B, is a compromise between the first two extremes; reassignments are made after t time periods have elapsed. A number of delay parameters t were tested with this rule in preliminary simulation studies. A value of t = 2 and SPT sequencing minimized mean flow time in these trial simulations. The value of t = 2 is consistent with computations using equation (4). The bottom line in Table 1 shows the results for Method A. This procedure did result in the least mean flow time, while Method B came in second. SPT with 0 delay, the same as strict SPT, had the second to worst mean flow time. These results were significant using paired-comparison t tests. The best performing value of p was .8 but values from .6 to .9 resulted in almost the same mean flow times.

The variance results are interesting. Rules with zero delays require workers to spend a great deal of time being reassigned, which increases transfers and setups. This results in a highly utilized system with very high flow time variances. Long delays in reassignment (parameter ∞) have the opposite effect.

TABLE 1. Simulation Results

Rule	Priority	Mean Flow	Flow Variance	% Setup
0 Delay	FCFS	771.51	1102.8	28.4
0 Delay	SPT	17.45	29,668	29.6
∞ Delay*	FCFS	4.69	17.4	13.8
∞ Delay	SPT	4.05	19.9	14.1
Method B**	SPT	3.86	40.4	15.0
Method A***	SPT	3.61	44.1	15.1

*Best Performing FCFS Rule
**Delay t = 2, Reduced Mean Flow Time in Other Simulations
***G(c,t), p=.8, Reduced Mean Flow Time in Other Simulations

IV. IMPLEMENTATION

A manufacturing facility in southern California is used to gather data that can be used with equations (1) and (2). This plant makes parts for hydraulic actuators and rotors and has typical work cells. The specific work cell studied here performs work on pistons with two eight-hour shifts. Utilization is 62.5%, and setup is 22% of mean job process time. Management is primarily concerned with meeting due dates and some jobs have been running late. The system is dual resource constrained (DRC) since workers are occasionally subleased out of the cell.

TABLE 2. G(c,t) at Manufacturing Facility

c =	t = 2	4	6	8
0.40	.611	.849	.941	.977
0.60	.709	.915	.975	.993
0.80	.764	.944	.987	.997
1.00	.797	.959	.992	.998
1.20	.819	.967	.994	.999
1.40	.833	.972	.995	.999

Table 2 reports G(c,t) for six values of c and four values of t using parameters from the actual work cell. Table 3, based on Method A with p equal to .8, provides a dispatch table for eight values of t. This table can assist management in determining when jobs and workers should be assigned to cells. For example, suppose that at time t (i.e. 3 from the table) all jobs at a cell have a process time greater than c (.481 according to the table). Then more jobs (likely shorter jobs) and possibly workers should be dispatched to that cell. It is interesting to note that during the first time period *no* jobs should be dispatched, as the probability of *any* jobs arriving during this period is less than p = .8.

An easier to use dispatch table, based on Method B, is shown in Table 4. As an example, the value λ for the manufacturing cell is about 1.2 and a p =.8 will again be used. The table gives a t of 2.122, so that new jobs are dispatched after 2.122 time units. This value of t is consistent with the simulation results reported in Table 1. In contrast, the actual firm currently dispatches jobs much more frequently with resultant long job flow times.

TABLE 3. Dispatch Table, Method A

Time Elapsed (t)	Characteristic (c)
1.0	∞
2.0	1.021
3.0	0.481
4.0	0.322
5.0	0.243
6.0	0.195
7.0	0.163
8.0	0.140

TABLE 4. Dispatch Table, Method B

λ =	p = 0.7	0.8	0.9
0.60	3.174	4.243	6.071
0.80	2.381	3.183	4.553
1.00	1.905	2.546	3.643
1.20	1.587	2.122	3.036

V. SUMMARY

It has been shown that there is an optimum time for delaying (1) job assignments to work cells from a dispatching center or (2) worker assignments to other cells. Table I showed that proper timing of dispatches can reduce job flow times using simulation. Method A, designed to reduce mean flow time, performed best. Method B, a simpler rule also designed to reduce mean flow time, performed second best. The case study indicated that dispatches in a firm can be too frequent and flow times too long. However, changes in dispatch timing should be easy to implement.

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