Research Notes for Chapter 15[*]

Sources and Comments

The reference list in the chapter provides a sample of papers on dynamic job shops, but it is just a sample: the literature on the subject is extensive indeed. We attributed the most important results explicitly; for instance, the early experiments by Conway (1965a and 1965b), the results of Kanet and Hayya (1982), and the clarifying experiments by Baker (1984). Table 15.6 attributes other important results to their respective sources. Here we discuss some additional results and provide further references.

Kanet (1981) discusses SCR. Kanet (1982) observes that "[a]mong jobs with negative slack, the job with minimum slack-per-operation might not be the logical dispatching choice." We addressed this phenomenon in the chapter as the anti-SPT behavior of slack based rules; in this connection, recall that the MST rule maximizes minimal lateness (see Theorem 2.7). As we mentioned, various authors use different experimental designs (which may cause differences in their conclusions). For example, Elvers and Taube (1973)—who deal only with PT as the performance measure—hold the mean flow allowance constant while raising utilization. Under our framework, the Elvers-Taube experimental design can be viewed as tightening the due dates, because mean flowtime was allowed to increase while the mean flow allowance was maintained. The crossover phenomena observed in those experiments can be interpreted as crossovers in tightness.

Beyond the results presented in the chapter, Ragatz and Mabert (1984) explore the possibility of a broader information base for setting due dates. Vepsalainen and Morton (1988) consider a general tardiness cost criterion and develop dispatching rules inspired by MDD for such a setting. Scudder and Hoffman (1987) examine an even broader cost structure and use cost-based parameters in their priority rules. Rachamadugu et al. (1993) examine the effects of flexibility in operation sequence. Wein (1988) recognizes the significance of throughput as a criterion. Priority dispatching has been studied in somewhat more complicated environments as well. Berry (1972) examines a setting in which the job shop provides replenishment for a finished goods inventory system. Adam, Bertrand and Surkis (1987) study extensions the basic job shop model to assembly jobs, which are characterized by the mating of subassemblies. Philipoom, Russell and Fry (1991), Goodwin and Goodwin (1982), and several others, also study various aspects of this problem. Dual-constrained systems, in which either labor or equipment can be a constraining resource, are addressed by Nelson (1970) and by Russell and Taylor (1985b). (We present a model for scheduling multiple inputs for an assembly in Chatper 18. That model provides a basic example of stochastic economic balance.)

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Stochastic Economic Balance, Queueing Models and Safe Scheduling

An area of research that is tangential to safe scheduling concerns the relationship between throughput and the type and number of jobs that are allowed in the shop at the same time. This line of research is based on the idea that controlling the amount of work in progress improves turnaround time without causing much of a drop in throughput'. Research on the relationship between throughput and work in progress allowance includes Spearman, Woodruff and Hopp (1990)—who address the flow shop case—and Atwater and Chakravorty (2002)—who study a simulated job shop. Trietsch and Quiroga (2009) discuss how to define and measure the necessary stochastic economic balance in such a shop and answer a research question posed by Atwater and Chakravorty—namely, how to optimize the capacity of the bottleneck resource. The answer boils down to the observation that under stochastic balance, no distinct resource should be allowed to be the consistent bottleneck. Instead, the criticality of each resource—defined as the probability it will be the bottleneck—should be proportional to the marginal cost of increasing the capacity of the resource. In Chapter 19 we discuss a similar model for finding for the criticalities of various activities in a project. However, the capacity-setting model of Trietsch and Quiroga is slightly more complex mathematically. Trietsch (2007) provides a less mathematical exposition of the Trietsch and Quiroga model, focusing on hierarchical implementation. Future research in this field is needed to determine the best mix of resources and job acceptance policies that lead to stochastically-balanced performance.

Restricting the number of jobs in the shop may cause queueing outside the shop whenever a job is ordered but the shop is full. Such queueing adds to the mean turnaround time of jobs. An exception is if jobs are rejected whenever they would have to queue outside the shop. Rejections can be captured by queueing models with balking, where jobs that find the system full are lost. Needless to say, balking has a deleterious effect on throughput (although the net throughput may be increased, as we discuss presently). A better business solution involves pricing jobs to maximize gross profit. This typically reduces throughput somewhat but improves response time. Nonetheless, opting for a cap on the number of jobs allowed within the shop but allowing external queues has the benefit of reducing physical congestion in the shop. Removing congestion can actually reduce the total turnaround time even accounting for external queueing. Equivalently, it may improve throughput even when balking occurs. For instance, using metering lights on highway ramps causes queueing outside the highway but utilizes the actual capacity of the highway better. As traffic load per lane approaches about 2000 vehicles per hour, the average speed drops to about 50 KPH (30 MPH) but throughput is maximized. Any attempt to increase throughput further (by "pushing" more vehicles onto the highway) is likely to cause traffic jams and generally entails lower speeds and lower throughput. This is the reason why metering lights are used.[*] Classical queueing models cannot account for such congestion effects, however. In classical queueing models, any restriction on the number of jobs in a shop can only decrease throughput because it can cause starvation inside the shop even though jobs are queued outside.

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[*] It is also a factor in the "two seconds rule" that calls for a distance between vehicles that takes two seconds to cover. If drivers were able to follow the rule exactly, and if we treat each vehicle as a point (that is, if we ignore its length), then up to about 1800 vehicles/hour would flow in each lane. Such a load would be close to optimal when the objective is to maximize throughput.

Broadly speaking, the study of dynamic shops is related both to deterministic scheduling theory and to queueing theory. Most queueing models (i) assume specific distributions of interarrival times and processing times, (ii) assume FCFS sequencing, and (iii) focus on mean waiting time. The most tractable models are based on the exponential distribution for both interarrival times and processing times, in which case they are called *Markovian*. The assumption of Markovian interarrivals is sometimes practical but Markovian processing times are usually assumed for mathematical convenience. In the Markovian case, it is possible to show that a network of queues of the type associated with dynamic job shops can be analyzed by treating each machine by a single server queueing model (Jackson, 1957). Once we take account of more sophisticated sequencing (and due date setting) rules, however, it is often imperative to rely on simulation for the analysis, as covered in the chapter. An alternative approach involves using approximations that use the squared coefficient of variation (*scv*) to estimate the queueing time as compared to the Markovian case. These approximations are not very reliable, however, and given the facility with which modern computers can simulate queueing systems, the usefulness of such approximations is debatable. The queueing approach—by theory or by simulation—can also provide a distribution for the total time in the system. Such a distribution can be used to set due dates with a given service level. This distribution, however, depends on the sequencing policy. Hence, to minimize total earliness and tardiness costs, it seems necessary to compare various sequencing policies. A study that combines advanced queueing theory with simulation is due to Wein (1991), who compares several sequencing and due date setting rules. He studies the issue in the context of an $M/G/1$ queue—that is, a queueing model with Markovian arrivals, general processing time distribution and a single server. Wein discusses the optimal due date setting for two models: one, where the objective is to minimize due dates subject to a service level constraint (which is identical to one of our safe scheduling models), and the other with a constraint on the expected tardiness (which is similar, but not identical, to our economic piecewise linear cost minimization approach). Wein's main observation is that setting due dates correctly is the most important single issue; that is, it is more important than selecting the best sequencing rule. The use of the TWK rule for setting due dates is supported by his results, and modified due dates are one of the effective sequencing rules. The best performance in his study was associated with dynamic due-date setting rules that take into account the number of jobs already in the system when a job arrives. Very slight improvements can be achieved by also considering the due dates of such jobs, because it may sometimes be possible to let a new job be scheduled earlier than some previous jobs if those jobs have large slack times (due to faster processing than anticipated when their due dates were set). Further research is required for more complex networks of queues.

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