Research Notes for Chapter 13*

Chapter 13 is essentially identical to Chapter 10 of Baker's *Elements of Sequencing and Scheduling* (ESS). That chapter, in turn, relies on Webster and Baker (1995) with respect to single machine models. Unfortunately, we committed an error of omission: that key citation is missing in the chapter. (ESS included an explicit acknowledgement of Scott Webster's contribution.) Our coverage here focuses mainly on the sources used in the chapter and in Webster and Baker, but we also list sources for more recent results. Next, we briefly discuss the effect of teardowns, as distinct from setups. Finally, the state of the art in scheduling groups of jobs is deterministic, but we briefly discuss stochastic aspects later.

Other Sources and Comments

The complexity of single-machine models with batching is discussed by Albers and Brucker (1993). To our knowledge, the specific case of the single-machine F_w-problem with family setup times (without the GT assumption) is open, however. Theorems 13.1 and 13.2 are due to Ham, Hitomi and Yoshida (1985). Bruno and Sethi (1978) had noted earlier that SWPT applies within a set of consecutive jobs of the same family, and proposed a dynamic programming model. Monma and Potts (1989) showed that SWPT applies even to jobs of the same family that are processed in different batches. Mason and Anderson (1991) strengthened that result by showing that SWPT order should also apply to a pseudo-job that represents the set of jobs that may separate two batches from the same family. The processing time of the pseudo-job is the combined setup time and processing time of the set and its weight is the total weight of the jobs in the set. Any such pseudo-job must obey SWPT order with the jobs on either side of it. As noted in the chapter, such dominance relationships allowed Mason and Anderson to solve larger instances than were tractable before. Additional dynamic programming models for the F-problem with families but without the GT assumption appear in several publications, including Monma and Potts (1989) and Ahn and Hyun (1990). Crauwels, Hariri, Potts and Van Wassenhove (1998) propose a branch and bound approach to the problem. Potts and Kovalyov (2000) review batching models with a focus on the availability of efficient dynamic programming models. Theorem 13.3 is a special case of Property 3 from Webster and Baker, but in the limited form we presented in the chapter it is due to Santos and Magazine (1985) and was also obtained independently by Dobson, Karmarkar and Rummel (1987). Bruno and Downey (1978) showed that the $L_{\max}$ problem with family setups is NP-hard (without the GT assumption). Theorem 13.4 is due to Potts and Van Wassenhove (1992). Theorem 13.5 is

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* The Research Notes series (copyright © 2009, 2019 by Kenneth R. Baker and Dan Trietsch) accompanies our textbook *Principles of Sequencing and Scheduling,* Wiley (2009, 2019). The main purposes of the Research Notes series are to provide historical details about the development of sequencing and scheduling theory, expand the book's coverage for advanced readers, provide links to other relevant research, and identify important challenges and emerging research areas. Our coverage may be updated on an ongoing basis. We invite comments and corrections.

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a special case of Property 7 from Webster and Baker. Theorems 13.6 and 13.7 are due to Coffman, Yannakakis, Magazine and Santos (1990). Naddef and Santos (1988) and Shallcross (1992) discuss the batching results we presented, including how to round them optimally to discrete values.

The FOE algorithm and Theorem 13.8 are due to Ikura and Gimple (1986). The dynamic programming solution in Section 13.4.3, minimizing F for a batch machine with release dates, is due to Ahmadi, Ahmadi, Dasu and Tang (1992). The results of Section 13.4.4 for batch-dependent processing times (i.e., when the jobs allocated to a batch dictate its processing time) are due to Lee, Uzsoy and Martin-Vega (1992) and to Chandru, Lee and Uzsoy (1993). As we noted in the summary, to work well, the two-level approach that we can employ under the GT assumption requires an efficient way to sequence jobs within each family such that this low-level sequence is optimal in any high-level sequence. We noted specifically that in the T-problem we do not have this property. Nakamura, Yoshida and Hitomi (1978) proposed the heuristic approach that we described, namely sequencing the lower level first, then the higher level, and back to the lower level iteratively for the T-problem. In addition to the review by Potts and Kovalyov (2000), Allahverdi, Ng, Cheng and Kovalyov (2008) gave a survey of papers with setups, which include papers with family setups and batch processors.

For the single-machine models in the chapter, we assumed each family has a given setup time. Webster and Baker also considered models with teardown time, t_j. For the $L_{\max}$-problem, we can add t_j to q_{ij} and define the family due date exactly as before. For the F_w-problem, let $s'_j = s_j + t_j$ and use the models of the chapter but with s'_j replacing s_j. It turns out that the difference between the two versions is constant for any sequence, and therefore the substitution will yield the optimal sequence. In single-machine models with batch availability, teardowns have the exact same effect as setups and the two effects are additive.

Consider the two-machine F-problem that we presented in Subsection 13.2.3. The source of that material is Baker (1995). Suppose now that in addition to setups there are also teardowns on each machine, denoted t_{1i} and t_{2i}. The definitions of A_i and B_i require a minor change, to incorporate t_{1i} and t_{2i}, respectively. As we indicated in the chapter, maximizing the body for each family can serve as the basis for the subsequent higher-level sequencing, and that remains true when teardown times are necessary on each machine. The key to the solution is that either the setups or the teardowns are critical. Therefore, to resolve the issue, we need to solve the problem twice. The first solution is exactly as described in the chapter, but using the new definitions of A_i and B_i with the correct s_{1i} and s_{2i} values. Denote the tentative makespan thus obtained by M_1. In the second solution we address the reversed problem, where machine 2 precedes machine 1, using the t_{2i} and t_{1i} values instead of s_{1i} and s_{2i}, respectively. Denote the second tentative makespan by M_2. Then, if $M_1 \geq M_2$, use the first sequence; otherwise use the second. Cheng, Gupta and Wang (2000) review flow shop models with setups.

The two-batch-machine minimal makespan model is due to Kleinau (1993). Kleinau also showed that without the GT assumption the problem is NP-hard. Sung, Kim and Yoon (2000) consider m-machine flow shops with batch processing machines. Sung and Min (2001) address the two-batch-machine flow shop with a common due date and an E/T objective. Azizoglu and Webster (2003) and Dunstall and Wirth (2005) develop branch and bound solutions for the F_w-problem with family setup times on parallel machines. The problem is NP-hard (because it generalizes the parallel machine model without setups that is already NP-hard). However, Webster and Azizoglu (2001) develop pseudopolynomial dynamic programming models that apply for a fixed number of machines and a fixed number of families.

The state of the art in scheduling groups of jobs is that the vast majority of models are still deterministic. Clearly, in some instances it makes sense to use the same model regardless of whether processing time is deterministic, and in some other cases, the deterministic counterpart should provide a useful basis for stochastic analysis. For instance, flowtime and expected flowtime are minimized by the same sequence, and the same applies for maximum lateness, subject to the caveats of Chapter 6. Or take burn-in models where the stochastic aspects are largely limited to random delays in loading or breakdowns. In such cases the deterministic counterpart solution may be optimal or at least a very good basis for practical scheduling. Van Oyen, Duenyas and Tsai (1999) address those models and the total weighted tardiness problem. For the latter, they only address a very special GT case and to obtain an optimal sequence by a list schedule they require very strong agreeability among several model parameters. In other words, they do not offer a general solution. When safe scheduling models are required, the focus can be on timing decisions for the deterministic counterpart solution.

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