Using Schedules for Operational Guidance

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The broad goal of production scheduling is to produce a factory behavior where products are produced in a timely and cost-effective manner. In complex environments, advance development of a schedule appears fundamental to this goal, as it is only through anticipation of resource contention (the primary obstacle to efficient factory behavior) that the deleterious effects of these conflicts can be minimized. However, the extent to which the behavior implied by a generated schedule is actually realized depends on the manner in which the schedule is "executed" on the factory floor. The unpredictability of factory operations (e.g. machine breakdowns, quality control failures) will inevitably force deviations from prescribed behavior, and an advance schedule will be of little use unless the guidance it contains is continually adapted to the specifics of the current factory state. Research in production scheduling [2] has traditionally ignored problems of schedule execution, evaluating its results as if the world were entirely predictable and generated schedules could be executed exactly as planned. On the other hand, research relevant to factory floor control [6] has emphasized the development of local dispatch heuristics for dynamic decision-making, and conceded any potential benefits of advance scheduling (with the exception of establishing release and due dates). In this talk we consider the scheduling problem from the operational perspective of providing global guidance to the actual decisions that must be made on the factory floor.

Our approach to integrating predictive scheduling with reactive control builds on the scheduling methodology implemented in the OPIS scheduling system [7]. This methodology is motivated by the view that effective compromise among conflicting objectives requires an ability to reason from different local scheduling perspectives (in particular from both order-centered and resource-centered viewpoints), and that decisions as to which local perspective to adopt at any point during scheduling should be made opportunistically on the basis of characteristics of current solution constraints. This point is argued in [8], and has been validated in the context of schedule generation in [5]. More relevant to the discussion here, the methodology also provides a basis for incrementally revising the current schedule in response to unanticipated changes in the production environment. In this case, detection and analysis of the actual constraint conflicts that have been introduced into the schedule (i.e. precisely those portions of the schedule that have become invalidated) are used to focus the revision process. In [4], we present a model for conflict analysis and selection of appropriate reactions, along with supporting experimental justification.

Assuming this methodology for reactively maintaining schedules, the issue of defining a *control policy* to govern its use in actual factory floor decision-making remains. One obvious candidate is a control policy of "follow the schedule", which implies that decision-making requires schedule revision whenever any discrepancy is detected between the schedule and the actual factory state. However there are several reasons why this is too extreme:

- In most scheduling applications, the scheduler must necessarily operate with approximations of actual temporal constraints (e.g. operation durations, resource setup times) that will consistently lead to minor discrepancies between the factory state and the schedule. Such discrepancies reflect the "normal" unpredictability of the production system, and are unlikely to undermine the sequencing and assignment decisions contained in the current schedule. Similarly, the scheduler may be forced to produce over-constrained decisions. In situations where detailed resource assignments are necessary to optimize sequencing decisions, it may be that only the sequences are important (and not the particular assignments). Generally speaking, a choice to revise the schedule should be predicated on some expectation that current discrepancies have more global implications.

- Even if it were possible to maintain a predictive schedule at the lowest level of detail in real-time (which is unlikely but depends on the specific application), it makes little sense to do so. Many scheduling decisions that must be made are locally contained (e.g. choices between functionally identical machines, product loading and unloading sequences, etc.) and are of no consequence to the global coordination problem. The scheduler should operate at a level of detail that is sufficient to impose global guidance yet retains as much execution-time flexibility as possible (again, a function of the specific application).

These arguments suggest the use of a control policy that provides some level of schedule interpretation/refinement at execution time. This, of course, requires that the control policy operate with knowledge of the scheduler's assumptions and intentions in establishing the constraints implied by the schedule. In this regard, we are investigating the use of preference constraints (as defined and used in the ISIS scheduling system [1]). This approach is outlined in [3] in the context of a petri-net based coordination subsystem.

A second issue bearing on the use of schedules as operational guidance concerns the extent to which the unpredictability of factory operations is reflected in the maintained schedule, as this can have a significant effect on both the frequency and the efficiency of schedule revision. Here, concepts from hierarchical, least-commitment planning are useful in some respects (e.g. in varying the level of abstraction at which the scheduler makes decisions according to how close the decisions being contemplated are to being executed). At the same time, the concept of least-commitment is somewhat at odds with the purpose of scheduling (i.e. to make choices as to when and where activities should be executed so as to best accommodate overall objectives). To arrive at a reasonable compromise between the desire to make choices and the desire to remain flexible, we are investigating techniques for taking into account knowledge about the specific sources of unpredictability in the production environment during scheduling. For example, in the production environment we are currently considering (a computer board assembly and test line), the failure of tests at various points in the process constitutes the primary source of unpredictability. In this case, historical data regarding success and failure rates, along with knowledge of the necessary repair operations for different failures, is used as a basis for introducing slack at strategic points in the schedule.

We are investigating the issues discussed above via use of a simulation testbed. The simulator is unique in its provision to define control policies that make use of an existing schedule and can involve the OPIS scheduler for schedule revision purposes. Thus, policies such as "follow the schedule" as well as local dispatch heuristics presume no schedule can be simulated and evaluated. By examining the results of the simulator (i.e. the "actual factory behavior") under different control policies and across different environmental conditions (e.g. levels of unpredictability), we feel we will be able to both better quantify the potential advantages of predictive guidance and establish the necessary coupling between scheduling and control.

We describe the above mentioned techniques that we are currently investigating, the experimental testbed, and the experimental results we have obtained to date.

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AAAI Workshop on Manufacturing Planning and Scheduling

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8:45am - 10:15: Process Planning

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10:30am - 12:30pm: Modeling and Control

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- DREAM A Framework For Distributed Reactive Factory Management, Hynynen.
- Qualitative Process Automation, Lagnese.
- Intentional-Opportunistic Planning And Scheduling For Robotic Assembly, Xia.

2pm - 5:30pm: Scheduling

- Knowledge Based Planning And Scheduling, Tozawa and Fukunaga.
- Crystall Planning And Scheduling System, Meier and Ashford.
- Using Schedules For Operational Guidance, Smith et al.
- Preferential Relaxation Of Temporal Period Constraints, Sadeh and Fox.
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