5

Supplements

When coping with real-life resource allocation problems, some of the assumptions of our three basic project scheduling problems may be too restrictive. This chapter is dedicated to expansions of the basic models which permit us to cover some features that are frequently encountered in practice.

In Section 5.1 we deal with *break calendars*, which specify time intervals during which some renewable resources cannot be used (such as weekends or night shifts, where skilled staff is not available). In that case, it is often necessary to relax the requirement that activities must not be interrupted when being in progress. Instead, we assume that the execution of certain activities can be suspended during breaks, whereas other activities still must not be interrupted. We explain how to perform temporal scheduling computations in presence of break calendars and outline how the enumeration scheme for regular objective functions discussed in Section 3.1 can be generalized to this problem setting.

When performing projects whose activities are distributed over different locations sharing common resources like manpower, heavy machinery, or equipment, *changeover times* for tear down, transportation, and reinstallation of resource units have to be taken into account. During the changeover, those resource units are not available for processing activities. Due to the transportation of resource units, the changeover times are generally sequence-dependent, which means that the time needed for changing over a resource unit between the execution of two consecutive activities depends on both activities. In Section 5.2 we show how to adapt the relaxation-based approaches to the occurrence of sequence-dependent changeover times.

In many applications of project management, the assignment of resources to the project activities is not (completely) predetermined by technology. We may then perform certain activities in *alternative execution modes*, which differ in durations, time lags, and resource requirements. The execution modes of an activity reflect tradeoffs between the time and resource demands. For example, the duration of an activity may be shortened by increasing the number of allotted resource units (time-resource tradeoff) or some resources used

may be replaced by other resources (resource-resource tradeoff). If in that case the selection of an appropriate execution mode for each activity in the project planning phase is deferred from the time and resource estimations to the resource allocation step, we obtain a multi-mode resource allocation problem. In Section 5.3 we are concerned with relaxation-based procedures for solving multi-mode resource allocation problems with finitely many execution modes.

As we have seen in Section 1.3, the concept of (discrete) cumulative resources offers a straightforward way of modelling constraints arising from discrete material flows in assembly environments. Sometimes, however, inventories of intermediate products are not depleted and replenished batchwise at the occurrence of certain events but rather continuously over the execution time of consuming and producing real activities. Such continuous material flows are, for example, typical of mass production in the process industries. Material flows may also be semicontinuous, which means that facilities may be operated in batch or continuous production modes. In Section 5.4 we develop the concept of *continuous cumulative resources* and we propose a relaxation-based approach to solving resource allocation problems with the latter type of resources and convex objective functions. Resource conflicts are stepwise resolved by introducing linear constraints which ensure that at the start or completion of some activity, the inventory level is between the safety stock and the storage capacity. For each activity we branch over the alternatives whether or not the activity contributes to settling the resource conflict in question.

In the following Sections 5.1 to 5.4 we closely follow the presentation in the book of Neumann et al. (2003*b*), Sects. 2.11, 2.14, 2.15, and 2.12.2.

5.1 Break Calendars

In many real-life projects, certain renewable resources are not available during breaks like weekends or scheduled maintenance times. Scheduling the activities subject to break calendars is termed *calendarization*. For what follows, we assume that some real activities may be interrupted during a break, whereas others must not be interrupted due to technical reasons. Hence, the set of all real activities V^a decomposes into the set V^a_{bi} of all (break-)interruptible activities and the set V^a_{ni} of all non-interruptible activities. The processing of interruptible activities $i \in V^a_{bi}$ can only be stopped at the beginning of a break and has to be resumed at the end of the break. This assumption distinguishes calendarization from preemptive project scheduling problems, where activities may be interrupted at any point in time (see, e.g., Demeulemeester and Herroelen 1996). Furthermore, for each interruptible activity $i \in V^a_{bi}$, a *minimum execution time* $e_i \in \mathbb{N}$ is prescribed during which i has to be in progress without being suspended, e.g., $e_i = 1$. To simplify notation, we set $e_i := p_i$ for non-interruptible activities $i \in V^a_{ni}$ and assume that for activities $i \in V^a_{bi}$, the time between any two successive breaks is not less than e_i.