Conclusions

Summary. In this book we have been concerned with models, algorithms, and applications of deterministic resource allocation problems in project management. A special emphasis has been placed on developing a unifying framework within which a variety of project scheduling problems can be treated. Those problems involve *general temporal constraints* given by prescribed minimum and maximum time lags, different types of *scarce resources*, and a broad class of *regular and nonregular objective functions*. The diversity of the models proposed allows to cover many features arising in applications beyond the proper field of project management like short-term production planning in the manufacturing or process industries.

The main contributions of this monograph are

- an in-depth analysis of temporal constraints and different kinds of resource constraints (Chapter 1),
- the formulation of resource constraints in terms of specific relations in the activity set, which permits a classification of schedules and objective functions (Chapter 2),
- the development of efficient solution procedures for time-constrained project scheduling and resource allocation, which are based on the results of the previous structural analysis (Chapters 3 and 4),
- the expansion of the basic resource allocation models to problems with break calendars, sequence-dependent changeover times in distributed projects, alternative execution modes for activities, and consumption and renewal of resources at constant rates (Chapter 5), and
- the application of concepts from resource allocation in project management to first, production scheduling in the manufacturing and process industries, second, the evaluation of investment projects with respect to variable project deadline and discount rate, and third, deterministic strategies for coping with uncertainty in project planning (Chapter 6).

In particular, we have generalized order-based approaches for project scheduling with renewable resources to resource allocation problems including

cumulative resources that are depleted and replenished over time. The concept of cumulative resources offers a natural way of studying several resource types that have been dealt with in literature (renewable, nonrenewable, and recyclable resources). In addition, cumulative resources have many immediate applications in their own right such as scarce budgets, material flows, or limited storage capacities.

Suggestions for future research. When planning real-life projects, managers usually have to deal with problems that are much less well-structured than the models treated in this book. However, to make resource allocation amenable to methods of Operations Research, it is generally necessary to make simplifying assumptions on the objectives pursued and constraints included. Thus, bridging the gap between theoretical concepts and practical requirements remains a challenging field of further research. The following topics may be directions of future developments.

- In certain applications it is more expedient to specify, for each activity, a *workload* rather than a fixed duration and fixed resource requirements because there is no need for keeping a constant amount of resource units allocated to the activities over their execution time. It is then necessary to define lower and upper bounds on the time-dependent resource requirements of activities and to relate the prescribed temporal constraints to the activity progress.
- The *scheduling policies* developed for project scheduling with stochastic activity durations assume a locally regular objective function. For this type of objective functions, the precedence relationships among activities can readily be translated into optimal start times during the project execution. When dealing with nonregular objective functions important in practice such as the project net present value or inventory holding cost, new concepts need to be developed for coping with stochastic activity durations.
- In literature, the concept of *partially renewable resources* has been devised for modelling resources whose availability is defined on unions of time intervals. Partially renewable resources allow for modelling timetabling and working-shift scheduling aspects like maximum working times during weekends or flexible break intervals (see Böttcher et al. 1999). The capacity of such a partially renewable resource can be regarded as being continuously consumed over the execution time of activities. It may thus be interesting to study the relationship between the concepts of continuous cumulative and partially renewable resources.
- Our computational experience with algorithms for resource allocation problems indicates that effective *consistency tests* have a large impact on the efficiency of exact solution methods. Until now, those consistence tests have primarily been devised for renewable-resource constraints. Hence, the development of new consistency tests referring to the scarcity of cumulative resources is an issue of future research.