Manufacturing Planning and Control

Stephen C. Graves
Massachusetts Institute of Technology
November 1999

Manufacturing planning and control entails the acquisition and allocation of limited resources to production activities so as to satisfy customer demand over a specified time horizon. As such, planning and control problems are inherently optimization problems, where the objective is to develop a plan that meets demand at minimum cost or that fills the demand that maximizes profit. The underlying optimization problem will vary due to differences in the manufacturing and market context. This chapter provides a framework for discrete-parts manufacturing planning and control and provides an overview of applicable model formulations.

Manufacturing Planning and Control

Stephen C. Graves
Massachusetts Institute of Technology
November 1999

Manufacturing planning and control address decisions on the acquisition, utilization and allocation of production resources to satisfy customer requirements in the most efficient and effective way. Typical decisions include work force level, production lot sizes, assignment of overtime and sequencing of production runs. Optimization models are widely applicable for providing decision support in this context.

In this article we focus on optimization models for production planning for discrete-parts, batch manufacturing environments. We do not cover detailed scheduling or sequencing models (e. g., Graves, 1981), nor do we address production planning for continuous processes (e. g., Shapiro, 1993). We consider only discrete-time models, and do not include continuous-time models such as developed by Hackman and Leachman (1989).

Our intent is to provide an overview of applicable optimization models; we present the most generic formulations and briefly describe how these models are solved. There is an enormous range of problem contexts and model formulations, as well as solution methods. We make no effort to be exhaustive in the treatment herein. Rather, we have made choices of what to include based on personal judgment and preferences.

We have organized the article into four major sections. In the first section we present a framework for the decisions, issues and tradeoffs involved in implementing an optimization model for discrete-part production planning. The remaining three sections present and discuss three distinct types of models. In the second section we discuss linear programming models for production planning, in which we have linear costs. This category is of great practical interest, as many important problem features can be captured with these models and powerful solution methods for linear programs are readily available. In the third section, we present a production-planning model for a single aggregate product with quadratic costs; this model is of historical significance as it represents one of the earliest applications of optimization to manufacturing planning. In the final section we introduce the multi-item capacitated lot-size problem, which is modeled as a mixed integer linear program. This is an important model as it introduces economies of scale in production, due to the presence of production setups.

Framework

There are a variety of considerations that go into the development and implementation of an optimization model for manufacturing planning and control. In this section we highlight and comment upon a number of key issues and questions that should be addressed. Excellent general references on production planning are Thomas and McClain (1993), Shapiro (1993) and Silver et al. (1998).

Any planning problem starts with a specification of customer *demand* that is to be met by the production plan. In most contexts, future demand is at best only partially known, and often is not known at all. Consequently, one relies on a forecast for the future demand. To the extent that any forecast is inevitably inaccurate, one must decide how to account for or react to this demand uncertainty. The optimization models described in this article treat demand as being known; as such they must be periodically revised and rerun to account for forecast updates.

A key choice is what *planning decisions* to include in the model. By definition, production-planning models include decisions on production and inventory quantities. But in addition, there might be resource acquisition and allocation decision, such as adding to the work force and upgrading the training of the current work force.

In many planning contexts, an important construct is to set a *planning hierarchy*. Namely, one structures the planning process in a hierarchical way by ordering the decisions according to their relative importance. Hax and Meal (1975) introduced the notion of hierarchical production planning and provide a specific framework for this, whereby there is an optimization model with each level of the hierarchy. Each optimization model imposes a constraint on the model at the next level of the hierarchy. Bitran and Tirupati (1993) provide a comprehensive survey of hierarchical planning methods and models.

The identification of the *relevant costs* is also an important issue. For production planning, one typically needs to determine the variable production costs, including setup-related costs, inventory holding costs, and any relevant resource acquisition costs. There might also be costs associated with imperfect customer service, such as when demand is backordered.

A planning problem exists because there are limited *production resources* that cannot be stored from period to period. Choices must be made as to which resources to include and how to model their capacity and behavior, and their costs. Also, there may be uncertainty associated with the production function, such as uncertain yields or lead times. One might only include the most critical or limiting resource in the planning problem, e. g., a bottleneck. Alternatively, when there is not a dominant resource, then one must model the resources that could limit production. We describe in this article two types of production functions. The first assumes a linear relationship between the production quantity and the resource consumption. The second assumes that there is a required fixed charge or setup to initiate production and then a linear relationship between the production quantity and resource usage.

Related to these choices is the selection of the *time period* and *planning horizon*. The planning literature distinguishes between “big bucket” and “small bucket” time periods. A time period is a big bucket if multiple items are typically produced within a time period; a small bucket is such that at most one item would be produced in the time period. For big bucket models, one has to worry about how to schedule or sequence the production runs assigned to any time period. The choice of planning horizon is dictated by the lead times to enact production and resource-related decisions, as well as the quality of knowledge about future demand.

Planning is typically done in a *rolling horizon* fashion. A plan is created for the planning horizon, but only the decisions in the first few periods are implemented before a revised plan is issued. Indeed, as noted above, the plan must be periodically revised due to the uncertainties in the demand forecasts and production. For instance a firm might plan for the next 26 weeks, but then revise this once a month to incorporate new information on demand and production.

Production planning is usually done at an *aggregate level*, for both products and resources. Distinct but similar products are combined into aggregate product families that can be planned together so as to reduce planning complexity. Similarly production resources, such as distinct machines or labor pools, are aggregated into an aggregate machine or labor resource. Care is required when specifying these aggregates to assure that the resulting aggregate plan can be reasonably disaggregated into feasible production schedules.

Finally for complex products, one must decide the level and extent of the *product structure* to include in the planning process. For instance, in some contexts it is sufficient to just plan the production of end items; the production plan for components and subassemblies is subservient to the master production schedule for end items. In other contexts, planning just the end items is sub-optimal, as there are critical resource constraints applicable to multiple levels of the product structure. In this instance, a multi-stage planning model allows for the simultaneous planning of end items and components or subassemblies. Of course, this produces a much larger model.