Mathematical and Computer Modelling 50 (2009) 1461–1473

Contents lists available at ScienceDirect

Mathematical and Computer Modelling

journal homepage: www.elsevier.com/locate/mcm

The capacity planning problem in make-to-order enterprises

Chin-Sheng Chen [b], Siddharth Mestry [b], Purushothaman Damodaran [a,*], Chao Wang [b]

[a] Department of Industrial and Systems Engineering, Northern Illinois University, DeKalb, IL 60115, United States
[b] Department of Industrial and Systems Engineering, Florida International University, Miami, FL 33174, United States

ARTICLE INFO

Article history:
Received 2 October 2007
Accepted 15 July 2009

Keywords:
Capacity planning
Make-to-order
Product mix
Production planning
Operations management

ABSTRACT

This paper addresses the short-term capacity planning problem in a make-to-order (MTO) operation environment. A mathematical model is presented to aid an operations manager in an MTO environment to select a set of potential customer orders to maximize the operational profit such that all the selected orders are fulfilled by their deadline. With a given capacity limit on each source for each resource type, solving this model leads to an optimal capacity plan as required for the selected orders over a given (finite) planning horizon. The proposed model considers regular time, overtime, and outsourcing as the sources for each resource type. By applying this model to a small MTO operation, this paper demonstrates a contrast between maximal capacity utilization and optimal operational profit.

1. Introduction

Manufacturing firms apply various policies for fulfilling customer orders. Some firms choose to fill orders through finished goods inventory. Such a policy is referred to in the literature as make-to-stock (MTS). Other firms choose to start working on an order only after it has been placed. Such a policy is referred to as make-to-order (MTO). There are a variety of MTO operations, depending on the timing the manufacturer gets involved in the product's life cycle [1]. The major difference between MTO and MTS is that MTS makes standard products using a standardized process, which do not exist for MTO at the time of capacity planning. Unlike in MTS, which hold finished goods in inventory as a buffer against variations in customer demand, MTO operations hold capacity in reserve to meet customer demand [2]. The most important aspect in MTO is the effective and efficient use of available capacity to meet customer demands. Since unused capacity represents a loss in revenue, an MTO operation manager needs to be conservative for holding their capacity.

Capacity planning determines the resources requirement of an organization to sustain a given demand over a planning horizon. There are three tiers of capacity planning in terms of their planning horizon. The long-term capacity planning focuses on yearly resources requirement of plants and divisions for new and existing product lines and processing technologies, subject to demand forecast and availability of capital investment funds. It determines (1) facility locations and plant capacities, (2) major supplier's plans and their vertical integration, (3) production technology such as new processing techniques or new automation systems, and (4) principle operation modes and production methods. The fundamentals of long-term capacity planning are mostly the same for both MTO and MTS operations.

The medium-term capacity planning focuses on setting monthly or quarterly resources requirement for each plant for typically a one-year planning horizon. It decides on workforce level, raw materials and inventory policy by product group and department. Based on sales' forecasts, it generates production capacity plans for (1) labor-employment level (layoffs, hiring, recalls, vacations, overtime, and part-timer), (2) inventory policy, (3) utility requirements, (4) facility modifications,

* Corresponding author. Tel.: +1 815 753 1269.
E-mail address: pdamodaran@niu.edu (P. Damodaran).

0895-7177/$ – see front matter
doi:10.1016/j.mcm.2009.07.010

(5) outsourcing, and (6) major material-supply contracts. Capacity requirements may vary from period to period in their regular time labor, overtime labor, inventory, and subcontracting.

Two conventional medium-term (aggregate) planning approaches for MTS are: (1) matching demand and (2) level capacity. With the matching demand approach, production capacity in each time period varies to exactly match the aggregate demand as forecasted for that time period, by hiring and laying-off workers. With the level capacity approach, production capacity is held constant over the planning horizon; and the difference between the constant production rate and the varying demand rate is made up by inventory, backlog, overtime labor, part time labor, temporary labor, and/or subcontracting. An MTO operation usually adopts a hybrid approach of both. On one hand, it needs to maintain a certain level of production capacity for its core competency. On the other, it cannot leverage on inventory, as every order is a backorder and it requires customization. The common practice thus is to maintain a minimum level of production capacity, and liberally relies on overtime and subcontracting to adjust its capacity and to accommodate demand fluctuation.

The short-term capacity planning sets a daily or weekly capacity plan for a planning horizon, long enough to accommodate each order's lead time. The objective of short-term capacity planning is to ensure an appropriate match between the resources availability and the capacity requirement for a production plan at the work center level [3]. For an MTO operation, it has to specify resources requirement of each labor and machine type for each customer order at its component level. Each customer order first is translated into internal orders and detailed work orders, which are then summarized into a load schedule (time-phased capacity requirements) by labor and/or equipment, in coordination with materials arrival. A typical MTO operation routinely considers the use of alternative sources such as overtime and outsourcing, in order to meet work order's deadline.

To assure a smooth production, an MTS operation usually imposes a freeze period, in which no change to the production plan can be made. In an MTO operation, however there is no freeze period imposed. An MTO manager has to constantly adjust to administrative and engineering changes to an existing order, while deciding if potential orders should be turned down or accepted into the system.

2. Problem description

This paper focuses on the short-term capacity planning problem in the MTO operation environment. In particular, this study focuses on the product mix problem, in which the MTO manager selects an optimal set of work/customer orders to maximize its operational profit over a planning horizon. Each selected order must be completed by its due date. No tardy delivery is allowed. Consequently, an MTO manager must have access to sufficient overtime and outsourcing for additional capacity to complete the selected orders on-time. The cost rate is assumed to be known for each resource and its source, though normally the cost rate for regular time is the least costly and thus should be used first, before alternative sources are considered.

The characteristics of the problem under consideration can be graphically illustrated as shown in Fig. 1. The job shop, shown in Fig. 1, includes three departments or resources, each resource may have one or more machines. Three customer orders are considered, each customer order may have its own process route. Each customer order may include several jobs (or operations) with linear precedence constraints. For example, the process route for customer order 1 is $1 \rightarrow 2 \rightarrow 3$, whereas the process route for customer order 2 is $2 \rightarrow 3 \rightarrow 2$. The processing times of the jobs on different resources are known. As shown in the example, some jobs may circulate (i.e. multiple visits to the same resource). All the three resources are available during regular time and overtime for production. In addition, subcontracting (or outsourcing) is also an option available for processing some jobs. It is assumed that the capacity of the subcontractor is large enough to fulfill any outsourcing. If we want to prevent outsourcing some jobs (i.e. the subcontractor does not have the capability), it can be easily modeled by adjusting the cost to outsource to a very large value. Although one could potentially subcontract everything, the cost of outsourcing will prevent this. It is assumed that the job that is outsourced is available at the subcontractor's facility either after the regular production time or after overtime. Resource breakdowns are not considered in this study. The selling price (or profit) of accepting an order and the order due date is given. All the accepted orders should be completed by their due dates.

The primary research objective is to formulate a mathematical model to help a MTO manager to select an optimal set of customer orders and to prescribe a schedule for each selected order such that they all are completed before their due date over a planning horizon. The model objective is to maximize the overall profit. The model helps to unify two decisions: which orders to accept and how much capacity is required of each resource in each source in order to complete an accepted order. The secondary research objective is to demonstrate the usefulness of the model by illustrating examples where conventional wisdom is not always profitable. The conventional wisdom is to maximize the utilization of the resources, but in MTO environment this does not guarantee profit maximization. The inputs to the model are the potential customer orders and their characteristics (such as process route, processing times, selling price, etc.) and job shop configuration (such as resources, their availability, etc.). The output from the model would be the list of accepted orders and their schedules.

3. Literature review

The short-term capacity planning problem for MTO operations is closely related to product mix problem, deadline setting, order acceptance, and demand/revenue management problems. Pourbabai [4] studied the short-term capacity