Lead Time Performance Measurement

Phillip J. Lederer
William E. Simon Graduate School of Business Administration, University of Rochester, Rochester NY 14627

Abstract

Abstract: This paper discusses the design of a performance evaluation system in a decentralized firm when subunits are organized as cost centers and lead time has an important effect on demand or cost. The model incorporates agency costs associated with manager’s effort and overhead absorption, and control costs due to inaccurate marginal cost estimates. The results include that if production and lead time decisions are delegated to cost centers, performance measurement systems exist that lead to a profit maximum. Very often firms use average cost to estimate marginal cost. Another important conclusion is that more accurate marginal cost estimates (and better production decisions) occur when non-valued-added time is removed from the production process. Thus, two benefits of just-in-time and business process reengineering are accurate estimates of marginal cost and superior general manager decisions about prices and profit maximizing production rates.

1 Introduction

Lead time, the time from customer order to receipt by the customer, is an increasingly important attribute of production. Lead time can be reduced by various operational improvements, such as better scheduling, redesigning the process, etc. However, it can also be reduced by organizational means such as using performance systems that give managers incentive to reduce lead time. If managers are evaluated on lead time performance, then the system can direct the manager to make a value maximizing tradeoff between lead time and cost. This paper studies such performance systems when subunits are organized as cost centers.

Cost centers are a very common form of organization for service and manufacturing subunits. In a cost center, managers are instructed to produce output at rates specified by general management (or another subunit). Cost center managers have decision rights on schedules, short term operations decisions, and short term capacity. Decisions on plant, and technology are made centrally. The cost center manager is evaluated on cost, quality, and delivery.

Lead time affects both revenue and cost. Short lead time is valuable to buyers because it reduces the time to consumption (by a consumer) or realization of cash flows (by an industrial purchaser). From a cost perspective, lead time is important because: it is proportional to work-in-process inventory, it causes the firm to hold finished goods, it may be favorably related with operations’ costs that are time related, and short lead time reduces agency costs. Agency costs are costs associated with measurement, control, and divergence of interest of the manager’s and the firm (Jensen and Meckling 1976).

This paper examines a model that considers the divergence in interest between cost center managers and the firm. For simplicity it is assumed that the cost center manager is risk neutral, but that effort is necessary to reduce lead time and overhead absorption both encourage managers to increase lead time. We assume that the cost center
manager seeks to maximize his/her compensation (which is based upon performance measures) net of effort related costs.

This paper demonstrates that if production and lead time decisions are delegated to cost centers, performance measurement systems exist that result in a profit maximum. The paper derives the weights on cost and lead time for measuring the cost center manager that yields maximum firm profit. A conclusion is that a firm that organizes production as a cost center can efficiently decentralize decisions. An important result is that more accurate marginal cost estimates (and better production decisions) occur when non-valued-added time is removed from the production process. This shows that one benefit of just-in-time or business process reengineering is better manager decisions about production rates (or, equivalently prices).

The reader is advised to consult Lederer and Rhee (1996) for a more complete exposition of these results and other conclusions.

2 The Model

We consider an one stage-one product production process that produces to customer order. Production takes place within a cost center and marketing and organizational decisions are made by general management that seeks to maximize the firm's profit. General management makes decisions of the production rate and the cost center performance system.

The cost center manager's decisions are: how much short term capacity (such as direct labor) to employ, and how much effort the manager should devote. The time to produce an order can be reduced in a number of ways. The manager can add more short term capacity in order to speed up the production rate, and reduce congestion delays. The cost of the capacity increase is the direct cost of capacity. The manager can also reduce non-value-added time from the process. We assume that manager's effort is required to reduce non-value-added time and the manager must be compensated for this effort.

Cost center managers are discouraged from lead time reduction when this causes overhead to be underabsorbed by the accounting system. We assume that the firm budgets its total overhead \( F \) and allocates it to the cost center manager. For any fixed production rate \( d \) and planned lead time \( T_0 \), the amount of planned work in process inventory is \( T_0d \). If \( T \) drops below \( T_0 \), then the wip underabsorbs overhead by \( F \frac{T_0-T}{T_0} \) which increases the reported cost of the profit center by this same amount.

We assume that the price that a customer is willing to pay is a function of the production rate and the expected lead time. The following notation is used in this paper:

\( p \) is the price for the product.
d is the production rate for the product,

\[ p = p(d, T) = a - bd - IT. \]

K is the short term capacity for cost center (rate of production in units/hour).

C(K) is the cost of short term capacity at cost center. ($/rate of production in units/hour).

e is the cost center manager's effort to reduce lead time through eliminating non-value added time

(rate of production in units/hour).

\( v(e) \) is the cost center manager's cost of effort \( e \).

T(d,K,e) is the total production lead time for production rate \( d \) with capacity \( K \) and effort \( e \). For ease, we assume that \( T \) is given by the \( M/M/1 \) queuing model.

t_o is the initial non-value-added lead time.

F is the fixed cost.

c is the direct production cost per unit of the product.

h is the cost per unit of work-in-process inventory.

W is the performance measure associated with lead time of the cost center.

The firm's objective is to maximize its profit and its problem is:

\[
\begin{align*}
\text{Max} \quad & \text{Profit} = pd - hdT(d,K,e) - cd - C(K) - v(e) - F \\
\text{s.t.} \quad & p = a - bd - IT, \\
\end{align*}
\]

\[ d \geq 0, \quad K \geq d, \quad e \geq 0. \]  

(1)

(2)

(3)

If the firm wishes to decentralize capacity decisions to a cost center manager, it can evaluate the manager on the basis of cost and lead time. Suppose that the manager's performance is evaluated on the basis of cost, weighted by lead time. The manager's expected wage, net of effort related costs must be at least the market wage rate of this type of work. We assume that the wage is zero (w.l.o.g.). The cost center manager's problem is:

\[
\begin{align*}
\text{Max} \quad & W_{o} - WT(d,K,e) - cd - C(K) - v(e) - F \frac{T_{o} - T}{T_{o}} \\
\text{s.t.} \quad & K \geq d, \quad e \geq 0
\end{align*}
\]

\( \{K \in \mathbb{K} \mid d \geq e \geq 0 \} \)

The constant \( W_{o} \) is optimally set to so that the manager's expected wage is exactly zero. Thus for any \( d \), we choose \( W_{o} = WT(d,K^{*},e^{*}) + cd + C(K^{*}) + v(e^{*}) + F \frac{T_{o} - T}{T_{o}} \), where the stars indicate optimal actions from the cost center manager's perspective.
Equivalently, the cost center manager wishes to minimize expected cost:

$$\text{Min } C = WT(d,K,e) + cd + C(K) + \nu(e) + F \frac{T_0 - T}{T_0}$$

subject to \( K \geq d, e \geq 0 \). The cost center's problem is to choose capacity and effort to minimize the sum of effort, capacity cost and weighted lead time subject to producing at the required production rate \( d \). The firm's problem can be rewritten as the sequential problem:

$$\text{Max } \{(a-b)d \mid \text{ Min } \{ (l+h)dT(d,K,e) + cd + C(K) + \nu(e) \} \}$$

$$\text{Subject to } d \geq 0 \quad K \geq d \quad e$$

The inner problem minimizes cost plus revenue losses due to lead time given the fixed production rate, \( d \). Observe that the cost center's problem is identical to the firm's inner problem when lead time weight is chosen to be \( W = (l+h)d + \frac{F}{T_0} = (l + h + \frac{F}{T_{od^*}}) d \).

PROPOSITION 1: The optimal lead time weight is \( W^* = (l+h+\frac{F}{T_{od^*}})d^* \) where \( d^* \) is the optimal production rate.

The firm's inner problem (and the cost center problem) finds an optimal \( K(d) \) that solves the inner minimization at production rate \( d \). For any \( d \), the solution to this problem, \( K(d) \) satisfies the first order conditions with respect to \( K \) and \( e \):

$$\begin{align*}
(l+h)d \frac{\partial T(d,K,e)}{\partial K} + \frac{\partial C(K)}{\partial K} &= 0, \text{ and} \\
(l+h)d \frac{\partial T(d,K,e)}{\partial e} + \frac{\partial \nu(e)}{\partial e} &= 0.
\end{align*}$$

2.1 An Example

We next present an example. Suppose that lead time is determined by two sorts of activities: removal of non-value-added steps and congestion. Removal of non-value-added steps directly reduces lead time. The time spent waiting in non valued added steps can be reduced by effort. We assume that this time is a constant less the amount of effort: \( t_0 - e \). Congestion results in queueing which is described by the M/M/1 queueing formula. Thus, we assume that the expected lead time is \( T = t_0 - e + \frac{1}{Kd} \). Thus, removal of non valued added steps reduces lead time directly, and effort can increase capacity (and reduce queues). Short term capacity costs are linear in the production rate, i.e., \( C(K) = gK \), with \( g > 0 \). Finally, the cost of effort to the manager is \( \nu(e) = te^2 \). Then, solving (6-7), yields:

$$K(d) = d + \sqrt{\frac{(l+h)d}{g}},$$
\[ T(d,K(d),e(d)) = t_0 - e^* + \sqrt{\frac{g}{(1+h)d}}, \text{ and} \]

\[ \frac{1+h}{2t} d \text{ if } \frac{1+h}{2t} d < t_0 \]

\[ e^* = \]

\[ t_0 \text{ if } \frac{1+h}{2t} d \geq t_0. \]

There are several interesting conclusions. Capacity is a concave increasing function of production rate. Lead time actually decreases with production rate. Capacity and lead time costs exhibit economies of scale. Effort increases as demand does, even though the cost of eliminating non-value-added steps does not depend on production rate!

Cost accounting systems estimate marginal cost using average cost. The accuracy of marginal cost estimates determines the quality of the firm's quantity decision. Next, we show that the quality of the marginal cost estimate depends on the amount of the non-valued-added time, \( t_0 \). When \( t_0 \) is very large, average cost underestimates the marginal cost, but when \( t_0 \) is small, average cost overestimates marginal cost. For this example, marginal cost is equal to:

\[ mc = c + (1+h)(t_0 + \frac{1+h}{2t} d) + g \frac{K(d)}{d} \text{ if } e^* < t_0. \]

\[ c + g \frac{K(d)}{d} \text{ if } e^* \geq t_0. \]

Marginal cost is monotone increasing in \( t_0 \). For purposes of discussion, we assume that inventory holding cost consists entirely of non-capital cost. Then, the difference between \( mc \) and \( emc \) is:

\[ mc-ac = (1+h)(t_0 + \frac{1+h}{2t} d) - \frac{(1+h)^2 d}{4t} \text{ if } e^* < t_0. \]

\[ - \frac{tt_0^2}{d} \text{ if } e^* \geq t_0. \]

As \( t_0 \) falls, the top branch decreases in value, falling to a negative value when \( e^* = t_0 \), at which point \( mc-ac \) are the same for the two cases. As \( t_0 \) falls farther, the second branch increases in value, converging to zero as \( t_0 \) approaches zero. The difference \( mc-ac \) is not monotone decreasing in \( t_0 \), but generally decreases as \( t_0 \) decreases. Clearly, when \( t_0 \) is large, the divergence between marginal cost and average cost is large. Then, large opportunity costs result when \( ac \) is used to choose production rate. When \( t_0 \) is small, the difference between \( ac \) and \( mc \) is small, and small opportunity costs result. Although we defined average cost without inventory related costs, it is clear that if we had included all inventory cost in computation of average cost, the identical conclusion holds.
A general result is that opportunity cost due to marginal cost misestimation can be reduced by reducing non-value-added time, $t_0$. BPR or JIT programs can reduce non-value-added time, and the general manager can make better decisions about production rate. Reducing non-value-added time causes two favorable effects on profit. First, the firm's cost is reduced and lead time to the customer is reduced, leading to higher sales. This directly increases profit. Second, the divergence between marginal cost and average cost declines: the effect is that the firm makes better production rate decisions, reducing opportunity costs, and increases firm profits.

References
