The Economic Order Quantity Model and Throughput Accounting

Marinus DeBruine and Donald J. Klein

EXECUTIVE SUMMARY

- Management usually focuses on *cost cutting* as the way to produce higher profits.
- One tool often used to minimize costs is the *economic order quantity* (EOQ) model for making trade-off decisions.
- Yet profits are not necessarily maximized even when costs are minimized. *The theory of constraints* (TOC) redirects management's focus away from cutting costs to focus instead on enhancing *throughput*.
- TOC concepts can be used to modify the conventional EOQ model—for example, by adding the opportunity cost of current and future throughput lost—in an attempt to link the effects of local decisions on the company's net income.
- The redefined EOQ model provides solutions that help "local" decision makers (e.g., managers in a particular department or business unit) contribute most effectively to the company's objective of maximizing profits.

A critical question in many production systems is the *optimal batch size* or the number of items to be produced in a single production run. Finding the optimal batch size for a scheduling decision involves trade-offs between various costs. Even when a product is manufactured in a continuous-production environment, many of the parts may be produced (or purchased) in batches. Management must thus decide how to combine orders to minimize inventory purchases and setups when considering orders for the same product or orders requiring common parts.

Decision makers have tried to minimize *relevant* costs by using the economic order quantity (EOQ) model to arrive at a compromise solution between the cost of *setting up* (or purchasing) too often and the cost of carrying too much inventory. By selecting a batch size

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that minimizes the total relevant costs, the conventional EOQ model offers a straightforward solution to this traditional trade-off decision. Yet the EOQ model can often lead managers to the wrong solution.

Proposed solutions are termed "right" or "wrong" depending on their impact on the company's primary objective of maximizing profits. The purpose of this article is to explore the ramifications of optimal batch size decisions in both *just-in-time* and *theory of constraints* manufacturing environments, and also to propose a modification to the conventional EOQ model. In particular, the usefulness of the EOQ model (in terms of producing the "right" solution) depends on the inclusion of *opportunity costs.*

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THE EOQ MODEL IN THE COST WORLD

Conventional wisdom suggests that the optimum batch size is one at which the sum of the purchasing or setup costs and the carrying costs associated with that batch size are minimized.

The EOQ model, which was developed earlier this century to determine the size of purchase orders, was thought to apply mainly to industries such as distribution, wholesaling, and retailing. Adapting the model to the production environment has caused considerable difficulty because costs are not as readily determinable.

The Conventional EOQ Model

The EOQ model is designed to help managers make cost minimization decisions. The challenge to cost accountants has been to identify and "unitize" all relevant (avoidable) costs used in the formula. The total relevant cost is the sum of a period's *setup costs* and inventory *carrying costs,* or

$$TRC = (D/Q) \cdot S + (Q/2) \cdot C \qquad (1)$$

where TRC is the total relevant cost (to be minimized), D is the expected number of units demanded per period, Q is the batch size, S is the cost for each setup, and C is the cost of carrying one unit in inventory for one period.

The economic order quantity (optimal batch size) Q^* that minimizes total relevant costs is obtained by taking the first derivative of TRC with respect to Q to get

$$Q^* = (2DS/C)^{1/2} \qquad (2)$$

Setup Costs

By letting S in the EOQ model represent the "each time" cost of either placing a purchase order or setting up for a production run, cost behavior assumptions become crucially important.

It is clear from the second equation that if the cost per setup is reduced, the optimal batch size decreases. This has led some to propose a new EOQ model incorporating a "learning curve effect" that recognizes the longer-term strategic effects of reducing setup time by systematically undersizing the optimal batch size (Replogle, 1988). Significant reductions in setup times put the emphasis of relevant cost minimization on the second term of the equation—the carrying costs.

Carrying Costs

Articles about carrying costs have often limited the relevant costs of carrying inventory to costs such as the following:

- Insurance;
- Personal property taxes;
- Obsolescence;
- Shrinkage;
- Spoilage;
- Utilities; and
- Interest charges.

Some authors have suggested that costs traditionally considered "fixed" (e.g., leasing costs for facilities, depreciation, and administrative costs) may be reduced—or even eliminated—if they are analyzed properly. Thus, they argue, these costs should be included as part of the avoidable costs in the determination of the optimal batch size (Shillinglaw, 1963; Jones, 1991).

An inspection of the second equation reveals that an immediate consequence of underestimating carrying costs as part of the total relevant cost is that the EOQ model systematically produces an optimal batch size for a production run that is too large.

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An Example

Speedy Company currently manufactures and sells 8,400 bicycles per year. The bikes are produced using various company resources, including labor and equipment.

Speedy's bikes are known and in demand for their lightweight, durable frames, which are made in a two-step process requiring the use of the same press but with different dies. Speedy has been unable to justify the acquisition of a second press or to have the frames formed elsewhere. Exhibit 1 contains the traditional accounting information produced for the batch size decision.

According to Exhibit 1, a batch size of about 40 (actually 37) bicycles minimizes the total relevant costs identified by Speedy's management. Based on the accountant's projections and management's decision to produce the bikes in batches of about 40, management expects to produce and sell 8,400 bikes, which will require incurring setup and carrying costs of $2,660. Exhibit 2 presents a graphical illustration of management's trade-off decision.

THE THROUGHPUT WORLD

In the late 1980s, a new management philosophy, the theory of constraints (TOC) emerged, which explored anew the impact of tra-

Exhibit 1. Speedy Company's "Cost World" Analysis

Accounting data:				
Selling price	$ 400			
Direct materials	(150)			
Labor and overhead	(175)			
Gross Margin	$ 75			
Cost for each setup at the frame press:			$ 6	
Annual carrying cost per bicycle:			$70	
Lot size (Q)	10	20	40	60
Average inventory (Q/2)	5	10	20	30
Number of setups (8,400/Q)	840	420	210	140
Setup cost (SC)	$5,040	$2,520	$1,260	$840
Carrying cost (CC)	350	700	1,400	2,100
Total relevant cost (TRC)	$5,390	$3,220	$2,660	$2,940

ditional financial measures on decision making in a just-in-time and *total quality management* environment (Goldratt and Fox, 1986; Umble and Srikanth, 1990; Goldratt and Cox, 1992).

The TOC philosophy suggests moving away from "cost world thinking," which is based on the notion that minimizing costs is the way to achieve profit maximization. As a result, cost cutting—often with little regard for the ultimate bottom-line effects—replaced profit maximization as the decision focus. By contrast, "throughput world thinking" denounces the notion that cost minimization *alone* means profit maximization.

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Maximizing Throughput

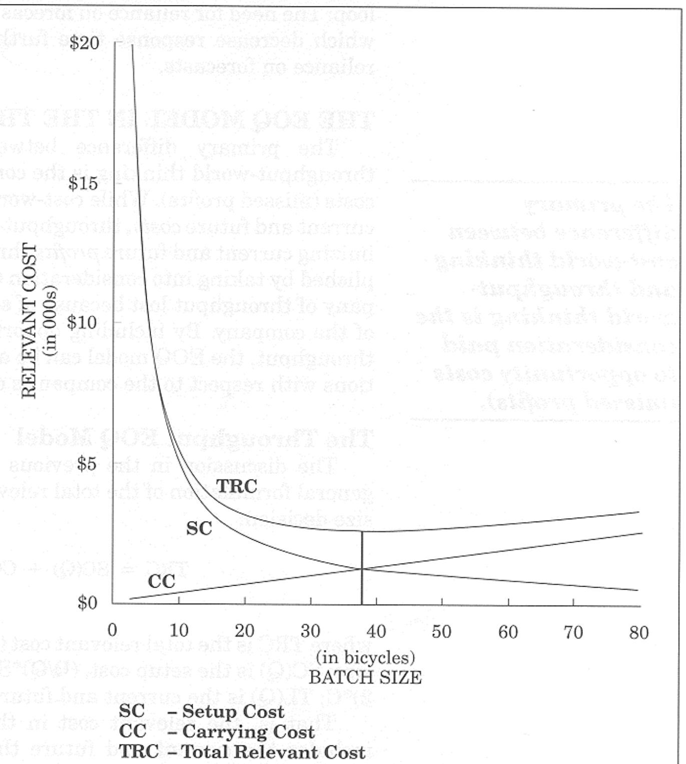
When the emphasis is on throughput, the focus is on enhancing current and future sales. Potential improvements in throughput (or sales) are often virtually unbounded, whereas potential reductions in operating expense (costs) are limited and subject to diminishing marginal returns. (Throughput is defined as sales minus raw materials and other strictly variable costs, such as sales commissions and outsourcing costs.)

For the example illustrated in Exhibit 1, assuming that all labor and overhead are fixed, the throughput per bicycle equals $250 ($400 − $150).

Minimizing Inventories

The TOC philosophy advocates the use of minimal inventories—that is, having only enough inventory to protect current throughput and enhance future throughput without endangering operational expenditures.

Exhibit 2. Conventional EOQ Model



> ***The indirect impact of excess inventories on foregone throughput goes largely unnoticed—and therefore unmeasured—by both executives and management accountants.***

Better-quality products, lower prices, or faster responses to changes are competitive-edge factors enhanced by carrying lower inventories. However, the indirect impact of excess inventories on foregone throughput goes largely unnoticed—and therefore unmeasured—by both executives and management accountants. For example, carrying more than minimal inventories can cause long delays before problems are detected, thus leading to costly rework and further delays.

More important, excess inventories can cause more missed deadlines and longer lead times, because companies have to devote resources to processing inventories that are not needed immediately. This lack of responsiveness to customer expectations can cause lower sales in the future. Even more detrimental, the longer lead times associated with excess inventories increase a company's dependency on forecasting for production decisions.

Forecasts are notoriously inaccurate and exacerbate the effect of unneeded inventories by feeding a potentially devastating decision loop: The need for reliance on forecasts results in higher inventories, which decrease response time further, which again increases the reliance on forecasts.

THE EOQ MODEL IN THE THROUGHPUT WORLD

The primary difference between cost-world thinking and throughput-world thinking is the consideration paid to opportunity costs (missed profits).

The primary difference between cost-world thinking and throughput-world thinking is the consideration paid to opportunity costs (missed profits). While cost-world thinking focuses on reducing current and future *costs*, throughput-world thinking focuses on maximizing current and future *profits* through more sales. This is accomplished by taking into consideration the opportunity cost to the company of throughput lost because of some action taken by a segment of the company. By including opportunity costs in the form of lost throughput, the EOQ model can be adapted to offer the "right" solutions with respect to the company's objective of maximizing profits.

The Throughput EOQ Model

The discussion in the previous section suggests the following general formulation of the total relevant costs for the optimal batch-size decision:

$$TRC = SC(Q) + CC(Q) + TL(Q) \qquad (3)$$

where TRC is the total relevant cost (to be minimized); Q is the batch size; SC(Q) is the setup cost, (D/Q)*S; CC(Q) is the carrying cost, (Q/2)*C; TL(Q) is the current and future throughput lost.

That is, the relevant cost in the optimal batch size decision includes the current and future throughput lost by not meeting unscheduled customer demand, "crowding out" other production, missing due dates, and quoting larger lead times. By expanding the conventional EOQ model to account for the opportunity costs that the batch-size decision causes, the throughput EOQ model better represents the impact of a (local) batch-size decision on the (global) performance measure.

For each batch-size decision, expectations must be made and translated into probabilities, multiplied by the appropriate unit throughput lost, and added into the relevant cost equation. Then, as before, the optimal batch size Q* minimizes TRC (see equation 2).

The EOQ model should also include the opportunity cost of (future) throughput foregone whenever the setup decision affects the capacity of the constraining resource.

Revisiting Setup Costs

Instead of limiting setup-related costs to the setup costs, the EOQ model should also include the opportunity cost of (future) throughput foregone whenever the setup decision affects the capacity of the constraining resource (Hahn, Bragg, & Shin, 1988).

For example, if a setup decision occurs at a capacity-constraining resource, the relevant costs should include the throughput foregone of choosing an additional setup and not producing some salable prod-

Exhibit 3. Speedy Company's "Throughput World" Analysis

Accounting data:				
Selling price	$ 400			
Direct materials	(150)			
Labor and overhead	(175)			
Gross Margin	$ 75			
Cost for each setup at the frame press:			$ 6	
Annual carrying cost per bicycle:			$70	
Lot size (Q)	10	20	40	60
Average inventory (Q/2)	5	10	20	30
Number of setups (8,400/Q)	840	420	210	140
Annual sales lost (in bicycles)	0	4	16	72
Setup cost (SC)	$5,040	$2,520	$1,260	$ 840
Carrying cost (CC)	350	700	1,400	2,100
Throughput lost (TL)	0	1,000	4,000	18,000
Total relevant cost (TRC)	$5,390	$4,220	$6,660	$20,940

uct instead. Assuming that an unfilled order is lost forever, the opportunity cost is the expected throughput lost.

Revisiting Carrying Costs

With respect to carrying costs, the impact of inventory levels on current and future throughput suggests the need for an extensive overhaul of the conventional carrying costs included in the total relevant cost equation.

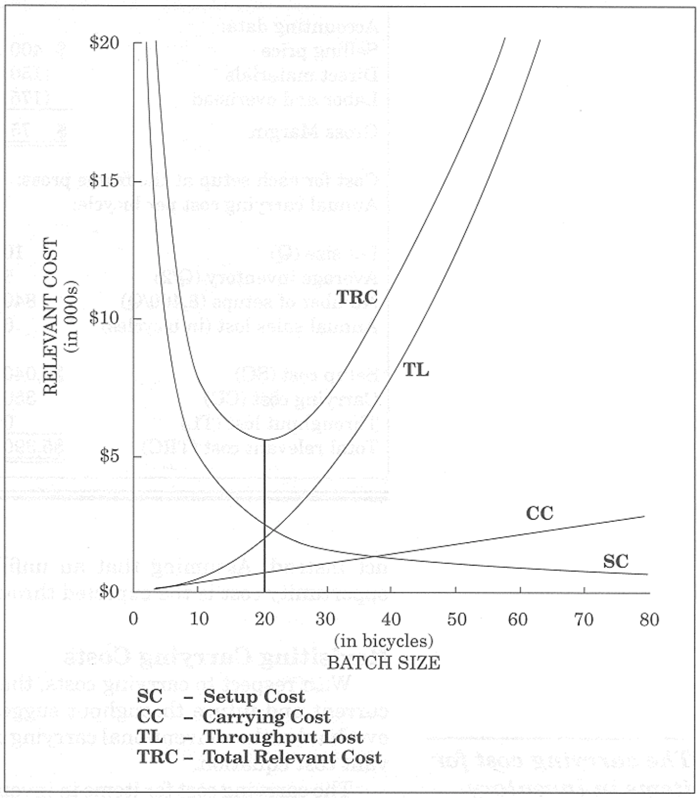
The carrying cost for items in inventory should include the opportunity cost of current and future throughput lost as a function of batch size.

The carrying cost for items in inventory should include the opportunity cost of current and future throughput lost as a function of batch size. That is, if increasing batch sizes "crowds out" other products or creates reduced customer responsiveness (for this or other products)—thus leading to fewer repeat sales—then carrying costs ought to reflect the opportunity cost of current and future throughput lost. Similarly, future sales may be lost if customers seek competitors that can promise shorter lead times.

Revisiting the Example

Assume now that Speedy Company wants to understand and measure its current and future throughput lost when it produces any particular batch size. Assume also that the machine for pressing frames operates near capacity when used to press 8,400 frames in batches of 40. Recall also that the bike frames require two different tool setups at the same machine to complete forming the frame; this requires that the dies be changed between runs. Even though setup times are much shorter than in the past, management assumes that

Exhibit 4. Throughput EOQ Model



the expected annual demand cannot be met if batch sizes fall below 10.

Further, when producing 160 bicycles in 4 batches of 40 (instead of in 8 batches of 20 or in 16 batches of 10), existing customers must wait up to two days to have their orders filled. Management fears that the company loses potential customers who may not be able or willing to wait up to two days. As a result of including the opportunity costs of current throughput lost, the optimal batch size shifts to 20 (rather than 40) per production run. Based on the accountant's projections and management's decision to produce in batches of 20, setup and carrying costs will go from $2,660 to $3,220, increasing costs by $560, as shown in Exhibit 3.

The additional throughput gained by this decision will be 12 additional bikes sold at $250 throughput per unit, or $3,000. Thus, the difference between the decision to produce in batch sizes of 20 instead of 40 provides Speedy Company with an additional net profit of $2,440 ($3,000 − $560) because the throughput lost ($3,000) in this example has a greater impact on Speedy's profitability than does the traditional cost or locally optimal decision (savings of $560) provided by the conventional EOQ model. Exhibit 4 includes the opportunity cost in the total relevant cost function.

Exhibit 4 illustrates several points. First, in the throughput world, it is neither necessary nor likely that setup costs will equal the carrying costs at the optimal batch size, as was the case in the conventional model. Also, even though few sales are expected to be lost as a result of the batch-size decision, Speedy's bottom line is much more affected by those lost sales than by the costs traditionally used for the batch-size decision. Finally, the impact of the local batch-size decision has been linked to the global performance measure of net income by making opportunity costs part of the total relevant cost concept.

CONCLUSION

This article proposes modifications to the conventional EOQ model by including opportunity costs. The conventional EOQ model, by focusing narrowly on minimizing costs, falls short of achieving the organization's objective. The adapted EOQ model takes throughput concepts into account to maximize profits, which is the true goal.

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