Reducing the Setup Cost

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There has been a lot of talk in the past few years about striving for zero inventory. The argument is that the less inventory a company carries, the more efficiently it is operating its business.[4] The question is whether this argument can be justified from an economic point of view, at least in the context of the EOQ models we have been discussing. We have seen that the main reason for carrying more inventory is the fixed setup cost K. If K is large, it is economical to order in larger quantities, which means that the average inventory level is large. So if this is true, what incentive is there for a company to strive for zero inventory?

One possible answer to this question is to reconsider whether the setup cost is really *fixed*. Is a company automatically stuck with some value of K, or is it possible to reduce this value of K and thereby justify smaller order quantities and smaller inventory levels? This is an interesting modeling question. How can we mathematically model the cost of reducing K?

One researcher, Evan Porteus, has proposed a model where a company can make a one-time investment to reduce the value of K (Porteus, 1985). Specifically, if the company's current setup cost is K_0, he assumes that by investing $f(K)$ dollars, the company can reduce the setup cost from K_0 to K, where $K < K_0$. Having a smaller value of K implies a lower total annual cost, but this reduction must be weighed against the one-time investment required to reduce the setup cost. Also, the optimal *amount* of setup cost reduction must be determined. Therefore, K becomes a decision variable along with the order quantity Q in the basic EOQ model. (We do not allow quantity discounts or shortages in this section.)

There are two modeling problems here. The first is to choose a reasonable form for the function $f(K)$. The second is to find a way to turn a one-time investment cost, $f(K)$, into an equivalent *annual* cost, so that the cost of reducing the setup cost is comparable to the annual operating costs we have been discussing. For the first problem, Porteus assumes that the investment required to reduce the setup cost from K_0 to K is of the form

$$f(K) = a_0 + a_1 \ln(K)$$

for some constants a_0 and a_1. (Here, ln is the natural logarithm.) This form is not as strange as it might look. It implies that each 10% decrease in K costs a *fixed* dollar amount. (The 10% figure is chosen for convenience; the same argument can be used for any other percentage.) Specifically, it can be shown that the cost of reducing K by 10% is $a_1 \ln(0.9) = -0.1054a_1$ dollars, regardless of whether the reduction is from \$300 to \$270, \$30 to \$27, \$3 to \$2.70, or any other 10% change. This constant cost per 10% decrease is a reasonable property for $f(K)$ to have.

We can fully specify the $f(K)$ function—that is, find a_0 and a_1—if we are given two inputs: the initial setup cost K_0 and the cost of a 10% reduction in K. To illustrate, suppose that the initial setup cost is $K_0 = \$500$, and it takes a one-time investment of \$1000 to reduce this by 10%. Then we set $-0.1054a_1 = 1000$ to obtain $a_1 = -9491$. Also, because it costs zero dollars to stay at level K_0, we have $f(K_0) = 0$, which implies that

$$0 = a_0 + a_1 \ln(K_0) = a_0 - 9491 \ln(500) = a_0 - 58{,}984$$

We need to convert a one-time investment cost into an equivalent annual cost. If the one-time cost is f(K), and i is the annual interest rate, then the equivalent annual cost is the product f(K)i.

or

$$a_0 = 58{,}984$$

Now we tackle the second problem. The investment cost $f(K)$ is a one-time investment. However, it is equivalent to an annual investment in perpetuity of $f(K)i$ dollars, where i is the annual interest rate. This follows from an NPV argument that we do not present here. In words, if the company were to pay $f(K)i$ dollars at the beginning of each year

[4] See the article by Zangwill (1992) for a discussion of the merits of keeping inventory low.

forever, this would be equivalent in NPV terms to a one-time payment of $f(K)$ dollars. Putting all of this together, the total annual cost to the company is $f(K)i$ plus the annual operating cost from any of our previous models. In addition to any previous decision variables, such as Q, we now need to choose K, subject to the constraint $K \le K_0$. We illustrate the procedure in the following example.

EXAMPLE 13.4 REDUCING THE SETUP COST AT COMPSERVE

The CompServe Company stocks expensive laser printers. The annual demand for this product is 300 units. The cost from CompServe's supplier is $1000 per printer, the cost of capital is 10%, and the storage cost per printer per year is $30. CompServe currently incurs a setup cost of $800 per order, but it believes that by streamlining its ordering and delivery operations, it can reduce this value and thereby achieve smaller inventory levels. Specifically, CompServe estimates that each 10% reduction in setup cost will require a $1500 investment. However, preliminary analysis shows that reducing the setup cost below $50 is physically impossible, regardless of the amount invested. Should the company invest in setup cost reductions, and if so, how does this affect its ordering policy?

Objective To check, in the context of the basic EOQ model, whether it is cost-effective to make a one-time investment in setup cost reduction.

Solution

We must first find the parameters a_0 and a_1 of the investment cost function $f(K)$ by using the information on the original setup cost, $800, and the cost per 10% setup cost reduction, $1500. Then we can express all annual costs in terms of the decision variables K and Q and use Solver to optimize. The details are explained next.

DEVELOPING THE SPREADSHEET MODEL

The spreadsheet solution shown in Figure 13.7 is very similar to the solution for the basic EOQ model. (See the file **EOQ4.xls**.) We list the key steps here:

Figure 13.7
Solution to the Setup Cost Reduction Example

	A	B	C	D	E
1	**CompServe's EOQ model with possible setup cost reduction**				
2					
3	**Inputs**			**Range names used:**	
4	Initial setup cost	$800		Annual_demand	=SetupReduction!$B$9
5	Minimal setup cost achievable	$50		Annual_interest_rate	=SetupReduction!$B$7
6	Storage cost per unit per year	$30		Cost_of_reduction_in_setup_cost	=SetupReduction!$B$10
7	Annual interest rate	10%		Initial_setup_cost	=SetupReduction!$B$4
8	Unit purchasing cost	$1,000		Intercept	=SetupReduction!$B$13
9	Annual demand	300		Minimal_setup_cost_achievable	=SetupReduction!$B$5
10	Cost of reduction in setup cost	$1,500		Order_quantity	=SetupReduction!$B$18
11				Orders_per_year	=SetupReduction!$B$20
12	**Parameters of setup cost reduction function**			Setup_cost_after_reduction	=SetupReduction!$B$17
13	Intercept	95168		Slope	=SetupReduction!$B$14
14	Slope	-14237		Storage_cost_per_unit_per_year	=SetupReduction!$B$6
15				Total_annual_cost	=SetupReduction!$B$28
16	**Analysis using the Solver**			Unit_purchasing_cost	=SetupReduction!$B$8
17	Setup cost after reduction	$103.94			
18	Order quantity	21.9			
19	Time between orders	0.346			
20	Orders per year	2.89			
21					
22	**Monetary values**				
23	One-time investment to reduce setup cost	$29,054			
24	Equivalent annual cost to reduce setup cost	$2,905			
25	Annual setup cost	$1,424			
26	Annual holding cost	$1,424			
27	Annual purchasing cost	$300,000			
28	Total annual cost	$305,753			

1 **Parameters of setup cost reduction function.** Calculate the parameters a_0 and a_1 of the setup cost reduction function in cells B13 and B14 using the procedure outlined previously. Specifically, calculate the slope a_1 with the formula

=Cost_reduction_in_setup_cost/LN(0.9)

Then calculate a_0 with the formula

=-Slope*LN(Initial_setup_cost)

This formula ensures that the cost of making *no* setup cost reduction is 0.

2 **Cost of reducing setup cost.** Enter the one-time investment in setup cost reduction in cell B23 with the formula

=Intercept+Slope*LN(Setup_cost_after_reduction)

Then enter the equivalent annual cost in cell B24 with the formula

=B23*Annual_interest_rate

USING SOLVER

The rest of the model is exactly like the basic EOQ model. To set up Solver, we identify annual cost as the objective to minimize, with cells B17 and B18 as the changing cells. We constrain cell B17 to be less than or equal to cell B4 and greater than or equal to cell B5, and we select the Assume Non-Negative option. (We could also constrain the order quantity to be an integer, but we have not done so.)

Discussion of the Solution

As Figure 13.7 indicates, CompServe should first invest \$29,054 to reduce the setup cost from \$800 to \$103.94. Then its optimal order quantity is about 22 printers, and the total annual cost, including the investment in setup cost reduction, is \$305,753. Of course, only \$5753 of this is affected by the decision variables. The other \$300,000 is the unavoidable annual purchase cost.

Has setup cost reduction worked? If this example is solved with the basic EOQ model, using the original \$800 setup cost, you can check that the optimal order quantity is 61 units, and the annual cost (not counting the \$300,000 purchase cost) is approximately \$7900. When setup cost reduction is allowed, the company reduces its setup cost from \$800 to slightly over \$100, and the ordering quantity drops sharply to 22 units. Instead of ordering about 5 times a year (300/61), it now orders almost 14 times a year (300/22). Also, the annual cost decreases by over \$2000. Because the company's initial investment of almost \$29,000 is equivalent to about \$2900 per year, the savings in annual ordering and holding costs is about \$4900. In addition, there may be other intangible benefits from holding less inventory, as Zangwill (1992) and many other authors have noted. ■

Synchronizing Orders for Several Products

Until now, we have assumed that a company orders a single product. If the company orders several products, it could calculate the EOQ for each product and order them according to separate schedules. However, there might be economies, particularly reduced setup costs, from synchronizing the orders so that several products are ordered simultaneously. This should be particularly attractive for products that come from the same supplier. Then, for example, the same truck can deliver orders for several products, thereby reducing the setup cost involved with the delivery. We develop a model in this section that takes advantage of synchronization, and we compare it to the "individual EOQs" policy that uses no synchronization. Although this model can be developed for any number of products, we keep things relatively simple by assuming that there are only *two* products. We illustrate the approach in the following example.

EXAMPLE 13.5 SYNCHRONIZED ORDERING AT SLEEPEASE

Sleepease, a retailer of bedding supplies, orders king-size and queen-size mattresses from a regional supplier. There is a fairly constant demand for each of these products. The annual demand for queens is 2200; the demand for kings is 250. The unit purchasing costs for queen-size and king-size mattresses are \$100 and \$120, and the company's cost to store either of these for one year is \$15. Sleepease's ordering cost is based primarily on the fixed cost of delivering a batch of mattresses. This ordering cost is \$500 if either queens or kings are ordered separately, but the ordering cost is only \$650 if both are ordered together. Sleepease's cost of capital is 10%. The company wants to know whether synchronizing orders is better than not synchronizing them, and if so, it wants to find the best synchronized ordering policy.

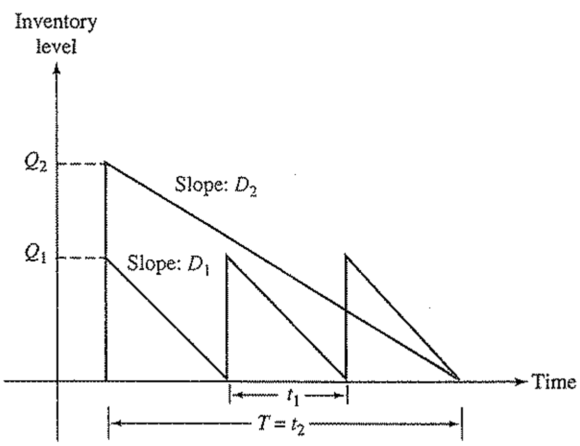
Objective To find the optimal synchronized ordering policy, and to compare it to the EOQ policy where orders for the two are not synchronized.

Solution

The only real cost benefit from synchronization is reduced setup costs. Let K_1 = \$500 be the setup cost for ordering queens alone, and define K_2 = \$500 similarly for kings. When both products are ordered simultaneously, we denote the setup cost for the order by K_{12} = \$650. The important point is that K_{12} is less than $K_1 + K_2$. This reflects the economy of scale achieved when both products are ordered together rather than individually. All other parameters (s, c, D, and i) are defined as before, except that each product has its own values of s, c, and D.

To model this problem, consider the graph in Figure 13.8. This depicts a synchronization policy where queens are ordered three times as often as kings. In general, let t_1 and t_2, respectively, be the time between orders of queens and kings, and let T be the cycle time, defined as the larger of t_1 and t_2. (In the graph, $t_2 > t_1$, so $T = t_2$.) Also, let n_1 and n_2, respectively, be the number of times queens and kings are ordered during a cycle. (In the graph, $n_1 = 3$ and $n_2 = 1$.) Then under a synchronization model, n_1 and n_2 are both positive

Figure 13.8
EOQ with Synchronization



integers, and at least one of them equals 1. (Actually, they could both be 1, in which case queens and kings are always ordered together.)

For the optimization model, it is convenient to let T, n_1, and n_2 be the decision variables—that is, the changing cells in the spreadsheet. We can easily recover the order quantities Q_1 and Q_2 from these values as follows. First, we know that t_1, the time between orders of queens, is T/n_1. Similarly, $t_2 = T/n_2$. Then given t_1 and t_2, the order quantities Q_1 and Q_2 must be $Q_1 = D_1t_1$ and $Q_2 = D_2t_2$ (because we want each Q to decrease to 0 in time t at rate D).

To develop the total annual cost, the purchasing and holding costs are exactly as before (for each product). Therefore, we concentrate on the setup cost. During an ordering cycle of length T, both products are ordered together exactly once, for a setup cost of K_{12}. Then product j (for $j = 1$ or $j = 2$) is ordered $n_j - 1$ times by itself, for a setup cost of $K_j(n_j - 1)$. (For at least one of the two products, this latter term is 0. For example, it is 0 for product 2 in Figure 13.8.) The number of cycles per year is $1/T$, so the total annual setup cost is

$$\text{Annual setup cost} = [K_{12} + (n_1-1)K_1+(n_2-1)K_2]/T \tag{13.7}$$

We are now ready to develop the spreadsheet model.

DEVELOPING THE SPREADSHEET MODEL

The spreadsheet model appears in Figure 13.9. (See the file **EOQ5.xls**.) The top part of the spreadsheet shows the analysis for the synchronized ordering policy. It can be formed as follows:

Figure 13.9
Solution to the Synchronized Ordering Example

	A	B	C	D	E	F	G	H	I
1	**Synchronized Ordering of Two Products**								
2									
3	**Inputs**							**Range names used:**	
4	Interest rate	10%						Cycle_time	=Synch!$B$17
5	Joint setup cost	$650						Interest_rate	=Synch!$B$4
6								Joint_setup_cost	=Synch!$B$5
7	Product	Setup cost (individual)	Storage cost	Purchasing cost	Combined holding cost	Annual demand		Orders_per_cycle	=Synch!$B$14:$B$15
8	Queens	$500	$15	$100	$25	2200		Synchronized_order_quantities	=Synch!$E$14:$E$15
9	Kings	$500	$15	$120	$27	250		Total_annual_cost	=Synch!$B$23
10									
11	**Optimal synchronized policy**								
12									
13	Product	Orders per cycle	Time between orders	Orders per year	Synchronized order quantities				
14	Queens	2	0.130	7.7	285				
15	Kings	1	0.259	3.9	65				
16									
17	Cycle time	0.259							
18									
19	Costs affected by ordering policy								
20	Annual setup cost	$4,438							
21	Annual holding cost	$4,438							
22	Annual purchasing cost	$250,000							
23	Total annual cost	$258,876							
24									
25	**Optimal policy with no synchronization (using individual EOQs)**								
26									
27	Product	Separate EOQs	Time between orders	Orders per year	Annual setup costs	Annual holding costs			
28	Queens	297	0.135	7.4	$3,708	$3,708			
29	Kings	96	0.385	2.6	$1,299	$1,299			
30	Totals				$5,007	$5,007			
31									
32	Annual purchasing cost	$250,000							
33	Total annual cost	$260,014							

1 **Inputs.** Enter the inputs in rows 4, 5, 8, and 9. As usual, note that the combined holding costs in the range E8:E9 are storage costs plus the interest rate multiplied by the purchasing costs.

2 **Orders per cycle and cycle time.** Enter *any* trial values in the cells B14, B15, and B17. The values in cells B14 and B15 correspond to n_1 and n_2; the value in cell B17 corresponds to T.

3 **Timing of orders.** Calculate the times between orders, t_1 and t_2, in the range C14:C15 by entering the formula

=Cycle_time/B14

in cell C14 and copying it down. Then calculate the orders per year in the range D14:D15 as the reciprocals of the values in C14:C15.

4 **Order quantities.** Calculate the order quantity for queens in cell E14 with the formula

=F8*C14

and copy this to cell E15 for the kings. Again, this expresses the order quantity as the annual demand multiplied by the time between orders.

5 **Annual setup cost.** Calculate the annual setup cost in cell B20 with the formula

=(Joint_setup_cost+SUMPRODUCT(Orders_per_cycle-1,B8:B9))/Cycle_time

This follows directly from equation (13.7). (Note how the term Orders_per_cycle-1 is used inside the SUMPRODUCT function. It takes the values in the Orders_per_cycle range, subtracts 1 from each of them, and multiplies these by the values in the B8:B9 range.)

6 **Other costs.** Calculate the other costs exactly as in previous EOQ models, except that now the holding and purchasing costs must be summed over the two products, queens and kings.

USING SOLVER

We can now use Solver to find the optimal synchronized policy. We minimize the annual cost, using cells B14, B15, and B17 as the changing cells. The constraints are that cell B17 should be nonnegative and cells B14 and B15 should be integers and greater than or equal to 1 (to ensure that Sleepease orders each product a positive integer number of times per cycle).

Discussion of the Solution

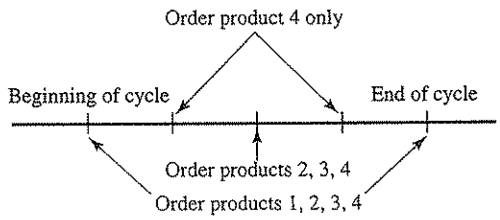
We see that there are about four cycles every year (because cycle time is about 1/4 year). Queens are ordered twice every cycle, and kings are ordered only once. The total annual cost (not counting the purchasing cost) from this synchronized ordering policy is $8876. For comparison, the bottom part of the spreadsheet in Figure 13.9 shows the unsynchronized policy from using individual EOQs. Now queens and kings are both ordered slightly less frequently than before, but because the orders are not synchronized, there are more ordering times per year. By comparing setup and holding costs, we see that this unsynchronized policy costs about 12.7% more than the best synchronized policy ($10,014 versus $8876). In addition, there is an important noneconomic advantage of synchronizing orders—the ordering process is easier to manage.

Would you have guessed that queens would be ordered more frequently than kings? The reason is that the number of orders per year for either product is D/Q. From the EOQ square-root formula, we know that the optimal number of orders per year is proportional to the square root of D. Now, kings and queens have very similar setup costs K (if ordered separately) and holding costs h. Therefore, their relative ordering frequencies are determined by their demand rates, and queens have a much larger demand rate. Therefore, it makes sense to order queens more frequently. (The analysis would not be this straightforward if kings and queens had different values for all three parameters K, D, and h). ■

More Than Two Products

Virtually the same spreadsheet could be used for more than two products, provided that we make a simplifying assumption. This assumption is that a setup cost reduction is available only when the company places an order for *all* of the products simultaneously. Unfortunately, it is probably more realistic to assume that there is a setup cost reduction when *any* subset of products is ordered simultaneously. To illustrate, suppose that there are four products, product 1 is ordered once per cycle, products 2 and 3 are ordered twice per cycle, and product 4 is ordered four times per cycle (see Figure 13.10). When all four products are ordered together at the beginning of a cycle, there is definitely a setup cost reduction, but there is probably also some setup cost reduction when products 2, 3, and 4 are ordered together in the middle of a cycle. If we allow this possibility, however, and then try to optimize over all possible synchronizations, the problem becomes difficult to model in a spreadsheet. Therefore, we do not pursue this multiple-product model any further here.

Figure 13.10
Another Way to Synchronize



PROBLEMS

Solutions for problems whose numbers appear within a color box can be found in the Student Solutions Files. Order your copy today at the Winston/Albright product Web site, http://www.thomsonedu.com/decisionsciences/winston.

Skill-Building Problems

1. In the basic EOQ model in Example 13.1, suppose that the fixed cost of ordering is $500. Use Solver to find the new optimal order quantity. How does it compare to the optimal order quantity in the example? Could you have predicted this from equation (13.4)?

2. If the lead time in Example 13.1 changes from one week to two weeks, how is the optimal policy affected? Does the optimal order quantity change?

3. In the quantity discount model in Example 13.2, suppose we want to see how the optimal order quantity and the total annual cost vary as the fixed cost of ordering varies. Use a *two-way* SolverTable to perform this analysis, allowing the fixed cost of ordering to vary from $50 to $200 in increments of $50. Indicate the optimal ordering policy for each fixed cost of ordering.

4. In the quantity discount model in Example 13.2, the minimum total annual cost in region 3 is clearly the best. Evidently, the larger unit purchase costs in the other two regions make these two regions unattractive. Could region 1 ever be best? What about region 2? To answer these questions, assume that there is no price break at all. Specifically, assume that the unit purchase cost is *always* $26. What is the optimal order quantity with this assumption? How does this help answer the preceding questions?

5. The quantity discount model in Example 13.2 uses one of two possible types of discount structures. It assumes that if the company orders 600 units, say, each unit costs $28. This provides a big incentive to jump up to a higher order quantity. For example, the total purchasing cost of 499 units is 499($30) = $14,970, whereas the total cost of 500 units is only 500($28) = $14,000. Change the discount structure so that the first 499 units cost $30 apiece, the next 300 units cost $28 apiece, and any units from 800 on cost $26 apiece. Now the cost of 500 units is 499($30) + $28 = $14,998. Modify the model to incorporate this structure, and find the optimal order quantity.

6. In Example 13.3, we used SolverTable to show what happens when the unit shortage cost varies. As the table indicates, the company orders more and allows more backlogging as the unit shortage cost decreases. Redo the SolverTable, this time trying even smaller unit shortage costs. Explain what happens when the unit shortage cost is really small. Do you think a company would ever use a really small shortage cost?

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Why or why not? Then redo the SolverTable again, this time trying even larger unit shortage costs. How do the results in this case compare to the results from the basic EOQ model with *no* shortages allowed?

7. In Example 13.4, we showed why a company might invest to reduce its setup cost. It all depends on how much this investment costs, as specified (in the model) by the cost of a 10% reduction in the setup cost. Use SolverTable to see how the results change as this cost of a 10% reduction varies. You can choose the range for this cost that makes the results "interesting." Within your range, does the lower limit on setup cost ($50) ever become a binding constraint?

8. Modify the synchronized ordering model in Example 13.5 slightly so that you can use a *two-way* SolverTable on the fixed costs. Specifically, enter a formula in cell B9 so that the fixed cost of ordering kings alone is equal to the fixed cost of ordering queens alone. Then let the two inputs for SolverTable be the fixed cost of ordering queens alone and the joint fixed cost of ordering both kings and queens together. Let these vary over a reasonable range, but make sure that the first input is less than the second, and the second input is less than twice the first. (Otherwise, the model wouldn't be realistic.) Capture the changing cells and the sum of annual setup and holding costs as SolverTable outputs. Describe your findings in a brief report.

Skill-Extending Problems

9. In the basic EOQ model in Example 13.1, suppose that the fixed cost of ordering and the unit purchasing cost are both multiplied by the same factor f. Use SolverTable to see what happens to the optimal order quantity and the corresponding annual fixed order cost and annual holding cost as f varies from 0.5 to 5 in increments of 0.25. Could you have discovered the same results algebraically, using equations (13.2) through (13.4)?

10. In the basic EOQ model, revenue is often omitted from the model. The reasoning is that all demand will be sold at the given selling price, so revenue is a fixed quantity that is independent of the order quantity. Change that assumption as follows. Make selling price a decision variable, which must be between $110 and $150. Then assume that annual demand is a nonlinear function of the selling price p: Annual Demand = $497000p^{-1.24}$. (This implies a constant elasticity of approximately -1.24 for the demand curve.) Modify the model in Example 13.1 as necessary and then use Solver to find the optimal selling price and order quantity. What are the corresponding demand and profit? Which appears to affect profit more in this model, order quantity or selling price?

11. In the quantity discount model in Example 13.2, the minimum total annual cost is region 3 is clearly the best. Evidently, the larger unit purchase costs in the other two regions make these two regions unattractive. When would a switch take place? To answer this question, change the model slightly. First, change the fixed cost of ordering to $40. Second, keep the unit cost in region 3 at $26, but change the unit costs in regions 1 and 2 to $26 + 2$k$ and $26 + k, where you can let k vary. (Currently, k is $2.) Use a *two-way* SolverTable, with k varied over some appropriate range to see how small k must be before it is optimal to order from region 1 or 2. What region is the optimal ordering quantity in if there is no price break at all ($k = 0$). How do you reconcile this with your SolverTable findings?

13.5 PROBABILISTIC INVENTORY MODELS

In most situations, companies that make ordering and production decisions face uncertainty about the future. Probably the most common and important element of uncertainty is customer demand, but there can be others. For example, there can be uncertainty in the amount of lead time between placement and receipt of an order. A company that faces uncertainty has three basic options. First, it can use best guesses for uncertain quantities and proceed according to one of the deterministic models we developed in the previous section (or according to one of the many other deterministic models that exist in the literature). Second, it can develop an analytical (nonsimulation) model to deal with the uncertainty. The advantage to such a model is that we can calculate bottom line results, such as expected cost, and then use Solver to optimize. The disadvantage is that these analytical models tend to be mathematically complex. The third possibility is to develop a simulation model. The advantage of a simulation model is that it is relatively easy to develop,