The topic of estimating inventory cost parameters has not received the same level of attention in the literature as the (sometimes highly theoretical) development of new mathematical models. And those papers that deal with the subject matter only offer general guidelines with sketchy details. The reason is that cost parameters are highly business specific, ranging from the familiar retailing and manufacturing businesses to the highly bureaucratic government entities. As such, the problem of estimating cost parameters is indeed tough, and no amount of details can lead to universal rules that cover all situations.

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Case Study: Kroger Improves Pharmacy Inventory Management[7]

Application Area: Pharmacies inventory control

Tools: Inventory formulas, heuristics, spreadsheet simulation

Software: Excel

Description of the situation

The Kroger Co., a supermarket chain, operates close to 2000 in-store pharmacies in the United States with a total retail value of about $8 billion. Most pharmacies typically carry an average of 2500 drugs each. The pharmacies receive the majority of their drug supplies from Kroger's warehouses. The rest is shipped from third-party warehouses.

The pressing issue has been how to manage the enormous drug inventory problem at the store level. Understocking means frequent shortages with its negative impact on revenue and customer loyalty, and overstocking leads to tying up capital, high maintenance cost, and possible drug obsolescence. The goal of good inventory management at Kroger is to strike a balance between overstocking and understocking.

[7]Based on Zhang, X. D., Meiser, Y. Liu, B. Bonner, and L. Lin, "Kroger Uses Simulation-Optimization to Improve Pharmacy Inventory Management," *Interfaces*, Vol. 44, No. 1, pp. 70–84, 2014.

Inventory policy

Kroger pharmacy employs the (s, S) periodic review policy that calls for bringing the inventory level up to S whenever the inventory position (on hand + on order) drops below the reorder point s. Thus, if at review time the current inventory level is $x\ (< s)$, an order of size $S - x$ is placed. Otherwise ordering must await the next review process. Order sizes are rounded up to a multiple of a prespecified package size. Reviews take place during the review period, normally one or two days before a scheduled delivery.

The ultimate goal of this study is to determine the quantities s and S of the inventory policy that will minimize the total inventory cost comprised of the three traditional cost of carrying inventory: (1) cost of placing an order, (2) inventory holding cost, and (3) shortage cost. The developed model must be user-friendly for the pharmacy personnel in charge of determining the inventory policy for the thousands of drugs each pharmacy carries.

Nature of demand

Typical demand for a drug per customer per day occurs in discrete values of 0, or 30-, 60-, and 90-day supplies. Higher quantities (e.g., 120-, 150-, and 180-day supplies) can occur when multiple customers buy the same drug on any one day. Demand for a specific drug varies widely among store locations depending on demographic factors, population composition, and prevailing diseases. The end result is that demand for the majority of the drugs is intermittent and irregular and likely cannot be represented by known theoretical distributions. The most practical way to model such demand is to use direct sampling from the empirical discrete distribution.

Spreadsheet simulation model

The spreadsheet was selected as the software of choice for modeling Kroger's inventory problem because it is a familiar tool to most computer users. This advantage was important in gaining the acceptance of the final software, not only by Kroger management but also by the pharmacy personnel responsible for deciding the inventory policy for each drug.

Figure 13.12 illustrates a 20-day spreadsheet simulation (normally the simulation runs for a full year).[8] Each spreadsheet deals with a single drug. Daily demand data (A9:A28) for the drug are generated randomly from the empirical discrete distribution of approximately one year of historical data. Column A provides one such (random) scenario using the inverse sampling method.[9] This scenario now forms a *deterministic* equivalence of the empirical demand distribution. It should remain *unaltered* throughout subsequent iterative search comparisons aimed at determining an acceptable inventory policy.

The main input data that drive the simulation are the periodic review values s and S in (B2:B3). The initial (s, S) values used to start iterative simulations are

Q = Economic order quantity (computed using file *excelEOQ.xls*, Section 13.3.1)

s = maximum demand of an order period based on historical data

$$S = s + Q$$

The output results of the simulation are then used to search for an (s, S) policy with lower cost, and, if found, the new (s, S) values are entered in (B2:B3) and the simulation is run anew for

[8] I had no access to any of the software or the spreadsheets used in the *Interfaces* article. I developed this spreadsheet using fictitious data. The goal is to demonstrate the functionality of the simulation.

[9] The inverse method for generating random discrete samples is presented in Section 19.3.2.

	A	B	C	D	E	F	G	H
1	Input				Output			
2	**Reorder pt. *s***	**120**	Start wk day	*Thu*	Average demand		24.00	**Normalize**
3	**Up-to qty. *S***	**180**	Starting inv	100	Average inventory		85.00	**d cost, *C***
4	*Reviews occur on MWF*		Pkge. Size	10	Average shortage		25	**15.31250**
5			Lead time	2	Number of orders		5	
6					Min. inv. Held (*I*+)		30	
7					Max. shortage (*I*-)		30	
8	**Demand**	**Week days**	**Beginning inventory**	**Inventory position**	**Place order?**	**Order quantity**	**Quantity received**	**Ending inventory**
9	0	*Thu*	100	100		0	0	100
10	60	Fri	100	100	yes	80	0	40
11	60	Sat	40	120		0	0	-20
12	0	Sun	-20	60		0	80	60
13	0	Mon	60	60	yes	120	0	60
14	30	Tue	60	180		0	0	30
15	0	Wed	30	150		0	120	150
16	0	Thu	150	150		0	0	150
17	0	Fri	150	150		0	0	150
18	0	Sat	150	150		0	0	150
19	0	Sun	150	150		0	0	150
20	30	Mon	150	150		0	0	120
21	60	Tue	120	120		0	0	60
22	30	Wed	60	60	yes	120	0	30
23	60	Thu	30	150		0	0	-30
24	0	Fri	-30	90	yes	90	120	90
25	60	Sat	90	180		0	0	30
26	90	Sun	30	120		0	90	30
27	0	Mon	30	30	yes	150	0	30
28	0	Tue	30	180		0	0	30

FIGURE 13.12

Excel spreadsheet simulation of a specific (s, S) policy for a given stream of daily demand (file *excelKrogerCase9.xls*)

the same demand stream in column A. The procedure is repeated until no better policy can be found, as will be explained below.

The remaining input data provide start week day (D2), starting inventory (D3), package size (D4), and lead time (D5). The start week day is used to enhance readability. All orders are rounded up to multiples of the package size. For simplicity this spreadsheet uses a constant lead time (= 2 days). Realistically, the lead time may be random (e.g., 2 days with probability .6 and 3 days with probability .4).

The spreadsheet calculations are based on the following ordering policy and simulation formulas:

Ordering policy:

1. On a review day, if (inventory position) $< s$ order (S–inventory position), else do not order.
2. Inventory position reviewed on days MWF.
3. Order is placed at end of day and remains outstanding throughout lead time.

4. Filled order is received at end of day.
5. All unfilled demand is backordered (no lost sales).

Simulation formulas (*day* i):

1. $(\text{Beginning inventory})_i = (\text{Ending inventory})_{i-1}$
2. $(\text{Ending inventory})_i = (\text{Beginning inventory})_i + (\text{Received order})_i - (\text{Demand})_i$
3. $(\text{Inventory position})_i = (\text{Beginning inventory})_i + (\text{On order})_{i-1}$

The primary reason for assuming the backordering policy is that it provides information about shortages. Successive simulations are then carried out to determine a periodic review (s, S)-policy that will reduce if not eliminate shortages.

A summary output of the simulation includes average demand (G2); average positive ending inventory (G3); average shortage ending inventory (G4); number of placed orders (G5); minimum positive ending inventory, I^+ (G6); and maximum shortage ending inventory, I^- (G7).

The output data include the (normalized) total inventory cost per day (H4) comprised of the sum of order setup cost, holding cost, and shortage cost.[10] This cost function evaluates different periodic review policies.

As explained next, the output data minimum positive inventory (G6) and maximum shortage (G7) are used to direct the search for finding a better inventory policy.

Local search algorithm

One way to find a good, if not optimal, solution is to assume a reasonable range of discrete values for s (e.g., 120 to 300 in steps of 10) and Q (e.g., 10 to 100 in steps of 10) and then run the simulation for all possible combinations s and $S\ (= s + Q)$. This, of course, is not efficient. The alternative is to devise heuristics that could lead to a good solution quickly.

The search starts with an initial review policy $(s, s + Q)$ defined previously. The values used in Figure 13.12 are $s = 120$ and $Q = 60$, giving $S = 180$. Define (s, S) as the best review policy so far found with cost C (initially, $C = \infty$) and quantities I^+ and I^- (G6:G7). The idea is to look for a better review policy in the neighborhood of (s, S) based on two steps:

Step 1. (Fixed Q):

- **(a)** Set $s' = s + I^-$ and $S' = s' + Q$ and run the simulation for the new policy (s', S'). If it yields a lower cost, update $(s, S) = (s', S')$ and repeat (a). Else go to (b).
- **(b)** Set $s' = s - I^+$ and $S' = s' + Q$ and run the simulation for the new policy (s', S'). If it yields a lower cost, update $(s, S) = (s', S')$ and repeat (a). Else, no better solution can be found for fixed Q. Go to Step 2.

Step 2. (Variable Q): Let $r = \min(I^+, I^-)$.

- **(a)** Set $S' = S + r$, yielding $Q' = S' - s\ (> Q)$, and run the simulation for the new policy (s, S'). If it yields a lower cost, update $(s, S) = (s', S)$ and go to step 1(a). Else go to (b).
- **(b)** Set $s' = s - r$, yielding $Q' = S - s'\ (<Q)$, and run the simulation for the new policy (s, S'). If it yields a lower cost, update $(s, S) = (s', S)$ and go to step 1(a). Else, no better solution can be found for variable Q. Stop.

[10]The source article does not specify the cost parameters of the total cost function nor does it explain how they are determined. For the lack of better data, I used a "normalized" definition in which the holding and shortage costs per unit per day are percentages of the setup cost (1% and 2.5%, respectively).

In step 1, Q is kept fixed by changing (increasing or decreasing) s and S by equal amounts. Step 1(a) increases both s and S in an attempt to eliminate the shortage I^- and step 1(b) tires to bring the minimum ending inventory I^+ to zero by decreasing both s and S. If step 1 fails to produce a better solution for a fixed Q, step 2 (with a similar line of reasoning as in step 1) varies the value of Q by changing s and S, one at a time. When step 2 cannot produce a better review policy, the search ends with the last (s, S) providing the best heuristic solution.

Implementation

Kroger reports that developed model was implemented in 2011 in all the pharmacies in the United States. It has resulted in appreciable reduction in shortages and increase in revenues. The increase in revenues is estimated at $80 million and was coupled with a reduction in inventory of about $120 million.

Plans are underway to extend the model to other store departments. In particular, perishable products could benefit from a similar inventory control application with the goal of eliminating losses resulting from spoilage.

PROBLEMS

Section	Assigned Problems	Section	Assigned Problems
13.1.1	13-1 to 13-2	13.3.3	13-18 to 13-21
13.3.1	13-3 to 13-12	13.4.1	13-22 to 13-25
13.3.2	13-13 to 13-17	13.4.2	13-26 to 13-36

***13-1.** The current-year balance sheet of a company shows a beginning and end inventories of $90.4 million and $20.2 million, respectively. The net revenue from sales for the year is $210.3 million and the gross profit is $30.4 million. The final report claims that the company's average days-in-inventory is about 4 months. Assess the company's claim.

13-2. A small business financial data show that its inventory level of an item held steady at 1000 units during the first 9 months of the year. Sales accelerated during the last quarter in time for Christmas shopping, ending the year with only 20 units left in stock. The company estimates the total inventory cost at $.10 per unit per day. It sells the item at $190 per unit, a markup of 60% over cost. Assess the company's inventory situation based on (a) simple inventory average based on starting and ending levels, and (b) the actual inventory average.

13-3. In each of the following cases, no shortage is allowed, and the lead time between placing and receiving an order is 35 days. Determine the optimal inventory policy and the associated cost per day.

(a) $K = \$120, h = \$.04, D = 25$ units per day

(b) $K = \$80, h = \$.03, D = 35$ units per day

(c) $K = \$100, h = \$.02, D = 50$ units per day

(d) $K = \$110, h = \$.03, D = 25$ units per day

***13-4.** McBurger orders ground meat at the start of each week to cover the week's demand of 300 lb. The fixed cost per order is $20. It costs about $.03 per lb per day to refrigerate and store the meat.

(a) Determine the inventory cost per week of the present ordering policy.

(b) Determine the optimal inventory policy that McBurger should use, assuming zero lead time between the placement and receipt of an order.