Example 13.7

Ordering Simulation Models

Background Information

- Home repair is a large hardware retail store for more hammers.
- The setup cost for placing an order is $500, independent of the size of the order. The unit cost per hammer is $20.
- Home Repair estimates that the cost of holding a hammer in inventory for 1 week is $3.
- The company defines its **inventory position** at the beginning of any week as the number of hammers in inventory plus any that have already been ordered but have not yet arrived.

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Background Information -- continued

- The company's ordering policy is an (*s,S*) policy, a common periodic review policy used by many companies.
- This policy, defined by two numbers *s* and *S*, where $s<S$, specifies that if the inventory position at the beginning of the week is at level *x*, where *x* is less than or equal to *s*, exactly enough hammers will be ordered to bring the inventory position up to *S* – that is, Home Repair will order *S* – *s* hammers.

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Background Information -- continued

- Otherwise, if the inventory position is greater than *s*, no order will be placed that week.
- If an order is placed, it will arrive after a lead time of 1, 2, or 3 weeks with probabilities 0.7, 0.2, and 0.1.
- The weekly demand for hammers is uncertain, but it can be described by a normal distribution with mean 300 and standard deviation 75.
- The company's policy is to satisfy all demand in the week it occurs.

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Background Information -- continued

- If weekly demand cannot be satisfied completely from on-hand inventory, then an emergency order will be placed at the end of the week for the shortage.
- This order will arrive virtually instantaneously, but at a step cost of $35 per hammer.
- It is currently the beginning of week 1, and the current inventory of hammers, including any that might just have arrived, is 600.
- There are no other orders on the way. Home Repair wants to simulate several (*s*,*S*) policies to see which does best in terms of total costs over the next 52 weeks.

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Solution

- We will use @Risk to simulate a 52-week period and keep track of the total costs for this period for each of several (*s*,*S*) policies.
- There is no way to optimize all possible (*s*,*S*) policies, but it is possible to test a number of "representative" policies and choose the best of these.

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ORDERSIM.XLS

- The simulation model is shown on the next slides.
- This file contains the model.

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Evaluating an ordering policy

Assumptions:
A company uses an ordering policy determined by two integers: s (reorder point) and S (order up to quantity). At the beginning of each week, right after any shipments have arrived, its inventory position is examined. This includes onhand inventory plus any that has been ordered but has not yet arrived. If the inventory position is greater than s, no ordering is done. But if it is less than or equal to s, an order is placed to bring the inventory position up to S, and this order arrives after a random lead time of one to three weeks. All demand is satisfied on time -- one way or the other. Either it is satisfied from onhand inventory, or if demand in any week is greater than onhand inventory, the demand is met by an emergency shipment (at a high cost).

Range names used:
FCost - B13
VCost - B14
HCost - B15
ECost - B16
LeadTimes - B20:B22
Probs - C20:C22
MeanDem - B25
StdevDem - B26
InitInv - B29
Due2 - B30
Due3 - B31
ReorderPt - B35
OrderUpToQ - B36
PolicyTable - E29:G36

	A	B	C	D	E	F	G
12	**Costs**						
13	Fixed order cost	$500					
14	Variable order cost	$20					
15	Inventory holding cost	$3					
16	Emergency shipment cost	$35					
17							
18	**Distribution of order lead time**						
19		Number of weeks	Probability				
20		1	0.7				
21		2	0.2				
22		3	0.1				
23							
24	**Distribution of demand in a week - Normal (rounded to nearest integer)**						
25	Mean	300					
26	Stdev	75					
27					**Ordering policies to try**		
28	**Other inputs**				Policy	s	S
29	Initial inventory	600			1	200	500
30	Due in week 2	0			2	350	500
31	Due in week 3	0			3	350	750
32					4	500	750
33	**Order parameters**				5	400	1000
34	Policy index	1			6	600	1000
35	Reorder point R	200			7	500	1250
36	Order up to quantity Q	500			8	700	1250

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	A	B	C	D	E	F	G	H	I	J	K	L	M
38	**Summary measures from 52-week simulation below**												
39		Fixed order	Var order	Holding	Emergency	Total							
40	Cost totals	$10,500	$179,920	$22,977	$229,215	$442,612							
41													
42	**Simulation**	Inventory and order quantities, and lead time information								Costs			
43	Week	Begin onhand	Due in	Inv position	Amt ordered	Week order arrives	Demand	End onhand	Emerg orders	Fixed order	Variable order	Holding	Emergency
44	1	600	0	600	0	NA	261	339	0	$0	$0	$1,409	$0
45	2	339	0	339	0	NA	393	0	54	$0	$0	$509	$1,890
46	3	0	0	0	500	5	324	0	324	$500	$10,000	$0	$11,340
47	4	0	500	500	0	NA	330	0	330	$0	$0	$0	$11,550
48	5	500	0	500	0	NA	415	85	0	$0	$0	$878	$0
49	6	85	0	85	415	7	381	0	296	$500	$8,300	$128	$10,360
50	7	415	0	415	0	NA	334	81	0	$0	$0	$744	$0
51	8	81	0	81	419	9	332	0	251	$500	$8,380	$122	$8,785
52	9	419	0	419	0	NA	373	46	0	$0	$0	$698	$0
53	10	46	0	46	454	11	282	0	236	$500	$9,080	$69	$8,260
54	11	454	0	454	0	NA	225	229	0	$0	$0	$1,025	$0
55	12	229	0	229	0	NA	144	85	0	$0	$0	$471	$0
56	13	85	0	85	415	14	246	0	161	$500	$8,300	$128	$5,635
91	48	0	0	0	500	50	225	0	225	$500	$10,000	$0	$7,875
92	49	0	500	500	0	NA	287	0	287	$0	$0	$0	$10,045
93	50	500	0	500	0	NA	227	273	0	$0	$0	$1,160	$0
94	51	273	0	273	0	NA	231	42	0	$0	$0	$473	$0
95	52	42	0	42	458	53	316	0	274	$500	$9,160	$63	$9,590

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Developing the Model

- It is mostly a matter of careful bookkeeping, as we describe in the following steps.
  - **Inputs**. Enter the inputs in the shaded ranges. These include the various costs, the parameters of the demand distribution, the current inventory situation, and possible combinations of *s* and *S* to test. Note that the values in cells B30 and B31 are 0 because we have assumed that no orders are currently on the way. However, we develop the model so that it could respond to nonzero values in these cells. They would correspond to orders placed before week 1 but not due in until after week 1.

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Developing the Model -- continued

– **Ordering policy**. As usual, we set up the model with a RISKSIMTABLE function so that we can test all of the selected ordering policies simultaneously. To do this, enter the formula **=RISKSIMTABLE(E29:E36)** in cell B34. Then enter the formulas **=VLOOKUP(B34,PolicyTable,2)** and **=VLOOKUP(B34,PolicyTable,3)** in cells B34 and B35 to capture the values of *s* and *S* that will be used in the simulation.

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Developing the Model -- continued

– **Beginning inventory**. Moving to the simulation model, our strategy is the same as in most multiperiod models. We fill in the logic for the first few weeks and then copy down. We begin with column B, which contains the beginning on-hand inventory, right after any order has arrived. For week 1, this is the initial 600 hammers, so enter the formula **=InitInv** in cell B44. For later weeks we have to sum the final inventory from the previous week and the amount due in, if any, from previous orders. To do this, enter enter the formulas **=H44+Due2+SUMIF($F$44:F44,A45,$E$44:E44)**, **=H45+Due3+SUMIF($F$44:F45,A46,$E$44:E45)** and **=H46+SUMIF($F$44:F46,A47,$E$44:E46)** in cells B45-B47. This last formula is general, so copy it down to the other weeks.

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Developing the Model -- continued

- **Due in**. In column C we record the amounts already ordered but not yet in, so that we can calculate the inventory position in column D. Do this by entering the formulas **=Due2+Due3**, **=Due3+SUMIF($F$44:F44,”>”&A45,$E$44:E44)** and **=SUMIF($F$44:F45,”>”&A46,$E$44:E45)** in cells C44-C46, and copy this latter formula down. The SUMIF function is used essentially as in the previous step, but now we want conditions (the middle argument) such as “>1”. TO do this in Excel, we must put the greater than sign in quotes, followed by an ampersand, and then a cell reference.
- **Inventory position**. The inventory position is the amount onhand plus the amount due in, so enter the formula **=B44+C44** in cell D44 and copy it down.

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Developing the Model -- continued

- **Order**. Following the logic of the (*s, S*) ordering policy, calculate the order quantity in cell E44 with the formula **=IF(D44<=ReorderPt,OrderUpToQ-D44,0)** and copy it down. Then to see when this order arrives, enter the formula **=IF(E44>0,A44+RISKDISCRETE(LeadTimes,Probs),”NA”)** in cell F44 and copy it down.
- **Demand**. Generate random demands in column G by entering the formula **=ROUND(RISKNORMAL(MeanDem,StdevDem),0)** in cell G44 and copying it down.

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Developing the Model -- continued

– **Ending inventory and emergency orders**. If customer demand is less than on-hand inventory, then ending inventory is the difference; otherwise it is 0. Therefore, enter the formula **=MAX(B44-G44,0)** in cell H44 and copy it down. Similarly, there are emergency orders only if customer demand is greater than onhand inventory, so enter the formula **=MAX(G44-B44,0)** in cell I44 and copy it down.

– **Weekly costs**. The weekly costs are straightforward. Calculate them for week 1 in cells J44-M44 with the formulas **=IF(E44>0,Fcost,0)**, **=Vcost*E44**, **=Hcost*(B44+H44)/2** and **=Ecost*I44** and then copy these down.

Developing the Model -- continued

– **Summary measures**. Calculate the total cost of the various types in row 40 and designate them as @Risk output cells. For example, the formula in cell B40 is **=RISKOUTPUT( )+SUM(J44:J95)**

- It is important to look at the completed model before running @Risk. Press F9 a couple of times to get random numbers and check the logic.

Using @Risk

- We use @Risk exactly as in Chapter 11 and 12. We set the number of iterations to 500 and the number of simulations to 8.
- After running @Risk and copying selected outputs back to Excel, we obtain the results on the next slide.
- The two shaded cells correspond to the smallest average total 52-week costs among all pairs of *s* and *S*.
- Home Repair might prefer the policy with *s*=500 and *S*=750.

13.1 | 13.2 | 13.3 | 13.4 | 13.5 | 13.6 |13.8

	A	B	C	D	E	F	G	H	I
97	**Selected @Risk results for total cost (based on 500 iterations)**								
98	Reorder point s	200	350	350	500	400	600	500	700
99	Order up to quantity S	500	500	750	750	1000	1000	1250	1250
100	Minimum	$390,598	$377,910	$374,522	$364,364	$359,364	$363,637	$378,733	$391,083
101	Maximum	$495,198	$488,932	$462,790	$454,839	$473,991	$456,879	$464,049	$456,974
102	Mean	$442,405	$430,299	$420,503	$408,894	$417,876	$409,231	$421,320	$421,697
103	Stdev	$17,196	$17,797	$17,314	$15,979	$16,741	$14,437	$14,824	$12,361
104	5th perc	$414,097	$401,932	$390,875	$382,018	$392,422	$385,615	$397,081	$402,864
105	10th perc	$420,372	$407,581	$396,751	$388,064	$396,943	$391,815	$402,327	$406,346
106	15th perc	$424,053	$411,506	$402,232	$392,326	$400,478	$395,366	$405,919	$409,082
107	20th perc	$427,718	$415,143	$405,883	$395,550	$404,000	$397,394	$408,717	$410,654
108	25th perc	$431,502	$417,676	$408,814	$398,820	$406,427	$399,721	$411,111	$411,994
109	30th perc	$434,118	$419,181	$411,750	$400,883	$408,867	$401,917	$413,680	$414,016
110	35th perc	$436,345	$423,092	$414,596	$402,956	$410,777	$403,437	$415,415	$416,490
111	40th perc	$437,774	$425,201	$416,045	$404,483	$413,456	$405,313	$418,015	$417,865
112	45th perc	$440,079	$426,855	$418,458	$406,425	$415,049	$406,469	$419,899	$419,492
113	50th perc	$442,648	$430,672	$421,127	$408,413	$416,691	$408,359	$421,593	$421,416
114	55th perc	$444,602	$432,997	$423,504	$410,355	$419,392	$410,041	$423,078	$422,642
115	60th perc	$447,394	$435,118	$425,625	$412,356	$421,892	$411,798	$424,920	$424,553
116	65th perc	$449,681	$437,195	$427,197	$413,923	$424,126	$414,169	$427,053	$426,162
117	70th perc	$452,116	$439,832	$429,566	$416,529	$426,112	$416,324	$429,065	$427,905
118	75th perc	$454,231	$442,588	$432,269	$418,725	$428,423	$418,016	$431,237	$429,514
119	80th perc	$456,665	$445,396	$434,995	$421,542	$431,713	$420,738	$433,381	$431,941
120	85th perc	$458,557	$449,195	$438,168	$426,483	$435,274	$423,453	$436,509	$435,395
121	90th perc	$463,014	$453,289	$442,617	$430,339	$439,008	$428,976	$440,490	$437,704
122	95th perc	$470,192	$459,458	$450,013	$436,448	$446,570	$434,493	$444,858	$443,423

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Using @Risk -- continued

- It has the smallest average total cost, it has the smallest 5th percentile, it is essentially ties for the smallest median, and its 95th percentile is close to the smallest.
- Even with this ordering policy, however, there is still considerably variability – from about $364,000 for the best of the 500 iterations to about $454,000 for the worst.

13.1 | 13.2 | 13.3 | 13.4 | 13.5 | 13.6 |13.8