ISYE 6201A,Q: Manufacturing Systems
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Midterm Exam I
March 11, 2014

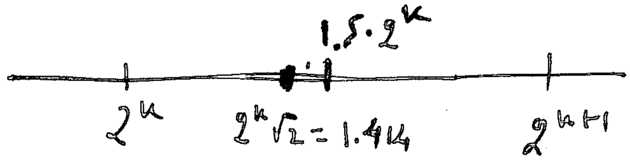
Name: SOLUTIONS

Answer the following questions (**8 points each**):

1. Provide two examples in which a company might decide the location of some of its operations on the basis of the proximity of that location to certain resources that are crucial for the considered operation. Please, explain clearly the reasons that would underlie the company decision.

1) Companies that need to control the transportation cost of their raw materials, like companies that produce various metals and alloys from certain minerals (the "bulk" nature of the raw material can render its transport over long distances cumbersome and expensive)
2) Companies that need to be close to cheap energy sources or logistical infrastructure like ports and airports
3) Companies that need to be close to technological expertise
4) Companies that process perishable products that cannot be carried over long distances
5) etc.

2. In class we showed that by using the thresholds of $\sqrt{2} \cdot 2^k$, $k = 1, 2, \ldots$, in the implementation of the "Powers-of-2-Order-Intervals" heuristic, the worst-case performance with respect to any item in the underlying set will be about a %6 inflation of the corresponding optimal cost. What would be the worst-case performance of this heuristic (defined as in the in-class analysis), w.r.t. any single item, if the employed thresholds were the (exact) middle points of the intervals $(2^k, 2^{k+1})$?



The new threshold can be represented as 1.5×2^k

Since $1.5 \times 2^k > \sqrt{2}\, 2^k \simeq 1.414 \times 2^k$, the worst-case performance for this new scheme will be obtained when $T^* \simeq 1.5 \times 2^k$, approaching from below, and therefore, it has to be replaced by 2^k. Then, using the relevant formula for $r(T)$ with $T = 2^k$, we get:

$$r(2^k) = \frac{1}{2}\left[\frac{2^k}{1.5 \cdot 2^k} + \frac{1.5 \cdot 2^k}{2^k}\right] =$$

$$= \frac{1}{2}\left[\frac{1}{1.5} + 1.5\right] \simeq 1.08\bar{3}$$

Hence, the worst-case cost inflation in this case is about 8.33%.

3. The expected demand (in units) for a certain item at a local distribution center for the next 5 weeks is estimated at: 250, 300, 350, 300, 300. Is it possible that the following ordering plan can ever be optimal: 500, 500, 500, 0, 0?

(a) YES (b) NO

Please, explain your answer.

Consider, for instance, a scenario where there is a ceiling for the provided deliveries of 500 units per period, and furthermore, deliveries become unavailable (or prohibitively expensive) during the last two periods.

Such constraints become even more prominent when one has to take into consideration finite production rates, maintenance plans, etc.

4. Consider an inventory that is controlled according to the basestock policy discussed in class, and with a replenishment lead time of l time units. Furthermore, the observed on-hand inventory at a certain time point t_0 is equal to 5 units, and the observed demand during the next l time units is equal to 10 units. Finally, at time $t_0 + l$, the system experiences a backorder of 3 units. Use the above information in order to determine the basestock level R for the considered policy implementation.

For this model we know the following facts:

1) $\forall t,\quad IP(t) = OHI(t) + O(t) - BO(t) = R$

2) $\forall t,\quad OHI(t) \cdot BO(t) = 0$

3) $\forall t$, $IP(t)$ is the free/uncommitted inventory that we have available in order to meet the demand that will occur during the next l time units

From the above facts and the provided info we have:

a) $BO(t_0) = OHI(t_0 + l) = \emptyset$

b) $IP(t_0) = 5 + O(t_0) = R$

c) $IP(t_0) - 10 = -3 \Rightarrow IP(t_0) = 7$

$$\left.\begin{array}{l} IP(t_0) = 5 + O(t_0) = R \\ IP(t_0) - 10 = -3 \Rightarrow IP(t_0) = 7 \end{array}\right\} \Rightarrow R = 7$$

Remark: The above discussion tries to provide a more complete picture of the considered case, but it should be obvious that, from a strictly technical standpoint, the key equations needed to solve the problem are the following two:

* $IP(t_0) - 10 = -3$
* $IP(t_0) = R$

5. Explain what is meant by the expression that the estimation of the fill rate of a (Q, r) inventory system according to the formula $S(Q, r) = 1 - \frac{1}{Q}B(r)$ is a *"conservative"* estimate.

The notion of "conservatism" here comes from the fact that, since the exact estimator of fill rate for the (Q, r) model is:

$$S(Q,r) = 1 - \frac{1}{Q}\left[B(r) - B(r+Q)\right]$$

$$= 1 - \frac{1}{Q}B(r) + \frac{1}{Q}B(r+Q)$$

and $\frac{1}{Q}B(r+Q) \geq 0$,

the employed approximation underestimates the actual fill rate, and when used to compute the ROP r necessary to meet a target fill rate, it will lead to an over-estimate of this quantity (and a (slightly) higher fill rate than the targeted value).

Problem 1 (30 points): A distribution center has the following two options for the inbound shipping of one of its inventoried items: (a) LTL (less than truckload) shipping at a cost of \$1.00 per unit, or (b) TL (truckload) shipping at the cost of \$400.00 per truck. Trucks can carry up to 1,000 units, and this puts a limit to the order size for both cases. Also, there is a transactional cost of \$100.00 for each order placed with the supplier. The considered item is purchased at the cost of \$50.00 per unit, and the relevant holding cost is estimated according to an annual interest rate of 20%. If the annual demand for this item is estimated at 10,000 units, which shipping option should be chosen by the company?

Option (a) can be "fit" into basic EOQ model with the following parameters:

- $D_1 = 10{,}000$
- $A_1 = 100$
- $c_1 = 50 + 1 = 51$
- $h_1 = 0.2 \cdot c = 0.2 \times 51 = 10.2$
- $\bar{Q}_1 = 1000$

Then,

$$Q_1^* = \sqrt{\frac{2 \cdot A_1 D_1}{h_1}} = \sqrt{\frac{2 \times 100 \times 10000}{10.2}} = 442.81 \simeq 442 < 1000$$

and

$$TAC_1(Q_1^*) = 51 \times 10000 + 100 \frac{10000}{442} + 10.2 \frac{442}{2} =$$

$$= 510{,}000 + 2262.44 + 2254.2 =$$

$$= 514516.64$$

Option (b) corresponds to an EOQ model with the following parameters:

- $D_2 = 10000$
- $A_2 = 100 + 400 = 500$
- $C_2 = 50$
- $h_2 = 0.2 \times 50 = 10$
- $\bar{Q}_2 = 1000$

Then,

$$Q_2^* = \sqrt{\frac{2 \cdot A_2 \cdot D_2}{h_2}} = \sqrt{\frac{2 \times 500 \times 10000}{10}} = 1000 \leq \bar{Q}_2$$

and

$$TAC_2(Q_2^*) = 50 \times 10000 + 500 \frac{10000}{1000} + 10 \frac{1000}{2} =$$

$$= 500000 + 5000 + 5000 = 510{,}000$$

Hence, truck load shipping (option (b)) should be used with an order size of 1000 units (i.e, full truckloads).

Problem 2 (30 points): The local Best Buy store has a policy of ordering a particular cell phone model from Motorola in lots of 500 units. The store weekly demand for these cell phones is normally distributed with a mean of 300 units and a st. deviation of 200 units. Motorola rakes two weeks to supply an order. If the store manager is targeting a fill rate of 99 percent, what safety stock should be carried by the store? What is the corresponding reorder point?

Remark: In your calculations, you can use the approximation $S(Q,r) \approx 1 - \frac{1}{Q}B(r)$ and also refer to the statistical table provided at the end of this booklet.

Assuming independence for the weekly demands (a "default" assumption unless something else is stated), we can see that the demand X_ℓ over a lead time interval is normally distributed with mean $\theta_\ell = 2 \times 300 = 600$ and variance $\sigma_\ell^2 = 2 \cdot 200^2 \Rightarrow \sigma_\ell = \sqrt{2} \cdot 200 \simeq 282.843$.

Then, using the suggested approximation for the fill rate, we have:

$$S(Q,r) \simeq 1 - \frac{1}{Q} B(r) = a \Rightarrow B(r) = (1-a)Q \quad (1)$$

Also, taking into consideration the normality of the lead time demand, (1) becomes:

$$\sigma_\ell \mathcal{L}\left(\frac{r-\theta_\ell}{\sigma_\ell}\right) = (1-a)Q \Rightarrow \mathcal{L}\left(\frac{ss}{\sigma_\ell}\right) = \frac{(1-a)Q}{\sigma_\ell} =$$

$$= \frac{(1-0.99) \cdot 500}{282.843} = 0.0177 \Rightarrow \frac{ss}{282.843} = \mathcal{L}^{-1}(0.0177) =$$

(from the provided tables) $= 1.71 \Rightarrow ss = 282.843 \times 1.71 = 483.66 \simeq 484$

and $r = ss + \theta_\ell = 484 + 600 = 1084$.

TABLE A–4
Normal Probability Distribution and Partial Expectations

Standardized Variate	Probabilities		Partial Expectations	
z	$F(z)$	$1 - F(z)$	$L(z)$	$L(-z)$
.00	.5000	.5000	.3989	.3989
.01	.5040	.4960	.3940	.4040
.02	.5080	.4920	.3890	.4090
.03	.5120	.4880	.3841	.4141
.04	.5160	.4840	.3793	.4193
.05	.5200	.4800	.3744	.4244
.06	.5239	.4761	.3697	.4297
.07	.5279	.4721	.3649	.4349
.08	.5319	.4681	.3602	.4402
.09	.5359	.4641	.3556	.4456
.10	.5398	.4602	.3509	.4509
.11	.5438	.4562	.3464	.4564
.12	.5478	.4522	.3418	.4618
.13	.5517	.4483	.3373	.4673
.14	.5557	.4443	.3328	.4728
.15	.5596	.4404	.3284	.4784
.16	.5636	.4364	.3240	.4840
.17	.5685	.4325	.3197	.4897
.18	.5714	.4286	.3154	.4954
.19	.5753	.4247	.3111	.5011
.20	.5793	.4207	.3069	.5069
.21	.5832	.4168	.3027	.5127
.22	.5871	.4129	.3027	.5186
.23	.5910	.4090	.2944	.5244
.24	.5948	.4052	.2904	.5304
.25	.5987	.4013	.2863	.5363
.26	.6026	.3974	.2824	.5424
.27	.6064	.3936	.2784	.5484
.28	.6103	.3897	.2745	.5545
.29	.6141	.3859	.2706	.5606
.30	.6179	.3821	.2668	.5668
.31	.6217	.3783	.2630	.5730
.32	.6255	.3745	.2592	.5792
.33	.6293	.3707	.2555	.5855
.34	.6331	.3669	.2518	.5918
.35	.6368	.3632	.2481	.5981
.36	.6406	.3594	.2445	.6045
.37	.6443	.3557	.2409	.6109
.38	.6480	.3520	.2374	.6174
.39	.6517	.3483	.2339	.6239
.40	.6554	.3446	.2304	.6304
.41	.6591	.3409	.2270	.6370
.42	.6628	.3372	.2236	.6436
.43	.6664	.3336	.2203	.6503
.44	.6700	.3300	.2169	.6569
.45	.6736	.3264	.2137	.6637
.46	.6772	.3228	.2104	.6704
.47	.6808	.3192	.2072	.6772
.48	.6844	.3156	.2040	.6840
.49	.6879	.3121	.2009	.6909
.50	.6915	.3085	.1978	.6978

TABLE A–4
(continued)

Standardized Variate z	Probabilities $F(z)$	$1 - F(z)$	Partial Expectations $L(z)$	$L(-z)$
.51	.6950	.3050	.1947	.7047
.52	.6985	.3015	.1917	.7117
.53	.7019	.2981	.1887	.7187
.54	.7054	.2946	.1857	.7257
.55	.7088	.2912	.1828	.7328
.56	.7123	.2877	.1799	.7399
.57	.7157	.2843	.1771	.7471
.58	.7190	.2810	.1742	.7542
.59	.7224	.2776	.1714	.7614
.60	.7257	.2743	.1687	.7687
.61	.7291	.2709	.1659	.7759
.62	.7324	.2676	.1633	.7833
.63	.7357	.2643	.1606	.7906
.64	.7389	.2611	.1580	.7980
.65	.7422	.2578	.1554	.8054
.66	.7454	.2546	.1528	.8128
.67	.7486	.2514	.1503	.8203
.68	.7517	.2483	.1478	.8278
.69	.7549	.2451	.1453	.8353
.70	.7580	.2420	.1429	.8429
.71	.7611	.2389	.1405	.8505
.72	.7642	.2358	.1381	.8581
.73	.7673	.2327	.1358	.8658
.74	.7703	.2297	.1334	.8734
.75	.7733	.2267	.1312	.8812
.76	.7764	.2236	.1289	.8889
.77	.7793	.2207	.1267	.8967
.78	.7823	.2177	.1245	.9045
.79	.7852	.2148	.1223	.9123
.80	.7881	.2119	.1202	.9202
.81	.7910	.2090	.1181	.9281
.82	.7939	.2061	.1160	.9360
.83	.7967	.2033	.1140	.9440
.84	.7996	.2004	.1120	.9520
.85	.8023	.1977	.1100	.9600
.86	.8051	.1949	.1080	.9680
.87	.8067	.1922	.1061	.9761
.88	.8106	.1894	.1042	.9842
.89	.8133	.1867	.1023	.9923
.90	.8159	.1841	.1004	1.0004
.91	.8186	.1814	.0986	1.0086
.92	.8212	.1788	.0968	1.0168
.93	.8238	.1762	.0955	1.0250
.94	.8264	.1736	.0953	1.0330
.95	.8289	.1711	.0916	1.0416
.96	.8315	.1685	.0899	1.0499
.97	.8340	.1660	.0882	1.0582
.98	.8365	.1635	.0865	1.0665
.99	.8389	.1611	.0849	1.0749
1.00	.8413	.1587	.0833	1.0833
1.01	.8438	.1562	.0817	1.0917
1.02	.8461	.1539	.0802	1.1002
1.03	.8485	.1515	.0787	1.1087
1.04	.8508	.1492	.0772	1.1172
1.05	.8531	.1469	.0757	1.1257

(continued)

TABLE A–4
(continued)

Standardized Variate	Probabilities		Partial Expectations	
z	$F(z)$	$1 - F(z)$	$L(z)$	$L(-z)$
1.06	.8554	.1446	.0742	1.1342
1.07	.8577	.1423	.0728	1.1428
1.08	.8599	.1401	.0714	1.1514
1.09	.8621	.1379	.0700	1.1600
1.10	.8643	.1357	.0686	1.1686
1.11	.8665	.1335	.0673	1.1773
1.12	.8686	.1314	.0659	1.1859
1.13	.8708	.1292	.0646	1.1946
1.14	.8729	.1271	.0634	1.2034
1.15	.8749	.1251	.0621	1.2121
1.16	.8770	.1230	.0609	1.2209
1.17	.8790	.1210	.0596	1.2296
1.18	.8810	.1190	.0584	1.2384
1.19	.8830	.1170	.0573	1.2473
1.20	.8849	.1151	.0561	1.2561
1.21	.8869	.1131	.0550	1.2650
1.22	.8888	.1112	.0538	1.2738
1.23	.8907	.1093	.0527	1.2827
1.24	.8925	.1075	.0517	1.2917
1.25	.8943	.1057	.0506	1.3006
1.26	.8962	.1038	.0495	1.3095
1.27	.8980	.1020	.0485	1.3185
1.28	.8997	.1003	.0475	1.3275
1.29	.9015	.0985	.0465	1.3365
1.30	.9032	.0968	.0455	1.3455
1.31	.9049	.0951	.0446	1.3446
1.32	.9066	.0934	.0436	1.3636
1.33	.9082	.0918	.0427	1.3727
1.34	.9099	.0901	.0418	1.3818
1.35	.9115	.0885	.0409	1.3909
1.36	.9131	.0869	.0400	1.4000
1.37	.9147	.0853	.0392	1.4092
1.38	.9162	.0838	.0383	1.4183
1.39	.9177	.0823	.0375	1.4275
1.40	.9192	.0808	.0367	1.4367
1.41	.9207	.0793	.0359	1.4459
1.42	.9222	.0778	.0351	1.4551
1.43	.9236	.0764	.0343	1.4643
1.44	.9251	.0749	.0336	1.4736
1.45	.9265	.0735	.0328	1.4828
1.46	.9279	.0721	.0321	1.4921
1.47	.9292	.0708	.0314	1.5014
1.48	.9306	.0694	.0307	1.5107
1.49	.9319	.0681	.0300	1.5200
1.50	.9332	.0668	.0293	1.5293
1.51	.9345	.0655	.0286	1.5386
1.52	.9357	.0643	.0280	1.5480
1.53	.9370	.0630	.0274	1.5574
1.54	.9382	.0618	.0267	1.5667
1.55	.9394	.0606	.0261	1.5761
1.56	.9406	.0594	.0255	1.5855
1.57	.9418	.0582	.0249	1.5949
1.58	.9429	.0571	.0244	1.6044
1.59	.9441	.0559	.0238	1.6138

TABLE A–4
(continued)

Standardized Variate z	Probabilities $F(z)$	$1 - F(z)$	Partial Expectations $L(z)$	$L(-z)$
1.60	.9460	.0540	.0232	1.6232
1.61	.9463	.0537	.0227	1.6327
1.62	.9474	.0526	.0222	1.6422
1.63	.9484	.0516	.0216	1.6516
1.64	.9495	.0505	.0211	1.6611
1.65	.9505	.0495	.0206	1.6706
1.66	.9515	.0485	.0201	1.6801
1.67	.9525	.0475	.0197	1.6897
1.68	.9535	.0465	.0192	1.6992
1.69	.9545	.0455	.0187	1.7087
1.70	.9554	.0446	.0183	1.7183
1.71	.9564	.0436	.0178	1.7278
1.72	.9573	.0427	.0174	1.7374
1.73	.9582	.0418	.0170	1.7470
1.74	.9591	.0409	.0166	1.7566
1.75	.9599	.0401	.0162	1.7662
1.76	.9608	.0392	.0158	1.7558
1.77	.9616	.0384	.0154	1.7854
1.78	.9625	.0375	.0150	1.7950
1.79	.9633	.0367	.0146	1.8046
1.80	.9641	.0359	.0143	1.8143
1.81	.9649	.0351	.0139	1.8239
1.82	.9656	.0344	.0136	1.8436
1.83	.9664	.0336	.0132	1.8432
1.84	.9671	.0329	.0129	1.8529
1.85	.9678	.0322	.0126	1.8626
1.86	.9685	.0314	.0123	1.8723
1.87	.9693	.0307	.0119	1.8819
1.88	.9699	.0301	.0116	1.8916
1.89	.9706	.0294	.0113	1.9013
1.90	.9713	.0287	.0111	1.9111
1.91	.9719	.0281	.0108	1.9208
1.92	.9726	.0274	.0105	1.9305
1.93	.9732	.0268	.0102	1.9402
1.94	.9738	.0262	.0100	1.9500
1.95	.9744	.0256	.0097	1.9597
1.96	.9750	.0250	.0094	1.9694
1.97	.9756	.0244	.0092	1.9792
1.98	.9761	.0239	.0090	1.9890
1.99	.9767	.0233	.0087	1.9987
2.00	.9772	.0228	.0085	2.0085
2.01	.9778	.0222	.0083	2.0183
2.02	.9783	.0217	.0080	2.0280
2.03	.9788	.0212	.0078	2.0378
2.04	.9793	.0207	.0076	2.0476
2.05	.9798	.0202	.0074	2.0574
2.06	.9803	.0197	.0072	2.0672
2.07	.9808	.0192	.0072	2.0770
2.08	.9812	.0188	.0068	2.0868
2.09	.9817	.0183	.0066	2.0966
2.10	.9821	.0179	.0065	2.1065
2.11	.9826	.0174	.0063	2.1163
2.12	.9830	.0170	.0061	2.1261
2.13	.9834	.0166	.0060	2.1360
2.14	.9838	.0162	.0058	2.1458

(continued)

TABLE A–4
(continued)

Standardized Variate z	Probabilities $F(z)$	Probabilities $1 - F(z)$	Partial Expectations $L(z)$	Partial Expectations $L(-z)$
2.15	.9842	.0158	.0056	2.1556
2.16	.9846	.0154	.0055	2.1655
2.17	.9850	.0150	.0053	2.1753
2.18	.9854	.0146	.0052	2.1852
2.19	.9857	.0143	.0050	2.1950
2.20	.9861	.0139	.0049	2.2049
2.21	.9864	.0136	.0048	2.2148
2.22	.9868	.0132	.0046	2.2246
2.23	.9871	.0129	.0045	2.2345
2.24	.9875	.0125	.0044	2.2444
2.25	.9878	.0122	.0042	2.2542
2.26	.9881	.0119	.0041	2.2641
2.27	.9884	.0116	.0040	2.2740
2.28	.9887	.0113	.0039	2.2839
2.29	.9890	.0110	.0038	2.2938
2.30	.9893	.0107	.0037	2.3037
2.31	.9896	.0104	.0036	2.3136
2.32	.9898	.0102	.0035	2.3235
2.33	.9901	.0099	.0034	2.3334
2.34	.9904	.0096	.0033	2.3433
2.35	.9906	.0094	.0032	2.3532
2.36	.9909	.0091	.0031	2.3631
2.37	.9911	.0089	.0030	2.3730
2.38	.9913	.0087	.0029	2.3829
2.39	.9916	.0084	.0028	2.3928
2.40	.9918	.0082	.0027	2.4027
2.41	.9920	.0080	.0026	2.4126
2.42	.9922	.0078	.0026	2.4226
2.43	.9925	.0075	.0025	2.4325
2.44	.9927	.0073	.0024	2.4424
2.45	.9929	.0071	.0023	2.4523
2.46	.9931	.0069	.0023	2.4623
2.47	.9932	.0068	.0022	2.4722
2.48	.9934	.0066	.0021	2.4821
2.49	.9936	.0064	.0021	2.4921
2.50	.9938	.0062	.0020	2.5020
2.51	.9940	.0060	.0019	2.5119
2.52	.9941	.0059	.0019	2.5219
2.53	.9943	.0057	.0018	2.5318
2.54	.9945	.0055	.0018	2.5418
2.55	.9946	.0054	.0017	2.5517
2.56	.9948	.0052	.0017	2.5617
2.57	.9949	.0051	.0016	2.5716
2.58	.9951	.0049	.0016	2.5816
2.59	.9952	.0048	.0015	2.5915
2.60	.9953	.0047	.0015	2.6015
2.61	.9955	.0045	.0014	2.6114
2.62	.9956	.0044	.0014	2.6214
2.63	.9957	.0043	.0013	2.6313
2.64	.9959	.0041	.0013	2.6413
2.65	.9960	.0040	.0012	2.6512
2.66	.9961	.0039	.0012	2.6612
2.67	.9962	.0038	.0012	2.6712
2.68	.9963	.0037	.0011	2.6811
2.69	.9964	.0036	.0011	2.6911
2.70	.9965	.0035	.0011	2.7011

TABLE A–4
(concluded)

Standardized Variate z	Probabilities		Partial Expectations	
	$F(z)$	$1 - F(z)$	$L(z)$	$L(-z)$
2.71	.9966	.0034	.0010	2.7110
2.72	.9967	.0033	.0010	2.7210
2.73	.9968	.0032	.0010	2.7310
2.74	.9969	.0031	.0009	2.7409
2.75	.9970	.0030	.0009	2.7509
2.76	.9971	.0029	.0009	2.7609
2.77	.9972	.0028	.0008	2.7708
2.78	.9973	.0027	.0008	2.7808
2.79	.9974	.0026	.0008	2.7908
2.80	.9974	.0026	.0008	2.8008
2.81	.9975	.0025	.0007	2.8107
2.82	.9976	.0024	.0007	2.8207
2.83	.9977	.0023	.0007	2.8307
2.84	.9977	.0023	.0007	2.8407
2.85	.9978	.0022	.0006	2.8506
2.86	.9979	.0021	.0006	2.8606
2.87	.9979	.0021	.0006	2.8706
2.88	.9980	.0020	.0006	2.8806
2.89	.9981	.0019	.0006	2.8906
2.90	.9981	.0019	.0005	2.9005
2.91	.9982	.0018	.0005	2.9105
2.92	.9982	.0018	.0005	2.9205
2.93	.9983	.0017	.0005	2.9305
2.94	.9984	.0016	.0005	2.9405
2.95	.9984	.0016	.0005	2.9505
2.96	.9985	.0015	.0004	2.9604
2.97	.9985	.0015	.0004	2.9704
2.98	.9986	.0014	.0004	2.9804
2.99	.9986	.0014	.0004	2.9904
3.00	.9986	.0014	.0004	3.0004

Source: R. G. Brown, *Decision Rules for Inventory Management* (Hinsdale, IL.: Dryden, 1967). Adapted from Table VI, pp. 95–103.