Matching Supply with Demand

An Introduction to
Operations Management

Appendix E

Solutions to Selected Practice Problems

This appendix provides solutions to marked (*) practice problems.

Chapter 2

Q2.1 (Dell)

The following steps refer directly to Exhibit 2.1.

Step 1. For 2001, we find in Dell's 10-k: Inventory = $400 (in millions)

Step 2. For 2001, we find in Dell's 10-k: COGS = $26,442 (in millions)

Step 3. Inventory turns $= \dfrac{\$26{,}442/\text{Year}}{\$400} = 66.105$ turns per year

Step 4. Per-unit inventory cost $= \dfrac{40\%\text{ per year}}{66.105\text{ per year}} = 0.605$ percent per unit

Chapter 3

Q3.1 (Process Analysis with One Flow Unit)

The following steps refer directly to Exhibit 3.1.

Step 1. We first compute the capacity of the three resources:

Resource 1: $\dfrac{2}{10}$ unit per minute = 0.2 unit per minute

Resource 2: $\dfrac{1}{6}$ unit per minute = 0.1666 unit per minute

Resource 3: $\dfrac{3}{16}$ unit per minute = 0.1875 unit per minute

Step 2. Resource 2 has the lowest capacity; process capacity therefore is 0.1666 unit per minute, which is equal to 10 units per hour.

Step 3. Flow rate = Min{Process capacity, Demand}

= Min{8 units per hour, 10 units per hour} = 8 units per hour

This is equal to 0.1333 unit per minute.

Step 4. We find the utilizations of the three resources as

Resource 1: 0.1333 unit per minute/0.2 unit per minute = 66.66 percent
Resource 2: 0.1333 unit per minute/0.1666 unit per minute = 80 percent
Resource 3: 0.1333 unit per minute/0.1875 unit per minute = 71.11 percent

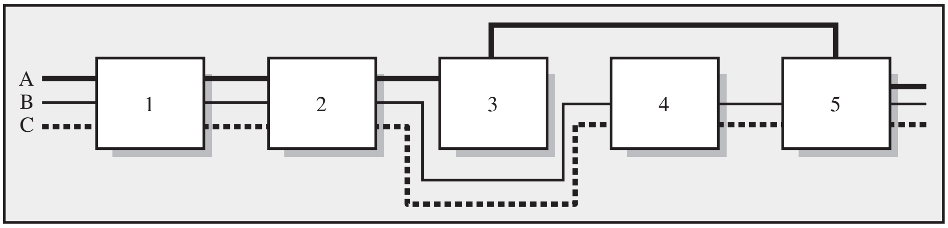
Q3.2 (Process Analysis with Multiple Flow Units)

The following steps refer directly to Exhibit 3.2.

Step 1. Each resource can contribute the following capacity (in minutes of work per day):

Resource	Number of Workers	Minutes per Day
1	2	$2 \times 8 \times 60 = 960$
2	2	$2 \times 8 \times 60 = 960$
3	1	$1 \times 8 \times 60 = 480$
4	1	$1 \times 8 \times 60 = 480$
5	2	$2 \times 8 \times 60 = 960$

Step 2. Process flow diagram:



Step 3. We create a table indicating how much capacity will be consumed by the three products at the resources.

Resource	Capacity Requirement from A	Capacity Requirement from B	Capacity Requirement from C
1	$5 \times 40 = 200$	$5 \times 50 = 250$	$5 \times 60 = 300$
2	$3 \times 40 = 120$	$4 \times 50 = 200$	$5 \times 60 = 300$
3	$15 \times 40 = 600$	$0 \times 50 = 0$	$0 \times 60 = 0$
4	$0 \times 40 = 0$	$3 \times 50 = 150$	$3 \times 60 = 180$
5	$6 \times 40 = 240$	$6 \times 50 = 300$	$6 \times 60 = 360$

Step 4. Add up the rows to get the workload for each resource:

Workload for resource 1: 200 + 250 + 300 = 750

Workload for resource 2: 120 + 200 + 300 = 620

Workload for resource 3: 600 + 0 + 0 = 600

Workload for resource 4: 0 + 150 + 180 = 330

Workload for resource 5: 240 + 300 + 360 = 900

Resource	Minutes per Day (see Step 1)	Workload per Day (see Step 4)	Implied Utilization (Step 4/Step 1)
1	960	750	0.78
2	960	620	0.65
3	480	600	1.25
4	480	330	0.69
5	960	900	0.94

Step 5. Compute implied utilization levels. Hence, resource 3 is the bottleneck. Thus, we cannot produce units A at a rate of 40 units per day. Since we are overutilized by 25 percent, we can produce units A at a rate of 32 units per day (four units per hour). Assuming the ratio between A, B, and C is constant (40:50:60), we will produce B at five units per hour and C at six units per hour. If the ratio between A, B, and C is *not* constant, this answer changes. In this case, we would produce 32 units of A and produce products B and C at the rate of demand (50 and 60 units per day, respectively).

Chapter 4

Q4.1 (Empty System, Labor Utilization)

Part a

The following computations are based on Exhibit 4.1 in the book. Time to complete 100 units:

Step 1. The process will take 10 + 6 + 16 minutes = 32 minutes to produce the first unit.

Step 2. Resource 2 is the bottleneck and the process capacity is 0.1666 unit per minute.

Step 3. Time to finish 100 units $= 32 \text{ minutes} + \dfrac{99 \text{ units}}{0.166 \text{ unit/minute}} = 626 \text{ minutes}$

Parts b, c, and d

We answer these three questions together by using Exhibit 4.2 in the book.

Step 1. Capacities are

$$\text{Resource 1: } \frac{2}{10}\text{unit/minute} = 0.2 \text{ unit/minute}$$

$$\text{Resource 2: } \frac{1}{6}\text{unit/minute} = 0.1666 \text{ unit/minute}$$

$$\text{Resource 3: } \frac{3}{16}\text{unit/minute} = 0.1875 \text{ unit/minute}$$

Resource 2 is the bottleneck and the process capacity is 0.1666 unit/minute.

Step 2. Since there is unlimited demand, the flow rate is determined by the capacity and therefore is 0.1666 unit/minute; this corresponds to a cycle time of 6 minutes/unit.

Step 3. Cost of direct labor $= \dfrac{6 \times \$10/\text{hour}}{60 \text{ minutes/hour} \times 0.1666 \text{ unit/minute}} = \$6/\text{unit}$

Step 4. Compute the idle time of each worker for each unit:

$$\begin{aligned}\text{Idle time for workers at resource 1} &= 6 \text{ minutes/unit} \times 2 - 10 \text{ minutes/unit} \\ &= 2 \text{ minutes/unit}\end{aligned}$$

$$\begin{aligned}\text{Idle time for worker at resource 2} &= 6 \text{ minutes/unit} \times 1 - 6 \text{ minutes/unit} \\ &= 0 \text{ minutes/unit}\end{aligned}$$

$$\begin{aligned}\text{Idle time for workers at resource 3} &= 6 \text{ minutes/unit} \times 3 - 16 \text{ minutes/unit} \\ &= 2 \text{ minutes/unit}\end{aligned}$$

Step 5. Labor content = 10 + 6 + 16 minutes/unit = 32 minutes/unit

Step 6. Average labor utilization $= \frac{32}{32 + 4} = 0.8888$

Chapter 5

Q5.1 (Window Boxes)

The following computations are based on Exhibit 5.1.

Part a

Step 1. Since there is sufficient demand, the step (other than the stamping machine) that determines flow rate is assembly. Capacity at assembly is $\frac{12}{27}$ unit/minute.

Step 2. The production cycle consists of the following parts:

- Setup for A (120 minutes).
- Produce parts A (360 × 1 minute).
- Setup for B (120 minutes).
- Produce parts B (720 × 0.5 minute).

Step 3. There are two setups in the production cycle, so the setup time is 240 minutes.

Step 4. Every completed window box requires one part A (one minute per unit) and two parts B (2 × 0.5 minute per unit). Thus, the per-unit activity time is two minutes per unit.

Step 5. Use formula

$$\begin{aligned}\text{Capacity given batch size} &= \frac{360 \text{ units}}{240 \text{ minutes} + 360 \text{ units} \times 2 \text{ minutes/unit}} \\ &= 0.375 \text{ unit/minute}\end{aligned}$$

Step 6. Capacity at stamping for a general batch size is

$$\frac{\text{Batch size}}{240 \text{ minutes} + \text{Batch size} \times 2 \text{ minutes/unit}}$$

We need to solve the equation

$$\frac{\text{Batch size}}{240 \text{ minutes} + \text{Batch size} \times 2 \text{ minutes/unit}} = \frac{12}{27}$$

for the batch size. The batch size solving this equation is Batch size = 960. We can obtain the same number directly by using

$$\text{Recommended batch size} = \frac{\text{Flow rate} \times \text{Setup time}}{1 - \text{Flow rate} \times \text{Time per unit}} = \frac{\frac{12}{27} \times 240}{1 - \frac{12}{27} \times 2} = 960$$

Q5.10 (Cat Food)

$$\frac{7 \times 500}{EOQ} = 1.62$$

Part a

Holding costs are \$0.50 × 15%/50 = 0.0015 per can per week. Note, each can is purchased for \$0.50, so that is the value tied up in inventory and therefore determines the holding cost. The EOQ is then

Part b

The ordering cost is \$7 per order. The number of orders per year is 500/EOQ. Thus, order cost = \$/week = \$81/year.

Part c

The average inventory level is EOQ/2. Inventory costs per week are thus 0.5 × EOQ × 0.0015 = \$1.62. Given 50 weeks per year, the inventory cost per year is \$81

Part d

Inventory Turns = Flow rate/Inventory

Flow Rate = 500 cans per week

Inventory = 0.5 3 EOQ

Thus, Inventory Turns = *R*/(0.5×EOQ) = 0.462 turns per week = 23.14 turns per year

Q5.11 (Beer Distributor)

The holding costs are 25% per year = 0.5% per week = 8*0.005 = \$0.04 per week

(a) $\text{EOQ} = \sqrt{\frac{2 \times 100 \times 10}{0.04}} = 223.6$

(b) Inventory turns = Flow Rate/Inventory = 100 × 50/(0.5 × EOQ) = 5000/EOQ = 44.7 turns per year

(c) $\text{Per unit inventory cost} = \sqrt{\frac{2 \times 0.04 \times 10}{100}} = 0.089\$/unit$

(d) You would never order more than Q = 600.

For Q = 600, we would get the following costs: 0.5 × 600 × 0.04 × 0.95 + 10 × 100/600 = 13.1.

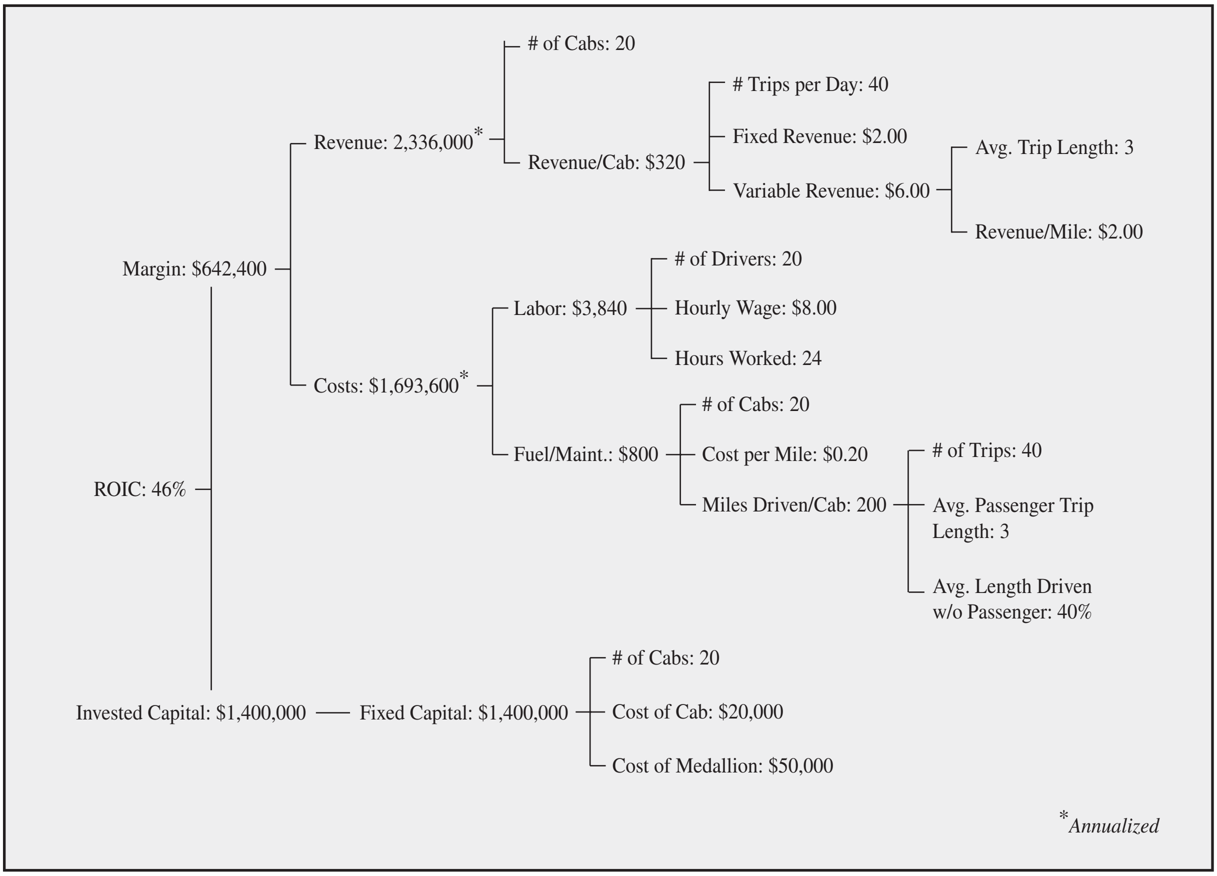
The cost per unit would be 13.1/100 = \$0.131.

The quantity discount would save us 5%, which is \$0.40 per case. However, our operating costs increase by \$0.131 − 0.089 = \$0.042. Hence, the savings outweigh the cost increase and it is better to order 600 units at a time.

Chapter 6

Q6.1 (Crazy Cab)

Part a/b
ROIC Tree:



Part c

There are several variables that could be classified as operational value drivers including the number of trips per day, the average trip length, the drivers' hourly wage, and the average distance driven without passengers. Other variables such as the revenue per passenger mile, the fixed fees and the maintenance/fuel cost per mile driven are harder for management to influence because they are either regulated through the cab medallions or are strongly influenced by fuel prices (management could, however, invest in more fuel-efficient cars to reduce this cost).

Given the high capital investments associated with purchasing a cab and medallion, as well as the fixed labor requirements, it is important that each cab maximizes its revenue. An additional trip is almost pure profit, particularly if it replaces idle driving time between passengers.

Part d

$$\begin{aligned}\text{Labor Efficiency} &= \text{Revenue/Labor Costs}\\ &= \text{Revenue/Mile} \times \text{Mile/Trip} \times \text{Trips/Day} \times \text{Day/Labor Costs}\end{aligned}$$

In this equation, the first ratio measures the company's operational yield, which is largely a reflection of the company's pricing power. The next two ratios are measures of efficiency: the length of each trip and the number of daily trips, respectively. The final ratio is a measure of the cost of a resource, in this instance the company's labor costs.

A similar equation can be evaluated to determine the efficiency of each cab within the fleet:

$$\begin{aligned}\text{Cab Efficiency} &= \text{Revenue/Cab}\\ &= \text{Revenue/Mile} \times \text{Mile/Trip} \times \text{Trips/Cab}\end{aligned}$$

Chapter 9

Q9.1 (Online Retailer)

Part a

We use Exhibit 9.1 for our computations.

Step 1. We collect the basic ingredients for the waiting time formula:

Activity time = 4 minutes

$$\text{CV}_p = \frac{2}{4}$$

Interarrival time = 2 minutes
$\text{CV}_a = 1$
Number of resources = 3

Step 2. This allows us to compute utilization as

$$p/am = 4/(2 \times 3) = 0.6666$$

Step 3. We then use the waiting time formula

$$T_q \approx \left(\frac{4}{3}\right) \times \left(\frac{0.666^{\sqrt{2(3+1)}-1}}{1 - 0.6666}\right) \times \left(\frac{1^2 + 0.5^2}{2}\right) = 1.19\,\text{minutes}$$

Step 4. We find the

Inventory in service: $I_p = m \times u = 3 \times 0.666 = 2$
Inventory in the queue: $I_q = T_q/a = 1.19/2 = 0.596$
Inventory in the system: $I = I_p + I_q = 2.596$

Part b

The number of e-mails that have been received but not yet answered corresponds to the total inventory of e-mails. We find this to be 2.596 e-mails (see Step 4 above).

Chapter 10

Q10.1 (Loss System)

We use Exhibit 10.1 to answer parts a through c.

Step 1. The interarrival time is 60 minutes per hour divided by 55 units arriving per hour, which is an interarrival time of $a = 1.0909$ minutes/unit. The processing time is $p = 6$ minutes/unit; this allows us to compute $r = p/a = 6/1.0909 = 5.5$.

Step 2. With $r = 5.5$ and $m = 7$, we can use the Erlang Loss Formula Table to look up $P_7(5.5)$ as 0.1525. Alternatively, we can use the actual loss formula (see Appendix C) to compute the probability that all seven servers are utilized:

$$\text{Prob}\{\text{all 7 servers are busy}\} = P_7(5.5) = \frac{\dfrac{5.5^7}{7!}}{1 + \dfrac{5.5^1}{1!} + \dfrac{5.5^2}{2!} + \cdots + \dfrac{5.5^7}{7!}} = 0.1525$$

Step 3. Compute the flow rate: $R = 1/a \times (1 - P_m) = 1/1.0909 \times (1 - 0.153) = 0.77$ unit per minute or 46.585 units per hour.

Step 4. Compute lost customers:

$$\text{Customers lost} = 1/a \times P_m = 1/1.0909 \times 0.153 = 0.14 \text{ unit per minute}$$

which corresponds to 8.415 units per hour.

Thus, from the 55 units that arrive every hour, 46.585 will be served and 8.415 will be lost.

Chapter 12

Q12.1 (Venture Fair)

Part a

Dependency Matrix:

			Information-Providing Activity (Upstream)										
			1	2	3	4	5	6	7	8	9	10	11
	1	Ideation											
	2	Interview Customers	X										
	3	Analyze Competing Products	X										
Information-Receiving Activity (Downstream)	4	User/Customer Observation		X									
	5	Send E-Mail Surveys		X									
	6	Target Specifications			X	X	X						
	7	Product Design						X					
	8	Get Price Quotes							X				
	9	Build Prototype							X				
	10	Test Prototype with Customers									X		
	11	Prepare Info for Venture Fair								X		X	
		Activity / Days	1 / 3	2 / 6	3 / 12	4 / 10	5 / 4	6 / 5	7 / 10	8 / 6	9 / 4	10 / 5	11 / 3

Part b

The critical path is A1→A2→A4→A6→A7→A9→A10→A11, which has a total duration of 3 + 6 + 10 + 5 + 10 + 4 + 5 + 3 = 46. If the project team must have the materials finished by the day before the project fair (April 17th), then they must begin no later than March 3rd (29 days of work in March and 17 days in April).

Chapter 14

Q14.1 (McClure Books)

Part a

We first find the z-statistic for 400 (Dan's blockbuster threshold): $z = (400 - 200)/80 = 2.50$. From the Standard Normal Distribution Function Table, we see that $\Phi(2.50) = 0.9938$. So there is a 99.38 percent chance demand is 400 or fewer. Demand is greater than 400 with probability $1 - \Phi(2.50) = 0.0062$; that is, there is only a 0.62 percent chance this is a blockbuster.

Part b

We first find the z-statistic for 100 units (Dan's dog threshold): $z = (100 - 200)/80 = -1.25$. From the Standard Normal Distribution Function Table, we see that $\Phi(-1.25) = 0.1056$. So there is a 10.56 percent chance demand is 100 or fewer; that is, there is a 10.56 percent chance this book is a dog.

Part c

Demand is within 20 percent of the mean if it is between $1.2 \times 200 = 240$ and $0.8 \times 200 = 160$. Using Exhibit 14.2, we first find the z-statistic for 240 units (the upper limit on that range): $z = (240 - 200)/80 = 0.5$. From the Standard Normal Distribution Function Table, we see that $\Phi(0.5) = 0.6915$. Repeat the process for the lower limit on the range: $z = (160 - 200)/80 = -0.5$ and $\Phi(-0.5) = 0.3085$. The probability demand is between 160 and 240 is $\Phi(0.5) - \Phi(-0.50) = 0.6915 - 0.3085 = 0.3830$; that is, 38.3 percent.

Part d

The underage cost is $C_u = 20 - 12 = 8$. The salvage value is $12 - 4 = 8$ because Dan can return leftover books for a full refund ($12) but incurs a $4 cost of shipping and handling. Thus, the overage cost is cost minus salvage value: $C_o = 12 - 8 = 4$. The critical ratio is $C_u/(C_o + C_u) = 8/12 = 0.6667$. In the Standard Normal Distribution Function Table, we see that $\Phi(0.43) = 0.6664$ and $\Phi(0.44) = 0.6700$, so use the round-up rule and choose $z = 0.44$. Now convert z into the order quantity for the actual demand distribution: $Q = \mu + z \times \sigma = 200 + 0.44 \times 80 = 235.2$.

Part e

We want to find a z such that $\Phi(z) = 0.95$. In the Standard Normal Distribution Function Table, we see that $\Phi(1.64) = 0.9495$ and $\Phi(1.65) = 0.9505$, so use actual $200 + 1.65 \times 80 = 332$.

Part f

If the in-stock probability is 95 percent, then the stockout probability (which is what we are looking for) is 1 minus the in-stock, that is, $1 - 95\% = 5$ percent.

Part g

The z-statistic for 300 units is $z = (300 - 200)/80 = 1.25$. From the Standard Normal Loss Function Table, we see that $L(1.25) = 0.0506$. Expected lost sales are $\sigma \times L(1.25) = 4.05$. Expected sales are $200 - 4.05 = 195.95$, expected leftover inventory is $300 - 195.95 = 104.05$, and

$$\begin{aligned}\text{Expected profit} &= (\text{Price} - \text{Cost}) \times \text{Expected sales} \\ &\quad - (\text{Cost} - \text{Salvage value}) \times \text{Expected leftover inventory} \\ &= (20 - 12) \times 195.95 - (12 - 8) \times 104.05 \\ &= 1151.4\end{aligned}$$

Q14.2 (EcoTable Tea)

Part a

We need to evaluate the stockout probability with $Q = 3$. From the Poisson Distribution Function Table, $F(3) = 0.34230$. The stockout probability is $1 - F(3) = 65.8$ percent.

Part b

They will need to mark down three or more baskets if demand is seven or fewer. From the Poisson Distribution Function Table, $F(7) = 0.91341$, so there is a 91.3 percent probability this will occur.

Part c

First evaluate their critical ratio. The underage cost (or cost of a lost sale) is \$55 – \$32 = \$23. The overage cost (or the cost of having a unit left in inventory) is \$32 – \$20 = \$12. The critical ratio is $C_u/(C_o + C_u) = 0.6571$. From the Poisson Distribution Function Table, with a mean of 4.5, we see that $F(4) = 0.53210$ and $F(5) = 0.70293$, so we apply the round-up rule and order five baskets.

Part d

With four baskets, expected lost sales is 1.08808, according to the Poisson Loss Function Table. Expected sales is then $4.5 - 1.08808 = 3.4$.

Part e

With six baskets, expected lost sales is 0.32312, according to the Poisson Loss Function Table. Expected sales is then $4.5 - 0.32312 = 4.17688$. Expected leftover inventory is then $6 - 4.17688 = 1.72312 \approx 1.8$.

Part f

From the Poisson Distribution Function Table, $F(6) = 0.83105$ and $F(7) = 0.91314$. Hence, order seven baskets to achieve at least a 90 percent in-stock probability (in fact, the in-stock probability will be 91.3 percent).

Part g

If they order eight baskets, then expected lost sales is 0.06758. Expected sales is $4.5 - 0.06758 = 4.43242$. Expected leftover inventory is $8 - 4.43242 = 3.56758$. Profit is then $\$23 \times 4.43242 - \$12 \times 3.56758 = \$59.13$.

Q14.3 (Pony Express Creations)

Part a

If they purchase 40,000 units, then they need to liquidate 10,000 or more units if demand is 30,000 units or lower. From the table provided, $F(30{,}000) = 0.7852$, so there is a 78.52 percent chance they need to liquidate 10,000 or more units.

Part b

The underage cost is $C_u = 12 - 6 = 6$, the overage cost is $C_o = 6 - 2.5 = 3.5$, and the critical ratio is $6/(3.5 + 6) = 0.6316$. Looking in the demand forecast table, we see that $F(25{,}000) = 0.6289$ and $F(30{,}000) = 0.7852$, so use the round-up rule and order 30,000 Elvis wigs.

Part c

We want to find a Q such that $F(Q) = 0.90$. From the demand forecast table, we see that $F(35{,}000) = 0.8894$ and $F(40{,}000) = 0.9489$, so use the round-up rule and order 40,000 Elvis wigs. The actual in-stock probability is then 94.89 percent.

Part d

If $Q = 50{,}000$, then expected lost sales from the table are only 61 units. Expected leftover inventory $= Q - \mu +$ Expected lost sales $= 50{,}000 - 25{,}000 + 61 = 25{,}061$.

Part e

A 100 percent in-stock probability requires an order quantity of 75,000 units. With $Q = 75{,}000$, then expected lost sales from the table are only two units. Use Exhibit 14.5 to evaluate expected sales, expected leftover inventory, and expected profit. Expected sales are expected demand minus expected lost sales = 25,000 – 2 = 24,998. Expected leftover inventory is 75,000 – 24,998 = 50,002.

$$\begin{aligned}\text{Expected profit} &= (\text{Price} - \text{Cost}) \times \text{Expected sales} \\ &\quad - (\text{Cost} - \text{Salvage value}) \times \text{Expected leftover inventory} \\ &= (12 - 6) \times 24{,}998 - (6 - 2.5) \times 50{,}002 \\ &= -25{,}019\end{aligned}$$

So a 100 percent in-stock probability is a money-losing proposition.

Q14.4 (Flextrola)

Part a

It is within 25 percent of the forecast if it is greater than 750 and less than 1,250. Use Exhibit 14.2. The z-statistic for 750 is $z = (750 - 1{,}000)/600 = -0.42$ and the z-statistic for 1,250 is $z = (1{,}250 - 1{,}000)/600 = 0.42$. From the Standard Normal Distribution Function Table, we see that $\Phi(-0.42) = 0.3372$ and $\Phi(0.42) = 0.6628$. So there is a 33.72 percent chance demand is less than 750 and a 66.28 percent chance it is less than 1,250. The chance it is between 750 and 1,250 is the difference in those probabilities: 0.6628 – 0.3372 = 0.3256.

Part b

The forecast is for 1,000 units. Demand is greater than 40 percent of the forecast if demand exceeds 1,400 units. Use Exhibit 14.2. Find the z-statistic that corresponds to 1,400 units:

$$z = \frac{Q - \mu}{\sigma} = \frac{1{,}400 - 1{,}000}{600} = 0.67$$

From the Standard Normal Distribution Function Table, $\Phi(0.67) = 0.7486$. Therefore, there is almost a 75 percent probability that demand is less than 1,400 units. The probability that demand is greater than 1,400 units is $1 - \Phi(0.67) = 0.2514$, or about 25 percent.

Part c

To find the expected profit-maximizing order quantity, first identify the underage and overage costs. The underage cost is $C_u = 121 - 72 = 49$ because each lost sale costs Flextrola its gross margin. The overage cost is $C_o = 72 - 50 = 22$ because each unit of leftover inventory can only be sold for \$50. Now evaluate the critical ratio:

$$\frac{C_u}{C_o + C_u} = \frac{49}{22 + 49} = 0.6901$$

Look up the critical ratio in the Standard Normal Distribution Function Table: $\Phi(0.49) = 0.6879$ and $\Phi(0.50) = 0.6915$, so choose $z = 0.50$. Now convert the z-statistic into an order quantity: $Q = \mu + z \times \sigma = 1{,}000 + 0.5 \times 600 = 1{,}300$.

Part d

Use Exhibit 14.4 to evaluate expected lost sales and then Exhibit 14.5 to evaluate expected sales. If $Q = 1{,}200$, then the corresponding z-statistic is $z = (Q - \mu)/\sigma = (1{,}200 - 1{,}000)/600 = 0.33$. From the Standard Normal Distribution Loss Table, we see that $L(0.33) = 0.2555$. Expected lost sales are then $\sigma \times L(z) = 600 \times 0.2555 = 153.3$. Finally, recall that expected sales equal expected demand minus expected lost sales: Expected sales $= 1{,}000 - 153.3 = 846.7$.

Part e

Flextrola sells its leftover inventory in the secondary market, which equals Q minus expected sales $1{,}200 - 846.7 = 353.3$.

Part f

To evaluate the expected gross margin percentage, we begin with

$$\begin{aligned}
\text{Expected revenue} &= (\text{Price} \times \text{Expected sales}) \\
&\quad + (\text{Salvage value} \times \text{Expected leftover inventory}) \\
&= (121 \times 846.7) + (50 \times 353.3) \\
&= 120{,}116
\end{aligned}$$

Then we evaluate expected cost $= Q \times c = 1{,}200 \times 72 = 86{,}400$. Finally, expected gross margin percentage $= 1 - 86{,}400/120{,}116 = 28.1$ percent.

Part g

Use Exhibit 14.5 and the results from parts d and e to evaluate expected profit:

$$\begin{aligned}
\text{Expected profit} &= (\text{Price} - \text{Cost}) \times \text{Expected sales} \\
&\quad - (\text{Cost} - \text{Salvage value}) \times \text{Expected leftover inventory} \\
&= (121 - 72) \times 846.7 - (72 - 50) \times 353.3 \\
&= 33{,}716
\end{aligned}$$

Part h

Solectric's expected profit is $1{,}200 \times (72 - 52) = 24{,}000$ because units are sold to Flextrola for \$72 and each unit has a production cost of \$52.

Part i

Flextrola incurs 400 or more units of lost sales if demand exceeds the order quantity by 400 or more units; that is, if demand is 1,600 units or greater. The z-statistic that corresponds to 1,600 is $z = (Q - \mu)/\sigma = (1{,}600 - 1{,}000)/600 = 1$. In the Standard Normal Distribution Function Table, $\Phi(1) = 0.8413$. Demand exceeds 1,600 with the probability $1 - \Phi(1) =$ 15.9 percent.

Part j

The critical ratio is 0.6901. From the graph of the distribution function, we see that the probability demand is less than 1,150 with the log normal distribution about 0.70. Hence, the optimal order quantity with the log normal distribution is about 1,150 units.

Q14.5 (Fashionables)

Part a

The underage cost is $C_u = 70 - 40 = 30$ and the overage cost is $C_o = 40 - 20 = 20$. The critical ratio is $C_u/(C_o + C_u) = 30/50 = 0.6$. From the Standard Normal Distribution Function Table, $\Phi(0.25) = 0.5987$ and $\Phi(0.26) = 0.6026$, so we choose $z = 0.26$. Convert that z-statistic into an order quantity $Q = \mu + z \times \sigma = 500 + 0.26 \times 200 = 552$. Note that the cost of a truckload has no impact on the profit-maximizing order quantity.

Part b

We need to find the z in the Standard Normal Distribution Function Table such that $\Phi(z) = 0.9750$ because $\Phi(z)$ is the in-stock probability. We see that $\Phi(1.96) = 0.9750$, so we choose $z = 1.96$. Convert to $Q = \mu + z \times \sigma = 500 + 1.96 \times 200 = 892$.

Part c

If 725 units are ordered, then the corresponding z-statistic is $z = (Q - \mu)/\sigma = (725 - 500)/200 = 1.13$. We need to evaluate lost sales, expected sales, and expected leftover inventory before we can evaluate the expected profit. Expected lost sales with the standard normal is obtained from the Standard Normal Loss Function Table, $L(1.13) = 0.0646$. Expected lost sales are $\sigma \times L(z) = 200 \times 0.0646 = 12.9$. Expected sales are $500 - 12.9 = 487.1$. Expected leftover inventory is $725 - 487.1 = 237.9$. Expected profit is

$$\begin{aligned}\text{Expected profit} &= (70 - 40) \times 487.1 - (40 - 20) \times 237.9 \\ &= 9{,}855\end{aligned}$$

So the expected profit per sweater type is 9,855. The total expected profit is five times that amount, minus 2,000 times the number of truckloads required.

Part d

The stockout probability is the probability demand exceeds the order quantity 725, which is $1 - \Phi(1.13) = 12.9$ percent.

Part e

If we order the expected profit-maximizing order quantity for each sweater, then that equals $5 \times 552 = 2{,}760$ sweaters. With an order quantity of 552 sweaters, expected lost sales are $56.5 = 200 \times L(0.26) = 200 \times 0.2824$, expected sales are $500 - 56.5 = 443.5$, and expected leftover inventory is $552 - 443.5 = 108.5$. Expected profit per sweater type is

$$\begin{aligned}\text{Expected profit} &= (70 - 40) \times 443.5 - (40 - 20) \times 108.5 \\ &= 11,135\end{aligned}$$

Because two truckloads are required, the total profit is then 5 × 11,136 – 2 × 2,000 = 51,675. If we order only 500 units per sweater type, then we can evaluate the expected profit per sweater to be 11,010. Total profit is then 5 × 11,010 – 2,000 = 53,050. Therefore, we are better off just ordering one truckload with 500 sweaters of each type.

Chapter 15

Q15.1 (Teddy Bower)

Part a

Teddy will order from the American supplier if demand exceeds 1,500 units. With Q = 1,500, the z-statistic is $z = (1{,}500 - 2{,}100)/1{,}200 = -0.5$. From the Standard Normal Distribution Function Table, we see that $\Phi(-0.50) = 0.3085$, which is the probability that demand is 1,500 or fewer. The probability that demand exceeds 1,500 is $1 - \Phi(-0.50) = 0.6915$, or about 69 percent.

Part b

The supplier's expected demand equals Teddy's expected lost sales with an order quantity of 1,500 parkas. From the Standard Normal Loss Function Table, $L(-0.50) = 0.6978$. Expected lost sales are $\sigma \times L(z) = 1{,}200 \times 0.6978 = 837.4$.

Part c

The overage cost is $C_o = 10 - 0 = 10$ because leftover parkas must have been purchased in the first order at a cost of $10 and they have no value at the end of the season. The underage cost is $C_u = 15 - 10 = 5$ because there is a $5 premium on units ordered from the American vendor. The critical ratio is $5/(10 + 5) = 0.3333$. From the Standard Normal Distribution Function Table, we see that $\Phi(-0.44) = 0.3300$ and $\Phi(-0.43) = 0.3336$, so choose $z = -0.43$. Convert to Q: $Q = 2{,}100 - 0.43 \times 1{,}200 = 1{,}584$.

Part d

First evaluate some performance measures. We already know that with $Q = 1{,}584$ the corresponding z is –0.43. From the Standard Normal Loss Function Table, $L(-0.43) = 0.6503$. Expected lost sales are then 1,200 × 0.6503 = 780.4; that is the expected order quantity to the American vendor. If the American vendor were not available, then expected sales would be 2,100 – 780.4 = 1,319.6. Expected leftover inventory is then 1,584 – 1,319.6 = 264.4. Now evaluate expected profit with the American vendor option available. Expected revenue is 2,100 × 22 = $46,200. The cost of the first order is 1,584 × 10 = $15,840. Salvage revenue from leftover inventory is 264.4 × 0 = 0. Finally, the cost of the second order is 780.4 × 15 = $11,706. Thus, profit is 46,200 – 15,840 – 11,706 = $18,654.

Part e

If Teddy only sources from the American supplier, then expected profit would be ($22 – $15) × 2,100 = $14,700 because expected sales would be 2,100 units and the gross margin on each unit is $22 – $15 = $7.

Q15.2 (Flextrola)

Part a

Expected sales = 1,000 and the gross margin per sale is 121 – 83.5 = $37.5. Expected profit is then 1,000 × $37.5 = $37,500.

Part b

$C_o = 72 - 50 = 22$; $C_u = 83.5 - 72 = 11.5$; therefore, the premium on orders from XE is \$11.5. The critical ratio is $11.5/(22 + 11.5) = 0.3433$. From the Standard Normal Distribution Function Table, $\Phi(-0.41) = 0.3409$ and $\Phi(-0.40) = 0.3446$, so $z = -0.40$. Convert to Q: $Q = 1{,}000 - 0.4 \times 600 = 760$.

Part c

The underage cost on an option is the change in profit if one additional option had been purchased that could be exercised. For example, if 700 options are purchased, but demand is 701, then 1 additional option could have been purchased. The cost of the option plus exercising it is \$25 + \$50 = \$75. The cost of obtaining the unit without the option is \$83.5, so purchasing the option would have saved C_u = \$83.5 – \$75 = \$8.5. The overage cost on an option is the extra profit that could have been earned if the option were not purchased assuming it isn't needed. For example, if demand were 699, then the last option would not be necessary. The cost of that unnecessary option is C_o = \$25. The critical ratio is $8.5/(25 + 8.5) = 0.2537$. From the Standard Normal Distribution Function Table, $\Phi(-0.67) = 0.2514$ and $\Phi(-0.66) = 0.2546$, so $z = -0.66$. Convert to Q: $Q = 1{,}000 - 0.66 \times 600 = 604$.

Part d

Evaluate some performance measures. Expected number of units ordered beyond the purchased options (expected lost sales) is $\sigma \times L(-0.66) = 600 \times 0.8128 = 487.7$. Expected number of options exercised (expected sales) is 1,000 – 487.7 = 512.3. Expected revenue is 1,000 × \$121 = \$121,000. So profit is revenue minus the cost of purchasing options (604 × \$25 = \$15,100), minus the cost of exercising options (512.3 × \$50 = \$25,615), minus the cost of units purchased without options (487.7 × \$83.5 = \$40,723): Profit = 121,000 – 15,100 – 25,615 – 40,723 = \$39,562.

Q15.3 (Wildcat Cellular)

Part a

The underage cost is C_u = 0.4 − 0.05 = \$0.35: If her usage exceeds the minutes she purchases then she could have lowered her cost by \$0.35 per minute if she had purchased more minutes. The overage cost is C_o = 0.05 because each minute purchased but not used provides no value. The critical ratio is $0.35/(0.05 + 0.35) = 0.8749$. From the Standard Normal Distribution Function Table Func Table $\Phi(1.15) = 0.8749$ and $\Phi(1.16) = 0.8770$, so $z = 1.16$. Convert to Q: $Q = 250 + 1.16 \times 24 = 278$.

Part b

We need to evaluate the number of minutes used beyond the quantity purchased (Expected lost sales). $z = (240 - 250)/24 = -0.42$, $L(-0.42) = 0.6436$, and expected lost sales = 24 × 0.6436 = 15.4 minutes. Each minute costs \$0.4, so the total surcharge is 15.4 × \$0.4 = \$6.16.

Part c

Find the corresponding z-statistic: $z = (280 - 250)/24 = 1.25$. Now evaluate performance measures. $L(1.25) = 0.0506$, and Expected lost sales = 24 × 0.0506 = 1.2 minutes, that is, only 1.2 minutes are needed on average beyond the 280 purchased. The minutes used out of the 280 (Expected sales) is 250 − 1.2 = 248.8. The unused minutes (Expected left over inventory) is 280 − 248.8 = 31.2.

Part d

Find the corresponding z-statistic: $z = (260 - 250)/24 = 0.42$. The number of minutes needed beyond the 260 is Expected lost sales: $L(0.42) = 0.2236$, and Expected lost sales = 24 × 0.2236 = 5.4 minutes. Total bill is 260 × 0.05 + 5.4 × 0.4 = \$15.16.

Part e

From the Standard Normal Distribution Function Table $\Phi(1.64) = 0.9495$ and $\Phi(1.65) = 0.9505$, so with $z = 1.65$ there is a 95.05 percent chance the outcome of a Standard Normal is less than z. Convert to Q: $Q = 250 + 1.65 \times 24 = 290$.

Part f

With "Pick Your Minutes," the optimal number of minutes is 278. The expected bill is then \$14.46: $z = (278 - 250)/24 = 1.17$; $L(1.17) = 0.0596$; Expected surcharge minutes = $24 \times 0.0596 = 1.4$; Expected surcharge = \$0.4 × 1.4 = \$0.56; Purchase cost is 278 × 0.05 = \$13.9; so the total is \$13.9 + 0.56. With "No Minimum," the total bill is \$22.5: Minutes cost \$0.07 × 250 = \$17.5; plus the fixed fee, \$5. So she should stick with the original plan.

Q15.9 (Steve Smith)

For every car Smith sells, he gets \$350 and an additional \$50 for every car sold over five cars. Look in the Poisson Loss Function Table for mean 5.5: The expected amount by which the outcome exceeds zero is $L(0) = 5.5$ (same as the mean) and the expected amount by which the outcome exceeds five is $L(5) = 1.178$. Therefore, the expected commission is $(350 \times 5.5) + (50 \times 1.178) = 1{,}984$.

Chapter 16

Q16.1 (Furniture Store)

Part a

Inventory position = Inventory level + On-order = 100 + 85 = 185. Order enough to raise the inventory position to the order-up-to level, in this case, 220 – 185 = 35 desks.

Part b

As in part a, Inventory position = 160 + 65 = 225. Because the inventory position is above the order-up-to level, 220, you do not order additional inventory.

Part c

Use Exhibit 16.6. From the Standard Normal Distribution Function Table: $\Phi(2.05) = 0.9798$ and $\Phi(2.06) = 0.9803$, so choose $z = 2.06$. The lead time l is 2, so $\mu = (2 + 1) \times 40 = 120$ and $\sigma = \sqrt{2+1} \times 20 = 34.64$

$$S = \mu + z \times \sigma = 120 + 2.06 \times 34.64 = 191.36$$

Part d

Use Exhibit 16.4. The z-statistic that corresponds to $S = 120$ is $S = (120 - 120)/34.64 = 0$. Expected back order is $\sigma \times L(0) = 34.64 \times 0.3989 = 13.82$. Expected on-hand inventory is $S - \mu$ + Expected back order = 120 – 120 + 13.82 = 13.82.

Part e

From part d, on-hand inventory is 13.82 units, which equals 13.82 × \$200 = \$2,764. Cost of capital is 15 percent, so the cost of holding inventory is 0.15 × \$2,764 = \$414.60.

Q16.2 (Campus Bookstore)

Part a

Use Exhibit 16.6. Mean demand over $l + 1$ periods is $0.5 \times (4 + 1) = 2.5$ units. From the Poisson Distribution Function Table, with mean 2.5 we have $F(6) = 0.9858$ and $F(7) = 0.9958$, so choose $S = 7$ to achieve a 99 percent in-stock.

Part b

Use Exhibit 16.4. Pipeline inventory is $l \times$ Expected demand in one period $= 4 \times 0.5 = 2$ units. The order-up-to level has no influence on the pipeline inventory.

Part c

Use Exhibit 16.4. From the Poisson Loss Function Table with mean 2.5, Expected back order $= L(5) = 0.06195$. Expected on-hand inventory $= 5 - 2.5 + 0.06195 = 2.56$ units.

Part d

A stockout occurs if demand is seven or more units over $l + 1$ periods, which is one minus the probability demand is six or fewer in that interval. From the Poisson Distribution Function Table with mean 2.5, we see that $F(6) = 0.9858$ and $1 - F(6) = 0.0142$; that is, there is about a 1.4 percent chance of a stockout occurring.

Part e

The store is out of stock if demand is six or more units over $l + 1$ periods, which is one minus the probability demand is five or fewer in that interval. From the Poisson Distribution Function Table with mean 2.5, we see that $F(5) = 0.9580$ and $1 - F(5) = 0.0420$; that is, there is about a 4.2 percent chance of being out of inventory at the end of any given week.

Part f

The store has one or more units of inventory if demand is five or fewer over $l + 1$ periods. From part e, $F(5) = 0.9580$; that is, there is about a 96 percent chance of having one or more units at the end of any given week.

Part g

Use Exhibit 16.6. Now the lead time is two periods (each period is two weeks and the total lead time is four weeks, or two periods). Demand over one period is 1.0 unit. Demand over $l + 1$ periods is $(2 + 1) \times 1 = 3.0$ units. From the Poisson Distribution Function Table with mean 3.0, we have $F(7) = 0.9881$ and $F(8) = 0.9962$, so choose $S = 8$ to achieve a 99 percent in-stock.

Part h

Use Exhibit 16.4. Pipeline inventory is average demand over l periods $= 2 \times 1 = 2.0$ units.

Q16.3 (Quick Print)

Part a

If $S = 700$ and the inventory position is $523 + 180 = 703$, then 0 units should be ordered because the inventory position exceeds the order-up-to level.

Part b

Use Exhibit 16.6. From the Standard Normal Distribution Function Table, $\Phi(2.32) = 0.9898$ and $\Phi(2.33) = 0.9901$, so choose $z = 2.33$. Convert to $S = \mu + z \times \sigma = 600 + 2.33 \times 159.22 = 971$.

Q16.4 (Main Line Auto Distributor)

Part a

Use Equation (16.2). The critical ratio is $25/($0.5 + $25) = 0.98039. The lead time is $l = 0$, so demand over $(l + 1)$ periods is Poisson with mean 1.5. From the Poisson Distribution

Function Table with mean 1.5, we see $F(3) = 0.9344$ and $F(4) = 0.9814$, so choose $S = 4$. There is currently no unit on order or on hand, so order to raise the inventory position to four: Order four units.

Part b

The in-stock probability is the probability demand is satisfied during the week. With $S = 3$ the in-stock is $F(3) = 0.9344$, that is, a 93 percent probability.

Part c

Demand is not satisfied if demand is five or more units, which is $1 - [F(4) = 0.9814] = 1 - 0.9814 = 0.0186$, or about 1.9 percent.

Part d

Use Exhibit 16.6. From the Poisson Distribution Function Table with mean 1.5, $F(4) = 0.9814$ and $F(5) = 0.9955$, so choose $S = 5$ to achieve a 99.5 percent in-stock probability.

Part e

Use Exhibit 16.4. If $S = 5$, then from the Poisson Loss Function Table with mean 1.5, we see expected back order $= L(5) = 0.0056$. Expected on-hand inventory is S – Demand over $(l + 1)$ periods = Expected back order $= 5 - 1.5 + 0.0056 = 3.51$ units. The holding cost is $3.51 \times \$0.5 = \$1.76$.

Q16.5 (Hotspices.com)

Part a

From the Standard Normal Distribution Function Table, $\Phi(2.43) = 0.9925$; so choose $z = 2.43$. Convert to S: $S = \mu + z \times \sigma = 159.62 + 2.43 \times 95.51 = 392$.

Part b

Use Equation (16.3). The holding cost is $h = 0.75$ and the back-order penalty cost is 50. The critical ratio is $50/(0.75 + 50) = 0.9852$. From the Standard Normal Distribution Function Table, $\Phi(2.17) = 0.9850$ and $\Phi(2.18) = 0.9854$, so choose $z = 2.18$. Convert to $S = \mu + z \times \sigma = 159.62 + 2.18 \times 95.51 = 368$.

Part c

Use Equation (16.3). The holding cost is $h = 0.05$ and the back-order penalty cost is 5. The critical ratio is $5/(0.05 + 5) = 0.9901$. Lead time plus one demand is Poisson with mean $1 \times 3 = 3$. From the Poisson Distribution Function Table, with $\mu = 3$, $F(7) = 0.9881$ and $F(8) = 0.9962$, so $S = 8$ is optimal.

Chapter 17

Q17.1 (Egghead)

Part a

New standard deviation is $30 \times \sqrt{50} = 212$.

Part b

Pipeline inventory = Expected demand per week × Lead time $= 200 \times 50 \times 10 = 100{,}000$.

Q17.2 (Two Products)

The coefficient of total demand (pooled demand) is the coefficient of the product's demand times the square root of (1 + Correlation)/2. Therefore, $\sqrt{(1 - 0.7)/2} \times 0.6 = 0.23$.

Q17.3 (Fancy Paints)

Part a

Assume Fancy Paints implements the order-up-to inventory model. Find the appropriate order-up-to level. With a lead time of 4 weeks, the relevant demand is demand over 4 + 1 = 5 weeks, which is $5 \times 1.25 = 6.25$. From the Poisson Distribution Function Table, $F(10) = 0.946$ and $F(11) = 0.974$, a base stock level $S = 11$ is needed to achieve at least a 95 percent in-stock probability. On-hand inventory at the end of the week is $S - 6.25 -$ Expected back order. From the Poisson Distribution Function Loss Function Table, the Expected back order is $L(11) = 0.04673$. Thus, on-hand inventory for one SKU is $11 - 6.25 + 0.04673 = 4.8$ units. There are 200 SKUs, so total inventory is $200 \times 4.8 = 960$.

Part b

The standard deviation over (4 + 1) weeks is $\sigma = \sqrt{5} \times 8 = 17.89$ and $\mu = 5 \times 50 = 250$. From the Standard Normal Distribution Function Table, we see that $\Phi(1.64) = 0.9495$ and $\Phi(1.65) = 0.9505$, so we choose $z = 1.65$ to achieve the 95 percent in-stock probability. The base stock level is then $S = \mu + z \times \sigma = 250 + 1.65 \times 17.89 = 279.5$. From the Standard Normal Loss Function Table, $L(1.65) = 0.0206$. So, on-hand inventory for one product is $S - 250 +$ Expected back order $= 279.5 - 250 + 17.89 \times 0.0206 = 29.9$. There are five basic SKUs, so total inventory in the store is $29.9 \times 5 = 149.5$.

Part c

The original inventory investment is $960 \times \$14 = \$13{,}440$, which incurs holding costs of $\$13{,}440 \times 0.20 = \$2{,}688$. Repeat part b, but now the target in-stock probability is 98 percent. From the Standard Normal Distribution Function Table, we see that $F(2.05) = 0.9798$ and $F(2.06) = 0.9803$, so we choose $z = 2.06$ to achieve the 98 percent in-stock probability. The base stock level is then $S = \mu + z \times \sigma = 250 + 2.06 \times 17.89 = 286.9$. From the Standard Normal Loss Function Table, $L(2.06) = 0.0072$. So, on-hand inventory for one product is $S - 250 +$ Expected back order $= 286.9 - 250 = 17.89 \times 0.0072 = 37.0$. There are five basic SKUs, so total inventory in the store is $37.0 \times 5 = 185$. With the mixing machine, the total inventory investment is $185 \times \$14 = \$2{,}590$. Holding cost is $\$2{,}590 \times 0.2 = \$518$, which is only 19 percent (518/2688) of the original inventory holding cost.

Q17.4 (Burger King)

Part a

Use the newsvendor model to determine an order quantity. Use Exhibit 14.6. From the table we see that $F(3{,}500) = 0.8480$ and $F(4{,}000) = 0.8911$, so order 4,000 for each store.

Part b

Use Exhibit 14.4 to evaluate expected lost sales and to evaluate the expected leftover inventory. Expected lost sales come from the table, $L(4{,}000) = 185.3$. Expected sales are $\mu - 185.3 = 2{,}251 - 185.3 = 2{,}065.7$. Expected leftover inventory is Q minus expected sales, $4{,}000 - 2{,}065.7 = 1{,}934.3$. Across 200 stores there will be $200 \times 1{,}934.3 = 386{,}860$ units left over.

Part c

The mean is 450,200. The coefficient of variation of individual stores is 1,600/2,251 = 0.7108. The coefficient of variation of total demand, we are told, is one-half of that, 0.7108/2 = 0.3554. Hence, the standard deviation of total demand is 450,200 × 0.3554 = 160,001. To find the optimal order quantity to hit an 85 percent in-stock probability, use Exhibit 14.6. From the Standard Normal Distribution Function Table, we see $\Phi(1.03) = 0.8485$ and $\Phi(1.04) = 0.8508$, so choose $z = 1.04$. Convert to $Q = 450{,}200 + 1.04 \times 160{,}001 = 616{,}601$.

Part d

Expected lost sales = 160,001 × $L(z)$ = 160,001 × 0.0772 = 12,352. Expected sales = 450,200 – 12,352 = 437,848. Expected leftover inventory = 616,601 – 437,848 = 178,753, which is only 46 percent of what would be left over if individual stores held their own inventory.

Part e

The total order quantity is 4,000 × 200 = 800,000. With a mean of 450,200 and standard deviation of 160,001 (from part c), the corresponding z is (800,000 – 450,200)/160,001 = 2.19. From the Standard Normal Distribution Function Table, we see $\Phi(2.19) = 0.9857$, so the in-stock probability would be 98.57 percent instead of 89.11 percent if the inventory were held at each store.

Q17.5 (Livingstion Tools)

Part a

With a lead time of 3 weeks, μ (3 + 1) × 5,200 = 20,800 and $\sigma = \sqrt{3+1} \times 3{,}800 = 7{,}600$. The target expected back orders is (5,200/7,600) × (1 – 0.999) = 0.0007. From the Standard Normal Distribution Function Table, we see that $\Phi(3.10) = 0.9990$, so we choose $z = 3.10$ to achieve the 99.9 percent in-stock probability. Convert to $S = 20{,}800 + 3.10 \times 7{,}600 = 44{,}360$. Expected back order is 7,600 × 0.0003 = 2.28. Expected on-hand inventory for each product is 44,360 – 20,800 + 2.28 = 23,562. The total inventory for the two is 2 × 23,562 = 47,124.

Part b

Weekly demand for the two products is 5,200 × 2 = 10,400. The standard deviation of the two products is $\sqrt{2 \times (1 - \text{Correlation})}$ × Standard deviation of one product = $\sqrt{2 \times (1 - 0.20)} \times 3{,}800 = 4{,}806.66$. Lead time plus one expected demand is 10,400 × 4 = 41,600. Standard deviation over $(l + 1)$ periods is $\sqrt{(3+1)} \times 4{,}806.66 = 9.613$. Now repeat the process in part a with the new demand parameters. Convert to $S = 41{,}600 + 3.10 \times 9{,}613 = 71{,}401$. Expected back order is 9,613 × 0.0003 = 2.88. Expected on-hand inventory is 71,401 – 41,600 + 2.88 = 29,804. The inventory investment is reduced by (47,124 – 29,804)/47,124 = 37 percent.

Q17.9 (Consulting Services)

Option a provides the longest chain, covering all four areas. This gives the maximum flexibility value to the firm, so that should be the chosen configuration. To see that it forms a long chain, Alice can do Regulations, as well as Bob. Bob can do Taxes, as well as Doug. Doug can do Strategy, as well as Cathy. Cathy can do Quota, as well as Alice. Hence, there is a single chain among all four consultants. The other options do not form a single chain.

Chapter 18

Q18.1 (The Inn at Penn)

Part a

The booking limit is capacity minus the protection level, which is 150 – 50 = 100; that is, allow up to 100 bookings at the low fare.

Part b

Use Exhibit 18.1. The underage cost is $C_u = 200 - 120 = 80$ and the overage cost is $C_o = 120$. The critical ratio is 80/(120 + 80) = 0.4. From the Standard Normal Distribution Function Table, we see $\Phi(-0.26) = 0.3974$ and $\Phi(-0.25) = 0.4013$, so choose $z = -0.25$. Evaluate Q: $Q = 70 - 0.25 \times 29 = 63$.

Part c

Decreases. The lower price for business travelers leads to a lower critical ratio and hence to a lower protection level; that is, it is less valuable to protect rooms for the full fare.

Part d

The number of unfilled rooms with a protection level of 61 is the same as expected leftover inventory. Evaluate the critical ratio, $z = (61 - 70)/29 = -0.31$. From the Standard Normal Loss Function Table, $L(z) = 0.5730$. Expected lost sales are $29 \times 0.5730 = 16.62$ and expected leftover inventory is $61 - 70 + 16.62 = 7.62$. So we can expect 7.62 rooms to remain empty.

Part e

$70 \times \$200 + (150 - 70) \times \$120 = \$23{,}600$ because, on average, 70 rooms are sold at the high fare and 150 – 70 = 80 are sold at the low fare.

Part f

$150 \times \$120 = \$18{,}000$.

Part g

If 50 are protected, we need to determine the number of rooms that are sold at the high fare. The z = statistic is $(50 - 70)/29 = -0.69$. Expected lost sales are $29 \times L(-0.69) = 24.22$. Expected sales are $70 - 24.22 = 45.78$. Revenue is then $(150 - 50) \times \$120 + 45.78 \times \$200 = \$21{,}155$.

Q18.2 (Overbooking The Inn at Penn)

Part a

Use Exhibit 18.2. The underage cost is \$120, the discount fare. The overage cost is \$325. The critical ratio is 120/(325 + 120) = 0.2697. From the table, $F(12) = 0.2283$ and $F(13) = 0.3171$, so the optimal overbook quantity is 13.

Part b

A reservation cannot be honored if there are nine or fewer no-shows. $F(9) = 0.0552$, so there is a 5.5 percent chance the hotel will be overbooked.

Part c

It is fully occupied if there are 15 or fewer no-shows, which has probability $F(15) = 0.5170$.

Part d

Bumped customers equal 20 minus the number of no-shows, so it is equivalent to leftover inventory. Lost sales are $L(20) = 0.28$, expected sales are $15.5 - 0.28 = 15.22$, and expected leftover inventory/bumped customers $= 20 - 15.22 = 4.78$. Each one costs \$325, so the total cost is $\$325 \times 4.78 = \$1{,}554$.

Q18.3 (WAMB)

Part a

First evaluate the distribution function from the density function provided in the table: $F(8) = 0$, $F(9) = F(8) + 0.05 = 0.05$, $F(10) = F(9) + 0.10 = 0.15$, and so on. Let Q denote the number of slots to be protected for sale later and let D be the demand for slots at \$10,000 each. If $D > Q$, we reserved too few slots and the underage penalty is $C_u = \$10{,}000 - \$4{,}000 = \$6{,}000$. If $D < Q$, we reserved too many slots and the overage penalty is $C_o = \$4{,}000$. The critical ratio is $6{,}000/(4{,}000 + 6{,}000) = 0.6$. From the table, we find $F(13) = 0.6$, so the optimal protection quantity is 13. Therefore, WAMB should sell $25 - 13 = 12$ slots in advance.

Part b

The underage penalty remains the same. The overage penalty is now $C_o = \$4{,}000 - \$2{,}500 = \$1{,}500$. Setting the protection level too high before meant lost revenue on the slot, but now at least \$2,500 can be gained from the slot, so the loss is only \$1,500. The critical ratio is $6{,}000/(1{,}500 + 6{,}000) = 0.8$. From the table, $F(15) = 0.8$, so protect 15 slots and sell $25 - 15 = 10$ in advance.

Part c

If the booking limit is 10, there are 15 slots for last-minute sales. There will be standby messages if there are 14 or fewer last-minute sales, which has probability $F(14) = 0.70$.

Part d

Over-overbooking means the company is hit with a \$10,000 penalty, so $C_o = 10{,}000$. Under-overbooking means slots that could have sold for \$4,000 are actually sold at the standby price of \$2,500, so $C_u = 4{,}000 - 2{,}500 = 1{,}500$. The critical ratio is $1{,}500/(10{,}000 + 1{,}500) = 0.1304$. From the Poisson Distribution Function Table with mean 9.0, $F(5) = 0.1157$ and $F(6) = 0.2068$, so the optimal overbooking quantity is six, that is, sell up to 31 slots.

Part e

The overage cost remains the same: We incur a penalty of \$10,000 for each bumped customer (and we refund the \$1,000 deposit of that customer, too). The underage cost also remains the same. To explain, suppose they overbooked by two slots but there are three withdrawals. Because they have one empty slot, they sell it for \$2,500. Had they overbooked by one more (three slots), then they would have collected \$4,000 on that last slot instead of the \$2,500, so the difference is $C_u = \$4{,}000 - \$2{,}500 = \$1{,}500$. Note, the nonrefundable amount of \$1,000 is collected from the three withdrawals in either scenario, so it doesn't figure into the change in profit by overbooking one more unit. The critical ratio is $1{,}500/(10{,}000 + 1{,}500) = 0.1304$. From the Poisson Distribution Function Table with mean 4.5, $F(1) = 0.0611$ and $F(2) = 0.17358$, so the optimal overbooking quantity is two, that is, sell up to 27 slots.

Q18.4 (Designer Dress)

Part a

The z-statistic is (100 – 70)/40 = 0.75. Expected lost sales are $40 \times L(z) = 40 \times 0.1312 = 5.248$. Expected sales are 70 – 5.248 = 64.752. Expected leftover inventory is 100 – 64.752 = 35.248.

Part b

Expected revenue is \$10,000 × 64.752 = \$647,520.

Part c

Use Exhibit 18.1. The underage cost is \$10,000 – \$6,000 = \$4,000 because underprotecting boutique sales means a loss of \$4,000 in revenue. Overprotecting means a loss of \$6,000 in revenue. The critical ratio is 4,000/(6,000 + 4,000) = 0.4. From the Standard Normal Distribution Function Table, we see $\Phi(-0.26) = 0.3974$ and $\Phi(-0.25) = 0.4013$, so choose $z = -0.25$. Evaluate Q: $Q = 40 - 0.25 \times 25 = 33.75$. So protect 34 dresses for sales at the boutique, which means sell 100 – 34 = 66 dresses at the show.

Part d

If 34 dresses are sent to the boutique, then expected lost sales are $\sigma \times L(z) = 25 \times L(-0.25) = 25 \times 0.5363 = 13.41$. Expected sales are 40 – 13.41 = 26.59. So revenue is 26.59 × \$10,000 + (100 – 34) × 6,000 = \$661,900.

Part e

From part d, expected sales are 26.59, so expected leftover inventory is 34 – 26.59 = 7.41 dresses.

Q18.5 (Overbooking, PHL–LAX)

Part a

Use Exhibit 18.2. The overage cost is \$800 (over-overbooking means a bumped passenger, which costs \$800). The underage cost is \$475 (an empty seat). The critical ratio is 475/(800 + 475) = 0.3725. From the Standard Normal Distribution Function Table, we see $\Phi(-0.33) = 0.3707$ and $\Phi(-0.32) = 0.3745$, so choose $z = -0.32$. Evaluate Y: $Y = 30 - 0.32 \times 15 = 25.2$. So the maximum number of reservations to accept is 200 + 25 = 225.

Part b

220 – 200 = 20 seats are overbooked. The number of bumped passengers equals 20 minus the number of no-shows, which is equivalent to leftover inventory with an order quantity of 20. The z-statistic is (20–30)/15 = –0.67. $L(-0.67) = 0.8203$, so lost sales are 15 × 0.8203 = 12.3. Sales are 30 – 12.3 = 17.7 and expected leftover inventory is 20 – 17.7 = 2.3. If 2.3 customers are bumped, then the payout is \$800 × 2.3 = \$1,840.

Part c

You will have bumped passengers if there are 19 or fewer no-shows. The z-statistic is (19 – 30)/15 = –0.73. $\Phi(-0.73) = 0.2317$, so there is about a 23 percent chance there will be bumped passengers.

Chapter 19

Q19.1 (Buying Tissues)

Part a

If orders are made every week, then the average order quantity equals one week's worth of demand, which is 25 cases. If at the end of the week there is one week's worth of inventory, then the average inventory is 25/2 + 25 = 37.5. (In this case, inventory "saw-tooths" from a high of two weeks' worth of inventory down to one week, with an average of 1.5 weeks.) On average the inventory value is 37.5 × 9.25 = \$346.9. The holding cost per year is 52 × 0.4% = 20.8 percent. Hence, the inventory holding cost with the first plan is 20.8% × \$346.9 = \$72. Purchase cost is 52 × 25 × \$9.25 = \$12,025. Total cost is \$12,025 + \$72 = \$12,097.

Part b

Four orders are made each year; each order on average is for (52/4) × 25 = 325 units. Average inventory is then 325/2 + 25 = 187.5. The price paid per unit is \$9.40 × 0.95 = \$8.93. The value of that inventory is 187.5 × \$8.93 = \$1,674. Annual holding costs are \$1,674 × 20.8% = \$348. Purchase cost is 52 × 25 × \$8.93 = \$11,609. Total cost is \$348 + \$11,609 = \$11,957.

Part c

P&G prefers our third plan as long as the price is higher than in the second plan, \$8.93. But the retailer needs a low enough price so that its total cost with the third plan is not greater than in the second plan, \$11,957 (from part b). In part a, we determined that the annual holding cost with a weekly ordering plan is approximately \$72. If we lower the price, the annual holding cost will be a bit lower, but \$72 is a conservative approximation of the holding cost. So the retailer's purchase cost should not exceed \$11,957 – \$72 = \$11,885. Total purchase quantity is 25 × 52 = 1,300 units. So if the price is \$11,885/1,300 = \$9.14, then the retailer will be slightly better off (relative to the second plan) and P&G is much better off (revenue of \$12,012 instead of \$11,885).

Q19.2 (Returning Books)

Part a

Use the newsvendor model. The overage cost is C_o = Cost – Salvage value = \$20 – \$28/4 = \$13. The underage cost is C_u = Price – Cost = \$28 – \$20 = \$8. The critical ratio is 8/(13 + 8) = 0.3810. Look up the critical ratio in the Standard Normal Distribution Function Table to find the appropriate z = statistic = –0.30. The optimal order quantity is $Q = \mu + z \times \sigma = 100 - 0.30 \times 42 = 87$.

Part b

Expected lost sales = $L(z) \times \sigma = 0.5668 \times 42 = 23.81$, where we find $L(z)$ from the Standard Normal Loss Function Table and z = –0.30 (from part a). Expected sales = μ – Expected lost sales = 100 – 23.81 = 76.2. Expected leftover inventory = Q – Expected sales = 87 – 76.2 = 10.8. Profit = Price × Expected sales = Salvage value × Expected leftover inventory – Q × Cost = \$28 × 76.2 + \$7 × 10.8 – 87 × \$20 = \$469.

Part c

The publisher's profit = Q × (Wholesale price – Cost) = 87 × (\$20 – \$7.5) = \$1,087.5.

Part d

The underage cost remains the same because a lost sale still costs Dan the gross margin, C_u = \$8. However, the overage cost has changed because Dan can now return books to the publisher. He buys each book for \$20 and then returns leftover books for a net salvage value of \$15 – \$1 (due to the shipping cost) = \$14. So his overage cost is now C_o = Cost – Salvage value = \$20 – \$14 = \$6. The critical ratio is 8/(6 + 8) = 0.5714. Look up the critical ratio in the Standard Normal Distribution Function Table to find the appropriate z = statistic = 0.18. The optimal order quantity is $Q = \mu + z \times \sigma = 100 + 0.18 \times 42 = 108$.

Part e

Expected lost sales = $L(z) \times \sigma = 0.3154 \times 42 = 13.2$, where we find $L(z)$ from the Standard Normal Loss Function Table and $z = 0.18$ (from part d). Expected sales = μ – Expected lost sales = 100 – 13.2 = 86.8. Expected leftover inventory = Q – Expected sales = 108 – 86.8 = 21.2. Profit = Price × Expected sales + Salvage value × Expected leftover inventory – Q × Cost = \$28 × 86.8 + \$14 × 21.2 – 108 × \$20 = \$567.

Part f

The publisher's sales revenue is \$20 × 108 = \$2,160. Production cost is \$7.5 × 108 = \$810. The publisher pays Dan \$15 × 21.2 = \$318. The publisher's total salvage revenue on returned books is \$6 × 21.2 = \$127.2. Profit is then \$2,160 – \$810 – \$318 + \$127.2 = \$1,159. Note that both the publisher and Dan are better off with this buy-back arrangement.

Part g

Equation (19.1) in the text gives the buy-back price that coordinates the supply chain (that is, maximizes the supply chain's profit). That buy-back price is \$1 + \$28 – (\$28 – \$20) × (\$28 – \$6)/(\$28 – \$7.5) = \$20.41. Note, the publisher's buy-back price is actually higher than the wholesale price because the publisher needs to subsidize Dan's shipping cost to return books: Dan's net loss on each book returned is \$20 – (20.41 – 1) = \$0.59.

Glossary

A

abandoning Refers to flow units leaving the process because of lengthy waiting times.

abnormal A variation is abnormal if it is not behaving in line with past data; this allows us to conclude that we are dealing with an assignable cause variation and are not just facing randomness in the form of common cause variation.

activity-on-node (AON) representation A way to graphically illustrate the project dependencies in which activities correspond to nodes in a graph.

activity time The duration that a flow unit has to spend at a resource, not including any waiting time; also referred to as service time or processing time.

A/F ratio The ratio of actual demand (A) to forecasted demand (F). Used to measure forecast accuracy.

anchoring bias The fact that human decision makers are selective in their acquisition of new information, looking for what confirms their initially held beliefs.

Andon cord A cord running adjacent to assembly lines that enables workers to stop production if they detect a defect. Just like the jidoka automatic shut-down of machines, this procedure dramatizes manufacturing problems and acts as a pressure for process improvements.

assemble-to-order Also known as make-to-order. A manufacturing system in which final assembly of a product only begins once a firm order has been received. Dell Inc. uses assemble-to-order with personal computers.

assignable cause variation Variation that occurs because of a specific change in input or in environmental variables.

attribute-based control chart A special control chart used for dealing with binary outcomes. It has all the features of the *X*-bar chart, yet does not require a continuous outcome variable. However, attribute-based charts require larger sample sizes, especially if defects occur rarely. Also known as *p*-charts.

authorization level For a fare class, the percentage of capacity that is available to that fare class or lower. An authorization level is equivalent to a booking limit expressed as a percentage of capacity.

automated forecasting Forecasts that are created by computers, typically with no human intervention.

Average labor utilization The average utilization across resources.

B

back-order penalty cost The cost incurred by a firm per back order. This cost can be explicit or implicit (e.g., lost goodwill and future business).

base stock level Also known as the order-up-to level. In the implementation of an order-up-to policy, inventory is ordered so that inventory position equals the base stock level.

batch A collection of units.

biased forecast A forecast that is wrong on average, thus an average forecast error different from zero.

bid price With bid price control, a bid price is assigned to each segment of capacity and a reservation is accepted only if its fare exceeds the bid prices of the segments of capacity that it uses.

bill of materials The list of components that are needed for the assembly of an item.

blocking The situation in which a resource has completed its work on a flow unit, yet cannot move the flow unit to the next step (resource or inventory) downstream as there is not space available.

booking limit The maximum number of reservations that are allowed for a fare class or lower.

bottleneck The resource with the lowest capacity in the process.

buckets A booking limit is defined for a bucket that contains multiple fare class–itinerary combinations.

buffer Another word for inventory, which is used especially if the role of the buffer is to maintain a certain throughput level despite the presence of variability.

bullwhip effect The propagation of demand variability up the supply chain.

buy-back contract A contract in which a supplier agrees to purchase leftover inventory from a retailer at the end of the selling season.

C

capacity Measures the maximum flow rate that can be supported by a resource.

capacity-constrained A process for which demand exceeds the process capacity.

cause–effect diagram A structured way to brainstorm about the potential root causes that have led to a change in an outcome variable. This is done by mapping out all input and environmental variables. Also known as a fishbone diagram or Ishikawa diagram.

channel stuffing The practice of inducing retailers to carry more inventory than needed to cover short-term needs.

coefficient of variation A measure of variability. Coefficient of variation = Standard deviation divided by the mean; that is, the ratio of the standard deviation of a random variable to the mean of the random variable. This is a relative measure of the uncertainty in a random variable.

collaborative planning, forecasting, and replenishment (CPFR) A set of practices designed to improve the exchange of information within a supply chain.

common cause variation Variation that occurs in a process as a result of pure randomness (also known as natural variation).

control charts Graphical tools to statistically distinguish between assignable and common causes of variation. Control charts visualize variation, thereby enabling the user to judge whether the observed variation is due to common causes or assignable causes.

critical path A project management term that refers to all those activities that—if delayed—would delay the overall completion of the project.

critical ratio The ratio of the underage cost to the sum of the overage and underage costs. It is used in the newsvendor model to choose the expected profit-maximizing order quantity.

cycle inventory The inventory that results from receiving (producing) several flow units in one order (batch) that are then used over a time period of no further inflow of flow units.

cycle time The time that passes between two consecutive flow units leaving the process. Cycle time = 1/Flow rate.

D

decision tree A scenario-based approach to map out the discrete outcomes of a particular uncertainty.

decoupling inventory See buffer inventory.

defect probability The statistical probability with which a randomly chosen flow unit does not meet specifications.

defective Not corresponding to the specifications of the process.

demand forecasting The process of creating statements about future realizations of demand.

demand-constrained A process for which the flow rate is limited by demand.

demand-pull An inventory policy in which demand triggers the ordering of replenishments.

density function The function that returns the probability the outcome of a random variable will exactly equal the inputted value.

dependent variable The variable that we try to explain in a regression analysis.

deseasonalize To remove the seasonal effect from past data.

discovery-driven planning A process that emphasizes learning about unknown variables related to a project with the goal of deciding whether or not to invest further resources in the project.

distribution function The function that returns the probability the outcome of a random variable will equal the inputted value or lower.

diversion The practice by retailers of purchasing product from a supplier only to resell the product to another retailer.

diverters Firms that practice diversion.

double exponential smoothing A way of forecasting a demand process with a trend that estimates both the demand and the trend using exponential smoothing. The resulting forecast is the sum of these two estimates. This is a type of momentum-based forecasting.

double marginalization The phenomenon in a supply chain in which one firm takes an action that does not optimize supply chain performance because the firm's margin is less than the supply chain's total margin.

E

earliest completion time (ECT) The earliest time a project activity can be completed, which can be computed as the sum of the earliest start time and the duration of the activity.

earliest due date (EDD) A rule that sequences jobs to be processed on a resource in ascending order of their due dates.

earliest start time (EST) The earliest time a project activity can start, which requires that all information providing activities are completed.

economies of scale Obtaining lower cost per unit based on a higher flow rate. Can happen, among other reasons, because of a spread of fixed cost, learning, statistical reasons (pooling), or the usage of dedicated resources.

Efficient Consumer Response The collective name given to several initiatives in the grocery industry to improve the efficiency of the grocery supply chain.

electronic data interchange (EDI) A technology standard for the communication between firms in the supply chain.

Emergency Severity Index (ESI) A scoring rule used by emergency rooms to rank the severity of a patient's injuries and then to prioritize their care.

environmental variables Variables in a process that are not under the control of management but nevertheless might impact the outcome of the process.

EOQ (economic order quantity) The quantity that minimizes the sum of inventory costs and fixed ordering cost.

Erlang loss formula Computes the proportion of time a resource has to deny access to incoming flow units in a system of multiple parallel servers and no space for inventory.

estimated standard deviation for X-bar The standard deviation of a particular sample mean, *x*-bar.

estimated standard deviation of all parts The standard deviation that is computed across all parts.

expected leftover inventory The expected amount of inventory at the end of the selling season.

expert panel forecasting Forecasts generated using the subjective opinions of management.

exponential distribution Captures a random variable with distribution Prob $\{x < t\} = 1 - \exp(-t/a)$, where a is the mean as well as the standard deviation of the distribution. If interarrival times are exponentially distributed, we speak of a Poisson arrival process. The exponential distribution is known for the memoryless property; that is, if an exponentially distributed service time with mean five minutes has been going on for five minutes, the expected remaining duration is still five minutes.

exponential smoothing forecasting method A forecasting method that predicts that the next value will be a weighted average between the last realized value and the old forecast.

external setups Those elements of setup times that can be conducted while the machine is processing; an important element of setup time reduction/SMED.

extrapolation Estimation of values beyond the range of the original observations by assuming that some patterns in the values present within the range will also prevail outside the range.

F

fences Restrictions imposed on a low-fare class to prevent high-fare customers from purchasing the low fare. Examples include advanced purchase requirements and Saturday night stay over.

fill rate The fraction of demand that is satisfied; that is, that is able to purchase a unit of inventory.

first-come-first-served (FCFS) A rule that sequences jobs to be processed on a resource in the order in which they arrived.

fishbone diagram A structured way to brainstorm about the potential root causes that have led to a change in an outcome variable. This is done by mapping out all input and environmental variables. Also known as a cause–effect diagram or Ishikawa diagram.

Five Whys A brainstorming technique that helps employees to find the root cause of a problem. In order to avoid stopping too early and not having found the real root cause, employees are encouraged to ask "Why did this happen?" at least five times.

flow rate (*R*) Also referred to as throughput. Flow rate measures the number of flow units that move through the process in a given unit of time. *Example:* The plant produces at a flow rate of 20 scooters per hour. Flow rate = Min{Demand, Capacity}.

flow time (*T*) Measures the time a flow unit spends in the process, which includes the time it is worked on at various resources as well as any time it spends in inventory. *Example:* A customer spends a flow time of 30 minutes on the phone in a call center.

flow unit The unit of analysis that we consider in process analysis; for example, patients in a hospital, scooters in a kick-scooter plant, and callers in a call center.

forecast combination Combining multiple forecasts that have been generated by different forecasters into one single value.

forecast error The difference between a forecasted value and the realized value.

forecast gaming A purposeful manipulation of a forecast to obtain a certain decision outcome for a decision that is based on the forecast.

forecast with consensus building An iterative discussion among experts about their forecasts and opinions that leads to a single forecast.

forecasting The process of creating statements about outcomes of variables that presently are uncertain and will only be realized in the future.

forward buying If a retailer purchases a large quantity during a trade promotion, then the retailer is said to forward buy.

G

Gantt chart A graphical way to illustrate the durations of activities as well as potential dependencies between the activities.

H

heijunka A principle of the Toyota Production System, proposing that models are mixed in the production process according to their mix in customer demand.

hockey stick phenomenon A description of the demand pattern that a supplier can receive when there is a substantial amount of order synchronization among its customers.

holding cost rate The cost incurred to hold one unit of inventory for one period of time.

horizontal pooling Combining a sequence of resources in a queuing system that the flow unit would otherwise visit sequentially; increases the span of control; also related to the concept of a work cell.

I

idle time The time a resource is not processing a flow unit. Idle time should be reduced as it is a non–value-adding element of labor cost.

ikko-nagashi An element of the Toyota Production System. It advocates the piece-by-piece transfer of flow units (transfer batches of one).

implied utilization The workload imposed by demand of a resource relative to its available capacity. Implied utilization = Demand rate/Capacity.

in-stock probability The probability all demand is satisfied over an interval of time.

incentive alignment bias Forecasting bias resulting from incentives and personal objectives that forecasters might have.

incentive conflicts In a supply chain, firms may have conflicting incentives with respect to which actions should be taken.

independent variables The variables influencing the dependent variable.

information turnaround time (ITAT) The delay between the occurrence of a defect and its detection.

input variables The variables in a process that are under the control of management.

integrated supply chain The supply chain considered as a single integrated unit, that is, as if the individual firms were owned by a single entity.

interarrival time The time that passes between two consecutive arrivals.

internal setups Those elements of setup times that can only be conducted while the machine is not producing. Internal setups should be reduced as much as possible and/or converted to external setups wherever possible (SMED).

inventory (I) The number of flow units that are in the process (or in a particular resource). Inventory can be expressed in (a) flow units (e.g., scooters), (b) days of supply (e.g., three days of inventory), or (c) monetary units ($1 million of inventory).

inventory turns How often a company is able to turn over its inventory. Inventory turns = 1/Flow time, which—based on Little's Law—is COGS/Inventory.

Ishikawa diagram A structured way to brainstorm about the potential root causes that have led to a change in an outcome variable. This is done by mapping out all input and environmental variables. Also known as a fishbone diagram or cause-effect diagram.

J

jidoka In the narrow sense, a specific type of machine that can automatically detect defects and automatically shut down itself. The basic idea is that shutting down the machine forces human intervention in the process, which in turn triggers process improvement.

job A flow unit that requires processing from one or more resources.

K

kaizen The continuous improvement of processes, typically driven by the persons directly involved with the process on a daily basis.

kanban A production and inventory control system in which the production and delivery of parts are triggered by the consumption of parts downstream (pull system).

L

labor content The amount of labor that is spent on a flow unit from the beginning to the end of the process. In a purely manual process, we find labor content as the sum of all the activity times.

lateness The difference between the completion time of a job and its due date. Lateness is negative when the job is completed before the due date (i.e., it is early).

latest completion time (LCT) The latest time a project activity has to be completed by to avoid delaying the overall completion time of the project.

latest start time (LST) The latest time a project activity can start without delaying the overall completion time of the project.

lead time The time between when an order is placed and when it is received. Process lead time is frequently used as an alternative word for flow time.

line balancing The process of evenly distributing work across the resources of a process. Line balancing reduces idle time and can (a) reduce cycle time or (b) reduce the number of workers that are needed to support a given flow rate.

location pooling The combination of inventory from multiple locations into a single location.

long-term forecasts Forecasts used to support strategic decisions with typical time ranges of multiple years.

longest processing time (LPT) A rule that sequences jobs to be processed on a resource in descending order of their processing times.

lower control limit (LCL) A line in a control chart that provides the smallest value that is still acceptable without being labeled an abnormal variation.

lower specification limit (LSL) The smallest outcome value that does not trigger a defective unit.

M

make-to-order A production system, also known as assemble-to-order, in which flow units are produced only once the customer order for that flow unit has been received. Make-to-order production typically requires wait times for the customer, which is why it shares many similarities with service operations. Dell Inc. uses make-to-order with personal computers.

make-to-stock A production system in which flow units are produced in anticipation of demand (forecast) and then held in finished goods inventory.

makespan The total time to process a set of jobs.

marginal cost pricing The practice of setting the wholesale price to the marginal cost of production.

materials requirement planning (MRP) A system that plans the delivery of components required for a manufacturing process so that components are available when needed but not so early as to create excess inventory.

maximum profit In the context of the newsvendor model, the expected profit earned if quantity can be chosen after observing demand. As a result, there are no lost sales and no leftover inventory.

mean The expected value of a random variable.

mean absolute error (MAE) A measure evaluating the quality of a forecast by looking at the average absolute value of the forecast error.

mean squared error (MSE) A measure evaluating the quality of a forecast by looking at the average squared forecast error.

mid-term forecasts Forecasts used to support capacity planning and financial accounting with typical time ranges from weeks to a year.

mismatch cost The sum of the underage cost and the overage cost. In the context of the newsvendor model, the mismatch cost is the sum of the lost profit due to lost sales and the total loss on leftover inventory.

momentum-based forecasts An approach to forecasting that assumes that the trend in the future will be similar to the trend in the past.

moving average forecasting method A forecasting method that predicts that the next value will be the average of the last realized values.

MRP jitters The phenomenon in which multiple firms operate their MRP systems on the same cycle, thereby creating order synchronization.

muda One specific form of waste, namely waste in the form of non–value-adding activities. Muda also refers to unnecessary inventory (which is considered the worst form of muda), as unnecessary inventory costs money without adding value and can cover up defects and other problems in the process.

N

naïve forecasting method A forecasting method that predicts that the next value will be like the last realized value.

natural variation Variation that occurs in a process as a result of pure randomness (also known as common cause variation).

nested booking limits Booking limits for multiple fare classes are nested if each booking limit is defined for a fare class or lower. With nested booking limits, it is always the case that an open fare class implies all higher fare classes are open and a closed fare class implies all lower fare classes are closed.

newsvendor model A model used to choose a single order quantity before a single selling season with stochastic demand.

no-show A customer who does not arrive for his or her appointment or reservation.

normal distribution A continuous distribution function with the well-known bell-shaped density function.

O

one-for-one ordering policy Another name for an order-up-to policy. (With this policy, one unit is ordered for every unit of demand.)

open-access appointment system An appointment system in which appointments are only available one day in advance and are filled on a first-come-first-served basis.

order batching A cause of the bullwhip effect. A firm order batches when it orders only in integer multiples of some batch quantity.

order inflation The practice of ordering more than desired in anticipation of receiving only a fraction of the order due to capacity constraints upstream.

order synchronization A cause of the bullwhip effect. This describes the situation in which two or more firms submit orders at the same moments in time.

order-up-to model A model used to manage inventory with stochastic demand, positive lead times, and multiple replenishments.

origin-destination control A revenue management system in the airline industry that recognizes passengers that request the same fare on a particular segment may not be equally valuable to the firm because they differ in their itinerary and hence total revenue.

outcome variables Measures describing the quality of the output of the process.

overage cost In the newsvendor model, the cost of purchasing one too many units. In other words, it is the increase in profit if the firm had purchased one fewer unit without causing a lost sale (i.e., thereby preventing one additional unit of leftover inventory).

overbooking The practice of accepting more reservations than can be accommodated with available capacity.

overconfidence bias The fact that human decision makers are overly confident in their ability to shape a positive outcome.

P

***p*-chart** A special control chart used for dealing with binary outcomes. It has all the features of the X-bar chart, yet does not require a continuous outcome variable. However, p-charts require larger sample sizes, especially if defects occur rarely. Also known as attribute-based control charts.

par level Another name for the order-up-to level in the order-up-to model.

Pareto diagram A graphical way to identify the most important causes of process defects. To create a Pareto diagram, we need to collect data on the number of defect occurrences as well as the associated defect types. We can then plot simple bars with heights indicating the relative occurrences of the defect types. It is also common to plot the cumulative contribution of the defect types.

parts per million The expected number of defective parts in a random sample of one million.

percent on time The fraction of jobs that are completed on or before their due date.

phantom orders An order that is canceled before delivery is taken.

pipeline inventory The minimum amount of inventory that is required to operate the process. Since there is a minimum flow time that can be achieved (i.e., sum of the activity times), because of Little's Law, there is also a minimum required inventory in the process. Also known as on-order inventory, it is the number of units of inventory that have been ordered but have not been received.

Poisson distribution A discrete distribution function that often provides an accurate representation of the number of events in an interval of time when the occurrences of the events are independent of each other. In other words, it is a good distribution to model demand for slow-moving items.

Poisson process An arrival process with exponentially distributed interarrival times.

poka-yoke A Toyota technique of "fool-proofing" many assembly operations, that is, by making mistakes in assembly operations physically impossible.

pooling The concept of combining several resources (including their buffers and their arrival processes) into one joint resource. In the context of waiting time problems, pooling reduces the expected wait time.

prediction markets A betting game in which forecasters can place financial bets on their forecasts.

price protection The industry practice of compensating distributors due to reductions in a supplier's wholesale price. As a result of price protection, the price a distributor pays to purchase inventory is effectively always the current price; that is, the supplier rebates the distributor whenever a price reduction occurs for each unit the distributor is holding in inventory.

process capability index The ratio between the width of the specification interval of the outcome variable and the variation in the outcome variable (measured by six times its estimated standard deviation). It tells us how many standard deviations we can move away from the statistical mean before causing a defect.

process capacity Capacity of an entire process, which is the maximum flow rate that can be achieved in the process. It is based on the capacity of the bottleneck.

process flow diagram Maps resources and inventory and shows graphically how the flow unit travels through the process in its transformation from input to output.

processing time The duration that a flow unit has to spend at a resource, not including any waiting time; also referred to as activity time or service time.

product pooling The practice of using a single product to serve two demand segments that were previously served by their own product version.

production cycle The processing and setups of all flow units before the resource starts to repeat itself.

protection level The number of reservations that must always be available for a fare class or higher. For example, if a flight has 120 seats and the protection level is 40 for the high-fare class, then it must always be possible to have 40 high-fare reservations.

pull system A manufacturing system in which production is initiated by the occurrence of demand.

push system A manufacturing system in which production is initiated in anticipation of demand.

Q

quantity discount Reduced procurement costs as a result of large order quantities. Quantity discounts have to be traded off against the increased inventory costs.

quantity flexibility (QF) contracts With this contract, a buyer provides an initial forecast to a supplier. Later on the buyer is required to purchase at least a certain percentage of the initial forecast (e.g., 75 percent), but the buyer also is allowed to purchase a certain percentage above the forecast (e.g., 125 percent of the forecast). The supplier must build enough capacity to be able to cover the upper bound.

Quick Response A series of practices in the apparel industry used to improve the efficiency of the apparel supply chain.

R

random variable A variable that represents a random event. For example, the random variable X could represent the number of times the value 7 is thrown on two dice over 100 tosses.

reactive capacity Capacity that can be used after useful information regarding demand is learned; that is, the capacity can be used to react to the learned demand information.

regression analysis A statistical process of estimating the relationship of one variable with multiple variables that influence this one variable.

reseasonalize To reintroduce the seasonal effect to the forecasted data.

resource The entity of a process that the flow unit has to visit as part of its transformation from input to output.

returns policy See buy-back contract.

revenue management Also known as yield management. The set of tools used to maximize revenue given a fixed supply.

rework An approach of handling defective flow units that attempts to invest further resource time into the flow unit in the attempt to transform it into a conforming (nondefective) flow unit.

rework loops An iteration/repetition of project or process activities done typically because of quality problems.

robust The ability of a process to tolerate changes in input and environmental variables without causing the outcomes to be defective.

root cause A root cause for a defect is a change in an input or an environmental variable that initiated a defect.

round-up rule When looking for a value inside a table, it often occurs that the desired value falls between two entries in the table. The round-up rule chooses the entry that leads to the larger quantity.

S

safety inventory The inventory that a firm holds to protect itself from random fluctuations in demand.

salvage value The value of leftover inventory at the end of the selling season in the newsvendor model.

scheduling The process of deciding what work to assign to which resources and when to assign the work.

seasonality A significant demand change that constitutes a repetitive fluctuation over time.

seasonality index (SI) The estimated multiplicative adjustment factor that allows us to move from the average overall demand to the average demand for a particular season.

service level The probability with which a unit of incoming demand will receive service as planned. In the context of waiting time problems, this means having a waiting time less than a specified target wait time; in other contexts, this also can refer to the availability of a product.

service time The duration that a flow unit has to spend at a resource, not including any waiting time; also referred to as activity time or processing time.

set of specifications A set of rules that determine if the outcome variable of a unit is defective or not.

short-term forecasts Forecasts used to support tactical decision making with typical time ranges from hours to weeks.

shortage gaming A cause of the bullwhip effect. In situations with a capacity constraint, retailers may inflate their orders in anticipation of receiving only a portion of their order.

shortest processing time (SPT) A rule that sequences jobs to be processed on a resource in ascending order of their processing times.

six-sigma process A process that has 6 standard deviations on either side of the mean and the specification limit.

slack time The difference between the earliest completion time and the latest completion time; measures by how much an activity can be delayed without delaying the overall project.

smoothing parameter The parameter that determines the weight new realized data have in creating the next forecast with exponential smoothing.

span of control The scope of activities a worker or a resource performs. If the resource is labor, having a high span of control requires extensive training. Span of control is largest in a work cell.

standard deviation A measure of the absolute variability around a mean. The square of the standard deviation equals the variance.

standard normal A normal distribution with mean 0 and standard deviation 1.

starving The situation in which a resource has to be idle as there is no flow unit completed in the step (inventory, resource) upstream from it.

stationary arrivals When the arrival process does not vary systemically over time; opposite of seasonal arrivals.

statistical noise Variables influencing the outcomes of a process in unpredictable ways.

statistical process control (SPC) A framework in operations management built around the empirical measurement and the statistical analysis of input, environmental, and outcome variables.

stockout Occurs if a customer demands a unit but a unit of inventory is not available. This is different from "being out of stock," which merely requires that there is no inventory available.

stockout probability The probability a stockout occurs over a predefined interval of time.

supply chain efficiency The ratio of the supply chain's actual profit to the supply chain's optimal profit.

supply-constrained A process for which the flow rate is limited by either capacity or the availability of input.

T

takotei-mochi A Toyota technique to reduce worker idle time. The basic idea is that a worker can load one machine and while this machine operates, the worker—instead of being idle—operates another machine along the process flow.

tandem queue A set of queues aligned in a series so that the output of one server flows to only one other server.

tardiness If a job is completed after its due date, then tardiness is the difference between the completion time of a job and its due date. If the job is completed before its due date, then tardiness is 0. Tardiness is always positive.

target variation The largest amount of variation in a process that does not exceed a given defect probability.

target wait time (TWT) The wait time that is used to define a service level concerning the responsiveness of a process.

tasks The atomic pieces of work that together constitute activities. Tasks can be moved from one activity/resource to another in the attempt to improve line balance.

theory of constraints An operation guideline that recommends managerial attention be focused on the bottleneck of a process.

time series analysis Analysis of old demand data.

time series–based forecast An approach to forecasting that uses nothing but old demand data.

trade promotion A temporary price discount off the wholesale price that a supplier offers to its retailer customers.

trend A continuing increase or decrease in a variable that is consistent over a long period of time.

tsukurikomi The Toyota idea of integrating quality inspection throughout the process. This is therefore an important enabler of the quality-at-the-source idea.

turn-and-earn An allocation scheme in which scarce capacity is allocated to downstream customers proportional to their past sales.

U

unbiased forecast A forecast that is correct on average, thus an average forecast error equal to zero.

underage cost In the newsvendor model, the profit loss associated with ordering one unit too few. In other words, it is the increase in profit if one additional unit had been ordered and that unit is sold.

universal design/product A product that is designed to serve multiple functions and/or multiple customer segments.

unknown unknowns (unk-unks) Project management parlance to refer to uncertainties in a project that are not known at the outset of the project.

upper control limit (UCL) A line in a control chart that provides the largest value that is still acceptable without being labeled an abnormal variation.

upper specification limit (USL) The largest outcome value that does not trigger a defective unit.

utilization The extent to which a resource uses its capacity when supporting a given flow rate. Utilization = Flow rate/Capacity.

V

variance A measure of the absolute variability around a mean. The square root of the variance equals the standard deviation.

vendor-managed inventory (VMI) The practice of switching control of inventory management from a retailer to a supplier.

virtual nesting A revenue management system in the airline industry in which passengers on different itineraries and paying different fare classes may nevertheless be included in the same bucket for the purchase of capacity controls.

virtual pooling The practice of holding inventory in multiple physical locations that share inventory information data so that inventory can be moved from one location to another when needed.

W

weighted shortest processing time (WSPT) A rule that sequences jobs to be processed on a resource in descending order of the ratio of their weight to their processing time. Jobs with high weights and low processing times tend to be sequenced early.

work in process (WIP) The inventory that is currently in the process (as opposed to inventory that is finished goods or raw material).

worker-paced line A process layout in which a worker moves the flow unit to the next resource or buffer when he or she has completed processing it; in contrast to a machine-paced line, where the flow unit moves based on a conveyor belt.

workload The request for capacity created by demand. Workload drives the implied utilization.

X

X-bar The average of a sample.

X-bar charts A special control chart in which we track the mean of a sample (also known as **X**-bar).

X-double-bar The average of a set of sample averages.

yield management Also known as revenue management. The set of tools used to maximize revenue given a fixed supply.

Z

***z*-statistic** Given quantity and any normal distribution, that quantity has a unique *z*-statistic such that the probability the outcome of the normal distribution is less than or equal to the quantity equals the probability the outcome of a standard normal distribution equals the *z*-statistic.

zero-sum game A game in which the total payoff to all players equals a constant no matter what outcome occurs.

References

Abernathy, F. H., J.T. Dunlop, J. Hammond, and D. Weil. *A Stitch in Time: Lean Retailing and the Transformation of Manufacturing—Lessons from the Apparel and Textile Industries.* New York: Oxford University Press, 1999.

Anupindi, R., S. Chopra, S. D. Deshmukh, J. A. Van Mieghem, and E. Zemel. *Managing Business Process Flows.* Upper Saddle River, NJ: Prentice Hall, 1999.

Bartholdi, J. J., and D. D. Eisenstein. "A Production Line That Balances Itself." *Operations Research* 44, no. 1 (1996), pp. 21–34.

Beatty, S. "Advertising: Infinity and Beyond? No Supply of Toys at Some Burger Kings." *The Wall Street Journal,* November 25, 1996, p. B-10.

Belobaba, P. "Application of a Probabilistic Decision Model to Airline Seat Inventory Control." *Operations Research* 37, no. 2 (1989), pp. 183–97.

Bohn, R. E., and R. Jaikumar. "A Dynamic Approach to Operations Management: An Alternative to Static Optimization." *International Journal of Production Economics* 27, no. 3 (1992), pp. 265–82.

Bohn, R. E., and C. Terwiesch. "The Economics of Yield-Driven Processes." *Journal of Operations Management* 18 (December 1999), pp. 41–59.

Breyfogle, F. W. *Implementing Six Sigma.* New York: John Wiley & Sons, 1999.

Brown, A., H. Lee, and R. Petrakian. "Xilinx Improves Its Semiconductor Supply Chain Using Product and Process Postponement." *Interfaces* 30, no. 4 (2000), p. 65.

Brynjolfsson, E., Y. Hu, and M. D. Smith. "Consumer Surplus in the Digital Economy: Estimating the Value of Increased Product Variety." *Management Science* 49, no. 11 (2003), pp. 1580–96.

Buzzell, R., J. Quelch, and W. Salmon. "The Costly Bargain of Trade Promotion." *Harvard Business Review* 68, no. 2 (1990), pp. 141–49.

Cachon, G. "Supply Chain Coordination with Contracts." In *Handbooks in Operations Research and Management Science: Vol. 11. Supply Chain Management, I: Design, Coordination, and Operation,* ed. T. Kok and S. Graves. Amsterdam: North-Holland, 2004.

Cannon, J., T. Randall, and C. Terwiesch. "Improving Earnings Prediction Based on Operational Variables: A Study of the U.S. Airline Industry." Working paper, The Wharton School and The Eccles School of Business, 2007.

W. Chan Kim and Renée Mauborgne. *Blue Ocean Strategy.* Harvard Business School Press. 2005.

Chase, R. B., and N. J. Aquilano. *Production and Operations Management: Manufacturing and Services.* 7th ed. New York: Irwin, 1995.

Chopra, S., and P. Meindl. *Supply Chain Management: Strategy, Planning and Operation.* 2nd ed. Upper Saddle River, NJ: Pearson Prentice Hall, 2004.

Cross, R. "An Introduction to Revenue Management." In *Handbook of Airline Economics,* ed. D. Jenkins, pp. 453–58. New York: McGraw-Hill, 1995.

Cross, R. *Revenue Management: Hard-Core Tactics for Market Domination.* New York: Broadway Books, 1997.

De Groote, X. Inventory Theory: A Road Map. Unpublished teaching note. INSEAD. March 1994.

Diwas Singh KC, Christian Terwiesch, (2012) An Econometric Analysis of Patient Flows in the Cardiac Intensive Care Unit. Manufacturing & Service Operations Management 14(1):50-65. https://doi.org/10.1287/msom.1110.0341

Drew, J., B. McCallum, and S. Roggenhofer. *Journey to Lean: Making Operational Change Stick.* New York: Palgrave Macmillan, 2004.

Feitzinger, E., and H. Lee. "Mass Customization at Hewlett-Packard: The Power of Postponement." *Harvard Business Review* 75 (January–February 1997), pp. 116–21.

Fisher, M. "What Is the Right Supply Chain for Your Product?" *Harvard Business Review* 75 (March–April) 1997, pp. 105–16.

Fisher, M., K. Rajaram, and A. Raman. "Optimizing Inventory Replenishment of Retail Fashion Products." *Manufacturing and Service Operations Management* 3, no. 3 (2001), pp. 230–41.

Fisher, M., and A. Raman. "Reducing the Cost of Demand Uncertainty through Accurate Response to Early Sales." *Operations Research* 44 (1996), pp. 87–99.

Fujimoto, T. *The Evolution of a Manufacturing System at Toyota.* New York: Oxford University Press, 1999.

Gans, N., G. Koole, and A. Mandelbaum. "Telephone Call Centers: Tutorial, Review, and Research Prospects." *Manufacturing & Service Operations Management* 5 (2003), pp. 79–141.

Gaur, V., M. Fisher, and A. Raman. "An Econometric Analysis of Inventory Turnover Performance in Retail Services." *Management Science* 51 (2005), pp. 181–94.

Geraghty, M., and E. Johnson. "Revenue Management Saves National Rental Car." *Interfaces* 27, no. 1 (1997), pp. 107–27.

Hall, R. W. *Queuing Methods for Services and Manufacturing.* Upper Saddle River, NJ: Prentice Hall, 1997.

Hansell, S. "Is This the Factory of the Future?" *New York Times,* July 26, 1998.

Harrison, M. J., and C. H. Loch. "Operations Management and Reengineering." Working paper, Stanford University, 1995.

Hayes, R. H., and S. C. Wheelwright. "Link Manufacturing Process and Product Life Cycles." *Harvard Business Review,* January–February 1979, pp. 133–40.

Hayes, R. H., S. C. Wheelwright, and K. B. Clark. *Dynamic Manufacturing: Creating the Learning Organization.* New York: Free Press, 1988.

Hillier, F. S., and G. J. Lieberman. *Introduction to Operations Research.* 7th ed. New York: McGraw-Hill, 2002.

Holweg, M., and F. K. Pil. *The Second Century: Reconnecting Customer and Value Chain through Build-to-Order, Moving beyond Mass and Lean Production in the Auto Industry.* New ed. Cambridge, MA: MIT Press, 2005.

Hopp, W. J., and M. L. Spearman. *Factory Physics I: Foundations of Manufacturing Management.* New York: Irwin/McGraw-Hill, 1996.

Jordon, W., and S. Graves. "Principles on the Benefits of Manufacturing Process Flexibility." *Management Science* 41 (1995), pp. 577–94.

Juran, J. *The Quality Control Handbook.* 4th ed. New York: McGraw-Hill, 1951.

Juran, J. *Juran on Planning for Quality.* New York: Free Press, 1989.

Karmarkar, U. "Getting Control of Just-in-Time." *Harvard Business Review* 67 (September–October 1989), pp. 122–31.

Kaufman, L. "Restoration Hardware in Search of a Revival." *New York Times,* March 21, 2000.

Kavadias, S., C. H. Loch, and A. DeMeyer, "DragonFly: Developing a Proposal for an Uninhabited Aerial Vehicle (UAV)." Insead case 600-003-1.

Kimes, S. "Revenue Management on the Links I: Applying Yield Management to the Golf-Course Industry." *Cornell Hotel and Restaurant Administration Quarterly* 41, no. 1 (February 2000), pp. 120–27.

Kimes, S., R. Chase, S. Choi, P. Lee, and E. Ngonzi. "Restaurant Revenue Management: Applying Yield Management to the Restaurant Industry." *Cornell Hotel and Restaurant Administration Quarterly* 39, no. 3 (1998), pp. 32–39.

Koller, T., M. Goedhart, and D. Wessels. *Valuation.* 4th ed. New York: John Wiley & Sons, 2005.

Lee, H. "Effective Inventory and Service Management through Product and Process Redesign." *Operations Research* 44, no. 1 (1996), pp. 151–59.

Lee, H., V. Padmanabhan, and S. Whang. "The Bullwhip Effect in Supply Chains." *MIT Sloan Management Review* 38, no. 3 (1997), pp. 93–102.

Loch C. H., A. DeMeyer, and M. T. Pich, *Managing the Unknown: A New Approach to Managing High Uncertainty and Risk in Projects.* John Wiley & Sons, 2006.

Magretta, J. 1998. "The Power of Virtual Integration: An Interview with Dell Computer's Michael Dell." *Harvard Business Review* 76 (March–April 1998), pp. 72–84.

McGill, J., and G. van Ryzin. "Revenue Management: Research Overview and Prospects." *Transportation Science* 33, no. 2 (1999), pp. 233–56.

McWilliams, G., and J. White. "Others Want to Figure Out How to Adopt Dell Model." *The Wall Street Journal,* December 1, 1999.

Antonio Moreno, Christian Terwiesch (2015) Pricing and Production Flexibility: An Empirical Analysis of the U.S. Automotive Industry. Manufacturing & Service Operations Management 17(4):428-444. https://doi.org/10.1287/msom.2015.0534

Motorola. "What Is Six Sigma?" Summary of Bill Weisz's videotape message, 1987.

Nahmias, S. *Production and Operations Analysis.* 5th ed. New York: McGraw-Hill, 2005.

Ohno, T. *Toyota Production System: Beyond Large-Scale Production.* Productivity Press, March 1, 1998.

Olivares, Marcelo, Christian Terwiesch, and Lydia Cassorla, "Structural Estimation of the Newsvendor Model: An Application to Reserving Operating Room Time," *Management Science,* Vol. 54, No. 1, 2008 (pp. 45–55).

Padmanabhan,V., and I. P. L. Png. "Returns Policies: Make Money by Making Good." *Sloan Management Review,* Fall 1995, pp. 65–72.

Papadakis, Y. "Operations Risk and Supply Chain Design." Working paper. The Wharton Risk Center, 2002.

Pasternack, B. "Optimal Pricing and Returns Policies for Perishable Commodities." *Marketing Science* 4, no. 2 (1985), pp. 166–76.

Petruzzi, N., and M. Dada. "Pricing and the Newsvendor Problem: A Review with Extensions." *Operations Research* 47 (1999), pp. 183–94.

Porter, M., M. Kramer. "Creating Shared Value: How to Reinvent Capitalism and Unleash a Wave of Innovation and Growth." *Harvard Business Review.* Jan–Feb, 2011.

Porteus, E. *Stochastic Inventory Theory.* Palo Alto, CA: Stanford University Press, 2002.

Ramstad, E. "Koss CEO Gambles on Inventory Buildup: Just-in-Time Production Doesn't Always Work." *The Wall Street Journal,* March 15, 1999.

Sakasegawa, H. "An Approximation Formula $L_q = \alpha\beta^{\rho}(1 - \rho)$." *Annals of the Institute of Statistical Mathematics* 29, no. 1 (1977), pp. 67–75.

Sechler, B. "Special Report: E-commerce, behind the Curtain." *The Wall Street Journal,* July 15, 2002.

Silver, E., D. Pyke, and R. Peterson. *Inventory Management and Production Planning and Scheduling.* New York: John Wiley & Sons, 1998.

Simchi-Levi, D., P. Kaminsky, and E. Simchi-Levi. *Designing and Managing the Supply Chain: Concepts, Strategies, and Case Studies.* 2nd ed. New York: McGraw-Hill, 2003.

Simison, R. "Toyota Unveils System to Custom-Build Cars in Five Days." *The Wall Street Journal,* August 6, 1999.

Smith, B., J. Leimkuhler, and R. Darrow. "Yield Management at American Airlines." *Interfaces* 22, no. 1 (1992), pp. 8–31.

Stevenson, W. *Operations Management.* 8th ed. McGraw-Hill/ Irwin, 2006.

Stringer, K. "As Planes Become More Crowded, Travelers Perfect Getting 'Bumped.'" *The Wall Street Journal,* March 21, 2002.

Talluri, K., and G. van Ryzin. *The Theory and Practice of Revenue Management.* Boston: Kluwer Academic Publishers, 2004.

Terwiesch, Christian, and Karl T. Ulrich, *Innovation Tournaments: Creating and Selecting Exceptional Opportunities,* Harvard Business School Press, 2009.

Terwiesch, C. "Paul Downs Cabinet Maker." Teaching case at The Wharton School, 2004.

Terwiesch, C., and C. H. Loch. "Pumping Iron at Cliffs and Associates I: The Cicored Iron Ore Reduction Plant in Trinidad." Wharton-INSEAD Alliance case, 2002.

Tucker, A. L. "The Impact of Operational Failures on Hospital Nurses and Their Patients." *Journal of Operations Management* 22, no. 2 (April 2004), pp. 151–69.

Ulrich, K. T., and S. Eppinger. *Product Design and Development.* 5th ed. McGraw Hill Irwin, 2011.

Upton, D. "The Management of Manufacturing Flexibility." *California Management Review* 36 (Winter 1994), pp. 72–89.

Upton, D. "What Really Makes Factories Flexible." *Harvard Business Review* 73 (July–August 1995), pp. 74–84.

Vitzthum, C. "Spain's Zara Cuts a Dash with 'Fashion on Demand.'" *The Wall Street Journal,* May 29, 1998.

Wadsworth, H. M., K. S. Stephens, and A. B. Godfrey. *Modern Methods for Quality Control and Improvement.* New York: John Wiley & Sons, 1986.

Weatherford, L. R., and S. E. Bodily. "A Taxonomy and Research Overview of Perishable-Asset Revenue Management: Yield Management, Overbooking and Pricing." *Operations Research* 40, no. 5 (1992), pp. 831–43.

Whitney, D. *Mechanical Assemblies: Their Design, Manufacture, and Role in Product Development.* New York: Oxford University Press, 2004.

Whitt, W. "The Queuing Network Analyzer." *Bell System Technology Journal* 62, no. 9 (1983).

Womack, J. P., D. T. Jones, and D. Roos. *The Machine That Changed the World: The Story of Lean Production.* Reprint edition. New York: Harper Perennial, 1991.

Zipkin, P. *Foundations of Inventory Management.* New York: McGraw-Hill, 2000.

Zipkin, P. "The Limits of Mass Customization." *Sloan Management Review,* Spring 2001, pp. 81–87.

Index of Key "How to" Exhibits

Summary of Key Notation and Equations

Chapter 2: The Process View of the Organization

$$\text{Little's Law: Average inventory} = \text{Average flow rate} \times \text{Average time}$$

Chapter 3: Understanding the Supply Process: Evaluating Process Capacity

$$\text{Implied utilization} = \frac{\text{Capacity requested by demand}}{\text{Available capacity}}$$

Chapter 4: Estimating and Reducing Labor Costs

$$\text{Flow rate} = \text{Min}\{\text{Available input, Demand, Process capacity}\}$$

$$\text{Cycle time} = \frac{1}{\text{Flow rate}}$$

$$\text{Cost of direct labor} = \frac{\text{Total wages}}{\text{Flow rate}}$$

$$\text{Idle time across all workers at resource } i = \text{Cycle time} \times (\text{Number of workers at resource } i) - \text{Processing time at resource } i$$

$$\text{Average labor utilization} = \frac{\text{Labor content}}{\text{Labor content} + \text{Total idle time}}$$

Chapter 5: Batching and Other Flow Interruptions: Setup Times and the Economic Order Quantity Model

$$\text{Capacity given batch size} = \frac{\text{Batch size}}{\text{Setup time} + \text{Batch size} \times \text{Time per unit}}$$

$$\text{Recommended batch size} = \frac{\text{Flow rate} \times \text{Setup time}}{1 - \text{Flow rate} \times \text{Time per unit}}$$

$$\text{Economic order quantity} = \sqrt{\frac{2 \times \text{Setup cost} \times \text{Flow rate}}{\text{Holding cost}}}$$

Chapter 9: Variability and Its Impact on Process Performance: Waiting Time Problems

$$m = \text{number of servers}$$
$$p = \text{processing time}$$
$$a = \text{interarrival time}$$

$$\text{CV}_a = \text{coefficient of variation for interarrivals}$$
$$\text{CV}_p = \text{coefficient of variation of processing time}$$

$$\text{Utilization } u = \frac{p}{a \times m}$$

$$T_q = \left(\frac{\text{Processing time}}{m}\right) \times \left(\frac{\text{Utilization}^{\sqrt{2(m+1)}-1}}{1 - \text{Utilization}}\right) \times \left(\frac{\text{CV}_a^2 + \text{CV}_p^2}{2}\right)$$

$$\text{Flow time } T = T_q + p$$

$$\text{Inventory in service } I_p = m \times u$$

$$\text{Inventory in the queue } I_q = T_q / a$$

$$\text{Inventory in the system } I = I_p + I_q$$

Chapter 10: Quality

$$\text{Yield of resource} = \frac{\text{Flow rate of units processed correctly at the resource}}{\text{Flow rate}}$$

Chapter 14: Betting on Uncertain Demand: The Newsvendor Model

$$Q = \text{order quantity}$$
$$C_u = \text{Underage cost}$$
$$C_o = \text{Overage cost}$$
$$\mu = \text{Expected demand}$$
$$\sigma = \text{Standard deviation of demand}$$

$$F(Q) = \text{Distribution function}$$
$$\Phi(Q) = \text{Distribution function of the standard normal}$$
$$L(Q) = \text{Loss function}$$
$$L(z) = \text{Loss function of the standard normal distribution}$$

$$\text{Critical ratio} = \frac{C_u}{C_o + C_u}$$

$$\text{A/F ratio} = \frac{\text{Actual demand}}{\text{Forecast}}$$

$$\text{Expected profit-maximizing order quantity: } F(Q) = \frac{C_u}{C_o + C_u}$$

$$z\text{-statistic or normalized order quantity: } z = \frac{Q - \mu}{\sigma}$$

$$Q = \mu + z \times \sigma$$

$$\text{Expected lost sales with a standard normal distribution} = L(z)$$

$$\text{Expected lost sales with a normal distribution} = \sigma \times L(z)$$

$$\text{In Excel: } L(z) = \sigma\text{*Normdist}(z, 0 , 1, 0) - z\text{*}(1 - \text{Normsdist}(z))$$

$$\text{Expected lost sales for nonnormal distributions} = L(Q) \text{ (from loss function table)}$$

$$\text{Expected sales} = \mu - \text{Expected lost sales}$$

$$\text{Expected leftover inventory} = Q - \text{Expected sales}$$

$$\begin{aligned}\text{Expected profit} = {} & [(\text{Price} - \text{Cost}) \times \text{Expected sales}] \\ & - [(\text{Cost} - \text{Salvage value}) \times \text{Expected leftover inventory}]\end{aligned}$$

$$\text{In-stock probability} = F(Q)$$

$$\text{Stockout probability} = 1 - \text{In-stock probability}$$

$$\text{In Excel: In-stock probability} = \text{Normsdist}(z)$$

$$\text{In Excel: } z = \text{Normsinv(Target in-stock probability)}$$

Chapter 15: Assemble-to-Order, Make-to-Order, and Quick Response with Reactive Capacity

$$\begin{aligned}\text{Mismatch cost} &= (C_o \times \text{Expected leftover inventory}) + (C_u \times \text{Expected lost sales}) \\ &= \text{Maximum profit} - \text{Expected profit}\end{aligned}$$

$$\text{Maximum profit} = (\text{Price} - \text{Cost}) \times \mu$$

$$\text{Coefficient of variation} = \text{Standard deviation/Expected demand}$$

Chapter 16: Service Levels and Lead Times in Supply Chains: The Order-up-to Inventory Model

l = Lead time
S = Order-up-to level

$$\begin{aligned}\text{Inventory level} &= \text{On-hand inventory} - \text{Back order} \\ \text{Inventory position} &= \text{On-order inventory} + \text{Inventory level} \\ \text{In-stock probability} &= 1 - \text{Stockout probability} \\ &= \text{Prob}\{\text{Demand over } (l + 1) \text{ periods} \leq S\}\end{aligned}$$

$$z\text{-statistic for normalized order quantity: } z = \frac{S - \mu}{\sigma}$$

$$\text{Expected back order with a normal distribution} = \sigma \times L(z)$$

$$\text{In Excel: Expected back order} = \sigma*(\text{Normdist}(z, 0, 1, 0) - z*(1 - \text{Normsdist}(z)))$$

$$\text{Expected back order for nonnormal distributions} = L(S) \text{ (from loss function table)}$$

$$\text{Expected inventory} = S - \text{Expected demand over } l + 1 \text{ periods} \\ + \text{Expected back order}$$

$$\text{Expected on-order inventory} = \text{Expected demand in one period} \times \text{Lead time}$$

Chapter 17: Risk-Pooling Strategies to Reduce and Hedge Uncertainty

$$\text{Expected pooled demand} = 2 \times \mu$$

$$\text{Standard deviation of pooled demand} = \sqrt{2 \times (1 + \text{Correlation})} \times \sigma$$

$$\text{Coefficient of variation of pooled demand} = \sqrt{\frac{1}{2}(1 + \text{Correlation})} \times \left(\frac{\sigma}{\mu}\right)$$

Chapter 18: Revenue Management with Capacity Controls

$$\text{Protection level: Critical ratio} = \frac{C_u}{C_o + C_u} = \frac{r_h - r_l}{r_h}$$

$$\text{Low-fare booking limit} = \text{Capacity} - Q$$

$$\text{Overbooking: Critical ratio} = \frac{C_u}{C_o + C_u} = \frac{r_l}{\text{Cost per bumped customer} + r_l}$$