Supply Chain Management Analytics

11 SUPPLEMENT

SUPPLEMENT OUTLINE

Alaska Airlines

LEARNING OBJECTIVES

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The 2011 Tōhoku earthquake and tsunami devastated eastern sections of Japan. The economic impact was felt around the globe, as manufacturers had been relying heavily—in some cases exclusively—on suppliers located in the affected zones. In the month immediately following the earthquake, the Japanese-built vehicle outputs for both Toyota and Honda were down 63%. Plants in other countries ceased or reduced operations due to part shortages. Manufacturers in several industries worldwide took 6 months or longer before they saw their supply chains working normally again. Although disasters such as this one occur relatively infrequently, supply chain managers should consider their probabilities and repercussions when determining the makeup of the supply base.

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Techniques for Evaluating Supply Chains

Many supply chain metrics exist that can be used to evaluate performance within a company as well as for its supply chain partners. This supplement introduces five techniques that are aimed at ways to build and evaluate performance of the supply chain.

Evaluating Disaster Risk in the Supply Chain

Disasters that disrupt supply chains can take many forms, including tornadoes, fires, hurricanes, typhoons, tsunamis, earthquakes, and terrorism. When you are deciding whether to purchase collision insurance for your car, the amount of insurance must be weighed against the probability of a minor accident occurring and the potential financial worst-case scenario if an accident happens (e.g., "totaling" of the car). Similarly, firms often use multiple suppliers for important components to mitigate the risks of total supply disruption.

LO S11.1 *Use* a decision tree to determine the best number of suppliers to manage disaster risk

As shown in Example S1, a decision tree can be used to help operations managers make this important decision regarding the number of suppliers. We will use the following notation for a given supply cycle:

S = the probability of a "super-event" that would disrupt *all* suppliers simultaneously

U = the probability of a "unique-event" that would disrupt only one supplier

L = the financial loss incurred in a supply cycle if *all* suppliers were disrupted

C = the marginal cost of managing a supplier

All suppliers will be disrupted simultaneously if either the super-event occurs or the super-event does not occur but a unique-event occurs for all of the suppliers. Assuming that the probabilities are all independent of each other, the probability of all n suppliers being disrupted simultaneously equals:

$$P(n) = S + (1 - S)U^n \qquad \text{(S11-1)}$$

Example S1

HOW MANY SUPPLIERS ARE BEST FOR MANAGING RISK?

Xiaotian Geng, president of Shanghai Manufacturing Corp., wants to create a portfolio of suppliers for the motors used in her company's products that will represent a reasonable balance between costs and risks. While she knows that the single-supplier approach has many potential benefits with respect to quality management and just-in-time production, she also worries about the risk of fires, natural disasters, or other catastrophes at supplier plants disrupting her firm's performance. Based on historical data and climate and geological forecasts, Xiaotian estimates the probability of a "super-event" that would negatively impact all suppliers simultaneously to be 0.5% (i.e., probability = 0.005) during the supply cycle. She further estimates the "unique-event" risk for any of the potential suppliers to be 4% (probability = .04). Assuming that the marginal cost of managing an additional supplier is $10,000, and the financial loss incurred if a disaster caused all suppliers to be down simultaneously is $10,000,000, how many suppliers should Xiaotian use? Assume that up to three nearly identical suppliers are available.

APPROACH ▶ Use of a decision tree seems appropriate, as Shanghai Manufacturing Corp. has the basic data: a choice of decisions, probabilities, and payoffs (costs).

SOLUTION ▶ We draw a decision tree (Figure S11.1) with a branch for each of the three decisions (one, two, or three suppliers), assign the respective probabilities [using Equation (S11-1)] and payoffs for each branch, and then compute the respective expected monetary values (EMVs). The EMVs have been identified at each step of the decision tree.

Using Equation (S11-1), the probability of a total disruption equals:

One supplier: $0.005 + (1 - 0.005)0.04 = 0.005 + 0.0398 = 0.044800$, or 4.4800%

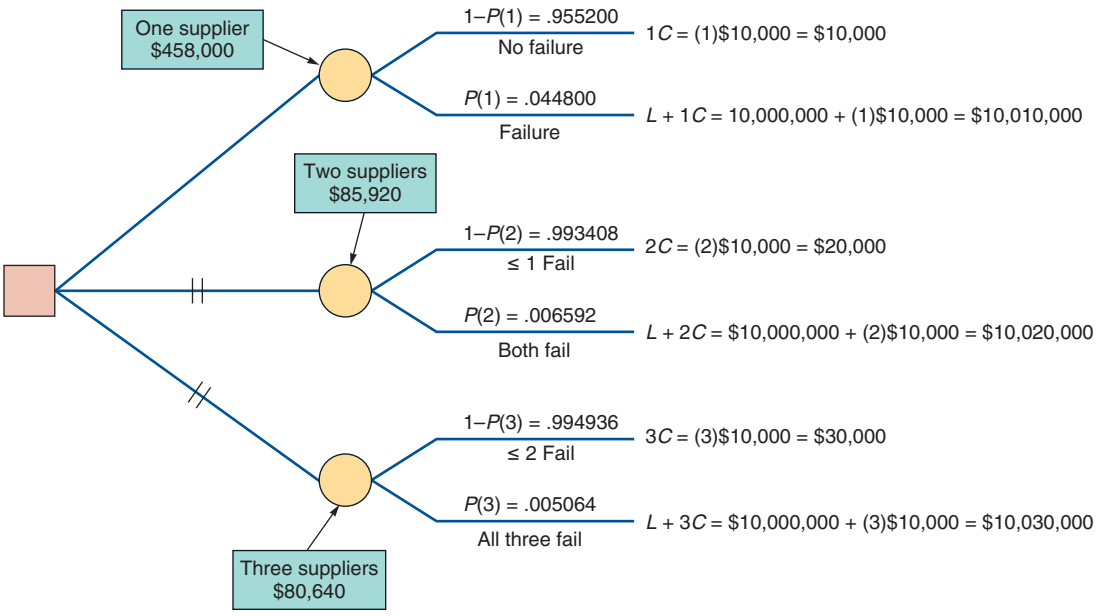
Two suppliers: $0.005 + (1 - 0.005)0.04^2 = 0.005 + 0.001592 = 0.006592$, or 0.6592%

Three suppliers: $0.005 + (1 - 0.005)0.04^3 = 0.005 + 0.000064 = 0.005064$, or 0.5064%

INSIGHT ▶ Even with significant supplier management costs and unlikely probabilities of disaster, a large enough financial loss incurred during a total supplier shutdown will suggest that multiple suppliers may be needed.

Figure **S11.1**

Decision Tree for Selection of Suppliers Under Risk



LEARNING EXERCISE ▶ Suppose that the probability of a super-event increases to 50%. How many suppliers are needed now? [Answer: 2.] Using the 50% probability of a super-event, suppose that the financial loss of a complete supplier shutdown drops to $500,000. Now how many suppliers are needed? [Answer: 1.]

RELATED PROBLEMS ▶ S11.1, S11.2, S11.3, S11.4, S11.5

An interesting implication of Equation (S11-1) is that as the probability of a super-event (S) increases, the advantage of utilizing multiple suppliers diminishes (all would be knocked out anyway). On the other hand, large values of the unique event (U) increase the likelihood of needing more suppliers. These two phenomena taken together suggest that when multiple suppliers are used, managers may consider using ones that are geographically dispersed to lessen the probability of all failing simultaneously.

Managing the Bullwhip Effect

Figure S11.2 provides an example of the *bullwhip effect*, which describes the tendency for larger order size fluctuations as orders are relayed to the supply chain from retailers. "Bullwhip" fluctuations create unstable production schedules, resulting in expensive capacity change adjustments such as overtime, subcontracting, extra inventory, backorders, hiring and laying off of workers, equipment additions, underutilization, longer lead times, or obsolescence of overproduced items.

Procter & Gamble found that although the use of Pampers diapers was steady and the retail-store orders had little fluctuation, as orders moved through the supply chain, fluctuations increased. By the time orders were initiated for raw material, the variability was substantial. Similar behavior has been observed and documented at many companies, including Campbell Soup, Hewlett-Packard, Barilla SpA, and Applied Materials.

The bullwhip effect can occur when orders decrease as well as when they increase. Table S11.1 identifies some of the major causes and remedies of the bullwhip effect. Often the human tendency to overreact to stimuli causes managers to make decisions that exacerbate the phenomenon. The overarching solution to the bullwhip effect is simply for supply-chain members to share information and work together, as in the *OM in Action* box "RFID Helps Control the Bullwhip."

Supplier coordination can help with demand shifts. During the recent worldwide recession, but prior to experiencing the economic recovery and increasing sales, Caterpillar started ordering more supplies. It also worked proactively with its suppliers to prepare them for a sharp increase in output. Caterpillar visited key suppliers individually. In some cases it helped suppliers obtain bank financing at favorable rates. As part of Caterpillar's risk assessment activities, suppliers had to submit written plans describing their ability to ramp production back up once the economy improved. Careful, coordinated planning can help alleviate shortages and delays that might otherwise occur as the bullwhip snaps back upward.

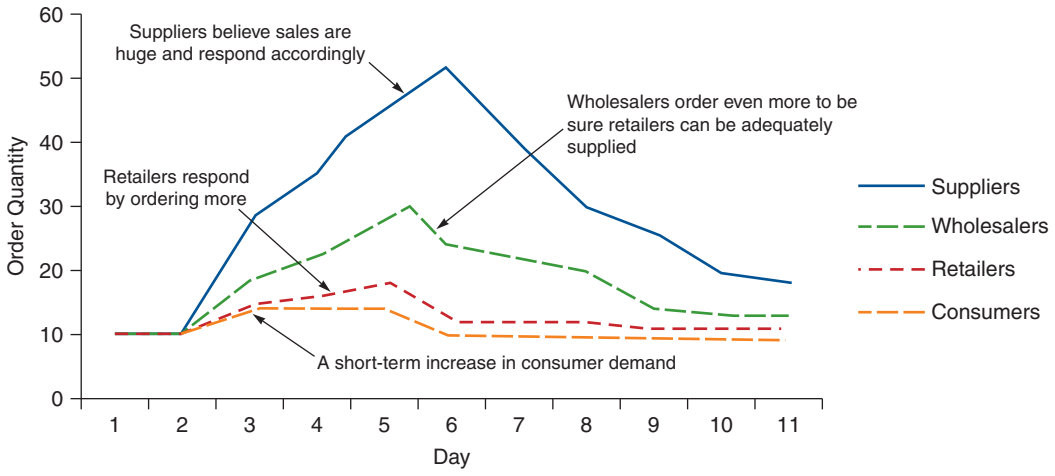


Figure **S11.2**

The Bullwhip Effect

The bullwhip effect causes members of the supply chain to overreact to changes in demand at the retail level. Minor demand changes at the consumer level may result in large ones at the supplier level.

TABLE S11.1 The Bullwhip Effect

CAUSE	REMEDY
Demand forecast errors (cumulative uncertainty in the supply chain)	Share demand information throughout the supply chain.
Order batching (large, infrequent orders leading suppliers to order even larger amounts)	Channel coordination: Determine lot sizes as though the full supply chain was one company.
Price fluctuations (buying in advance of demand to take advantage of low prices, discounts, or sales)	Price stabilization (everyday low prices).
Shortage gaming (hoarding supplies for fear of a supply shortage)	Allocate orders based on past demand.

A Bullwhip Effect Measure

LO S11.2 *Explain* and measure the bullwhip effect

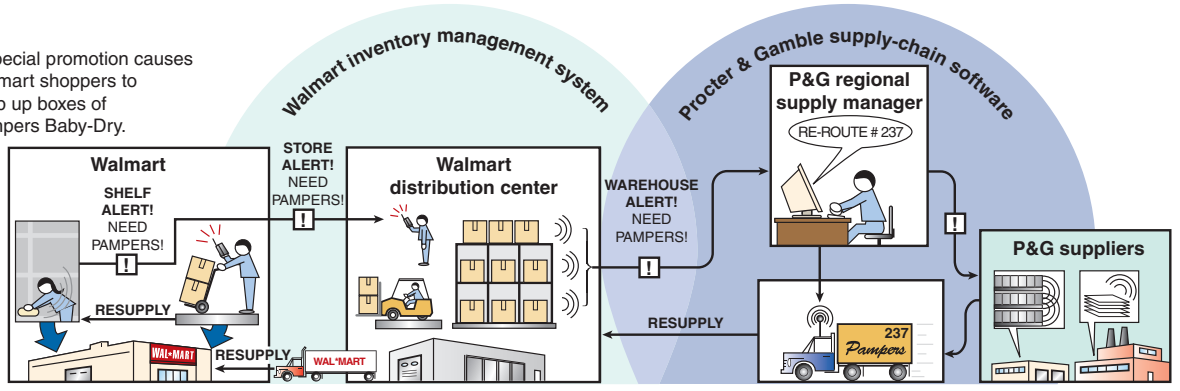
A straightforward way to analyze the extent of the bullwhip effect at any link in the supply chain is to calculate the *bullwhip measure*:

$$\text{Bullwhip} = \frac{\text{Variance of orders}}{\text{Variance of demand}} = \frac{\sigma^2_{\text{orders}}}{\sigma^2_{\text{demand}}} \qquad \text{(S11-2)}$$

Variance *amplification* (i.e., the bullwhip effect) is present if the bullwhip measure is greater than 1. This means the size of a company's orders fluctuate more than the size of its incoming demand. If the measure equals 1, then no amplification is present. A value less than 1 would imply a *smoothing* or *dampening* scenario as orders move up the supply chain toward suppliers. Example S2 illustrates how to use Equation (S11-2) to analyze the extent of the bullwhip effect at each stage in the supply chain.

OM in Action RFID Helps Control the Bullwhip

Supply chains work smoothly when sales are steady, but often break down when confronted by a sudden surge or rapid drop in demand. Radio frequency ID (RFID) tags can change that by providing real-time information about what's happening on store shelves. Here's how the system works for Procter & Gamble's (P&G's) Pampers.



2. Each box of Pampers has an RFID tag. Shelf-mounted scanners alert the stockroom of urgent need for restock.

3. Walmart's inventory management system tracks and links its in-store stock and its warehouse stock, prompting quicker replenishment and providing accurate real-time data.

4. Walmart's systems are linked to the P&G supply-chain management system. Demand spikes reported by RFID tags are immediately visible throughout the supply chain.

5. P&G's logistics software tracks its trucks with GPS locators, and tracks their contents with RFID tag readers. Regional managers can reroute trucks to fill urgent needs.

6. P&G suppliers also use RFID tags and readers on their raw materials, giving P&G visibility several tiers down the supply chain, and giving suppliers the ability to accurately forecast demand and production.

Sources: *Supply Chain Digest* (July 21, 2012); *Arkansas Business* (July 2, 2012); and *Business 2.0* (May 2002).

The U.S. *Cash for Clunkers* program produced an unintended bullwhip effect in the automobile industry. In an effort to stimulate the economy and improve fuel efficiency, the U.S. offered attractive rebates for trading old cars in exchange for new, more fuel-efficient vehicles. The $3 billion, 8-week program proved to be very popular with consumers. Fearing a shortage and assuming that they would not receive 100% of their orders, some dealers inflated orders for new cars to try to receive a larger pool of allocated vehicles. In one month, *Cash for Clunkers* increased demand by 50% for automakers, many of whom had already cut capacity significantly. Almost overnight, manufacturers and parts suppliers had to transform from a shift reduction mode to an overtime mode.

Paul Brennan/Shutterstock

Example S2

CALCULATING THE BULLWHIP EFFECT

Chieh Lee Metals, Inc. orders sheet metal and transforms it into 50 formed tabletops that are sold to furniture manufacturers. The table below shows the weekly variance of demand and orders for each major company in this supply chain for tables. Each firm has one supplier and one customer, so the order variance for one firm will equal the demand variance for its supplier. Analyze the relative contributions to the bullwhip effect in this supply chain.

FIRM	VARIANCE OF DEMAND	VARIANCE OF ORDERS	BULLWHIP MEASURE
Furniture Mart, Inc.	100	110	110/100 = 1.10
Furniture Distributors, Inc.	110	180	180/110 = 1.64
Furniture Makers of America	180	300	300/180 = 1.67
Chieh Lee Metals, Inc.	300	750	750/300 = 2.50
Metal Suppliers Ltd.	750	2000	2000/750 = 2.67

APPROACH ▶ Use Equation (S11-2) to calculate the bullwhip measure for each firm in the chain.

SOLUTION ▶ The last column of the table displays the bullwhip measure for each firm.

INSIGHT ▶ This supply chain exhibits a classic bullwhip effect. Despite what might be a very stable demand pattern at the retail level, order sizes to suppliers vary significantly. Chieh Lee should attempt to identifiy the causes for her own firm's order amplification, and she should attempt to work with her supply chain partners to try to reduce amplification at every level of the chain.

LEARNING EXERCISE ▶ Suppose that Chieh Lee is able to reduce her bullwhip measure from 2.50 to 1.20. If the measure for all other firms remained the same, what would be the new reduced variance of orders from Metal Suppliers? [Answer: 961.]

RELATED PROBLEMS ▶ S11.6, S11.7, S11.8, S11.9

STUDENT TIP The factor-weighting model adds objectivity to decision making.

Supplier Selection Analysis

Selecting suppliers from among a multitude of candidates can be a daunting task. Choosing suppliers simply based on the lowest bid has become a somewhat rare approach. Various, sometimes competing, factors often play a role in the decision. Buyers may consider such supplier characteristics as product quality, delivery speed, delivery reliability, customer service, and financial performance.

The *factor-weighting* technique, presented here, simultaneously considers multiple supplier criteria. Each factor must be assigned an importance *weight,* and then each potential supplier is *scored* on each factor. The weights typically sum to 100%. Factors are scored using the same scale (e.g., 1–10). Sometimes a key is provided for supplier raters that converts qualitative ratings into numerical scores (e.g., "Very good" = 8). Example S3 illustrates the weighted criteria in comparing two competing suppliers.

LO S11.3 *Describe* the factor-weighting approach to supplier evaluation

Example S3

FACTOR-WEIGHTING APPROACH TO SUPPLIER EVALUATION

Erick Davis, president of Creative Toys in Palo Alto, California, is interested in evaluating suppliers who will work with him to make nontoxic, environmentally friendly paints and dyes for his line of children's toys. This is a critical strategic element of his supply chain, and he desires a firm that will contribute to his product.

APPROACH ▶ Erick has narrowed his choices to two suppliers: Faber Paint and Smith Dye. He will use the factor-weighting approach to supplier evaluation to compare the two.

SOLUTION ▶ Erick develops the following list of selection criteria. He then assigns the weights shown to help him perform an objective review of potential suppliers. His staff assigns the scores and computes the total weighted score.

		FABER PAINT		*SMITH DYE*	
CRITERION	WEIGHT	SCORE (1–5) (5 HIGHEST)	WEIGHT × SCORE	SCORE (1–5) (5 HIGHEST)	WEIGHT × SCORE
Engineering/innovation skills	.20	5	1.0	5	1.0
Production process capability	.15	4	0.6	5	0.75
Distribution capability	.05	4	0.2	3	0.15
Quality performance	.10	2	0.2	3	0.3
Facilities/location	.05	2	0.1	3	0.15
Financial strength	.15	4	0.6	5	0.75
Information systems	.10	2	0.2	5	0.5
Integrity	.20	5	1.0	3	0.6
Total	1.00		3.9		4.2

Smith Dye received the higher score of 4.2 and, based on this analysis, would be the preferred vendor.

INSIGHT ▶ The use of a factor-weighting approach can help firms systematically identify the features that are important to them and evaluate potential suppliers in an objective manner. A certain degree of subjectivity remains in the process, however, with regard to the criteria chosen, the weights applied to those criteria, and the supplier scores that are applied to each criterion.

LEARNING EXERCISE ▶ If Erick believes that integrity should be twice as important while production process capability and financial strength should both only be 1/3 as important, how does the analysis change? [Answer: Faber Paint's score becomes 4.1, while Smith Dye's score becomes 3.8, so Faber Paint is now the preferred vendor.]

RELATED PROBLEMS ▶ S11.10, S11.11, S11.12 (S11.13 is available in MyOMLab)

Transportation Mode Analysis

The longer a product is in transit, the longer the firm has its money invested. But faster shipping is usually more expensive than slow shipping. A simple way to obtain some insight into this trade-off is to evaluate holding cost against shipping options. We do this in Example S4.

Example S4

DETERMINING DAILY COST OF HOLDING

A shipment of new connectors for semiconductors needs to go from San Jose to Singapore for assembly. The value of the connectors is $1,750, and holding cost is 40% per year. One airfreight carrier can ship the connectors 1 day faster than its competitor, at an extra cost of $20.00. Which carrier should be selected?

APPROACH ▶ First we determine the daily holding cost and then compare the daily holding cost with the cost of faster shipment.

SOLUTION ▶ Daily cost of holding the product = (Annual holding cost × Product value)/365

$$= (.40 \times \$1{,}750)/365$$

$$= \$1.92$$

LO S11.4 *Evaluate* cost-of-shipping alternatives

Because the cost of saving one day is $20.00, which is much more than the daily holding cost of $1.92, we decide on the less costly of the carriers and take the extra day to make the shipment. This saves $18.08 ($20.00 − $1.92).

INSIGHT ▶ The solution becomes radically different if the 1-day delay in getting the connectors to Singapore delays delivery (making a customer angry) or delays payment of a $150,000 final product. (Even 1 day's interest on $150,000 or an angry customer makes a savings of $18.08 insignificant.)

LEARNING EXERCISE ▶ If the holding cost is 100% per year, what is the decision? [Answer: Even with a holding cost of $4.79 per day, the less costly carrier is selected.]

RELATED PROBLEMS ▶ S11.14, S11.15, S11.16, S11.17

Example S4 looks only at holding cost versus shipping cost. For the operations or logistics manager there are many other considerations, including ensuring *on-time delivery*, coordinating shipments to maintain a schedule, getting a new product to market, and keeping a customer happy. Estimates of these other costs can be added to the estimate of the daily holding cost. Determining the impact and cost of these considerations makes the evaluation of shipping alternatives a challenging OM task.

Warehouse Storage

Storage represents a significant step for many items as they travel through their respective supply chains. The U.S. alone has more than 13,000 buildings dedicated to warehouse and storage. Some exceed the size of several connected football fields. In fact, more than 35% have over 100,000 square feet of floor space.

Care should be taken when determining which items to store in various locations in a warehouse. In large warehouses in particular, hundreds or thousands of trips are made each day along very long aisles. Proper placement of items can improve efficiency by shaving significant travel time for workers. In Example S5, we observe a simple way to determine storage locations in a warehouse.

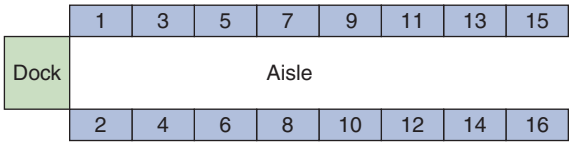
Example S5

DETERMINING STORAGE LOCATIONS IN A WAREHOUSE

Erika Marsillac manages a warehouse for a local chain of specialty hardware stores. As seen in Figure S11.3, the single-aisle rectangular warehouse has a dock for pickup and delivery, along with 16 equal-sized storage blocks for inventory items.

Figure **S11.3**

Storage Locations in the Warehouse



LO S11.5 *Allocate* items to storage locations in a warehouse

The following table shows: (1) the category of each item stored in the warehouse, (2) the estimated number of times per month (trips) that workers need to either store or retrieve those items, and (3) the area (number of specialized blocks) required to store the items. Erika wishes to assign items to the storage blocks to minimize average distance traveled.

ITEM	MONTHLY TRIPS TO STORAGE	BLOCKS OF STORAGE SPACE NEEDED
Lumber	600	5
Paint	260	2
Tools	150	3
Small hardware	400	2
Chemical bags	90	3
Lightbulbs	220	1

APPROACH ► For each item, calculate the ratio of the number of trips to blocks of storage area needed. Rank the items according to this ratio, and place the *highest*-ranked items closest to the dock.

SOLUTION ► The following table calculates the ratio for each item and ranks the items from highest to lowest. Based on the ranking, items are assigned to the remaining blocks that are as close to the dock as possible. (Where applicable, given a choice between two equidistant blocks, items should be placed next to items of the same type rather than across the aisle from them.)

ITEM	TRIPS/BLOCKS	RANKING	ASSIGNED BLOCKS
Lumber	600/5 = 120	4	6, 7, 8, 9, 10
Paint	260/2 = 130	3	3, 5
Tools	150/3 = 50	5	11, 12, 13
Small hardware	400/2 = 200	2	2, 4
Chemical bags	90/3 = 30	6	14, 15, 16
Lightbulbs	220/1 = 220	1	1

INSIGHT ► This procedure allocates items with the highest "bang-for-the-buck" first. The "bang" (value) here is the number of trips. Because we want to minimize travel, we would like to place items with high-frequency visits near the front. The storage space represents the "buck" (cost). We want items that take up a lot of space moved toward the back because if they were placed near the front, we would have to travel past their multiple blocks every time we needed to store or retrieve an item from a different category. This bang versus buck trade-off is neatly accommodated by using the trips/blocks ratio (column 2 of the solution table). In this example, even though lumber has the highest number of trips, the lumber takes up so much storage space that it is placed further back, toward the middle of the warehouse.

LEARNING EXERCISE ► Order frequency for paint is expected to increase to 410 trips per month. How will that change the storage plan? [Answer: Paint and small hardware will switch storage locations.]

RELATED PROBLEMS ► S11.18, S11.19, S11.20

Summary

Myriad tools have been developed to help supply-chain managers make well-informed decisions. We have provided a small sampling in this supplement. A decision tree can help determine the best number of suppliers to protect against supply disruption from potential disasters. The bullwhip measure can identify each supply chain member's contribution to exacerbating ordering fluctuations. The factor-weighting approach can be used to help select suppliers based on multiple criteria. Inventory holding costs can be computed for various shipping alternatives to better compare their overall cost impact. Finally, items can be ranked according to the ratio of (trips/blocks of storage) to determine their best placement in a warehouse.

Discussion Questions

1. What is the difference between "unique-event" risk and "super-event" risk?
2. If the probability of a "super-event" increases, does the "unique-event" risk increase or decrease in importance? Why?
3. If the probability of a "super-event" decreases, what happens to the likelihood of needing multiple suppliers?
4. Describe some ramifications of the bullwhip effect.
5. Describe causes of the bullwhip effect and their associated remedies.
6. Describe how the bullwhip measure can be used to analyze supply chains.
7. Describe some potentially useful categories to include in a factor-weighting analysis for supplier selection.
8. Describe some potential pitfalls in relying solely on the results of a factor-weighting analysis for supplier selection.
9. Describe some disadvantages of using a slow shipping method.
10. Besides warehouse layout decisions, what are some other applications where ranking items according to "bang/buck" might make sense?

Solved Problems

Virtual Office Hours help is available in MyOMLab.

SOLVED PROBLEM S11.1

Jon Jackson Manufacturing is searching for suppliers for its new line of equipment. Jon has narrowed his choices to two sets of suppliers. Believing in diversification of risk, Jon would select two suppliers under each choice. However, he is still concerned about the risk of both suppliers failing at the same time. The "San Francisco option" uses both suppliers in San Francisco. Both are stable, reliable, and profitable firms, so Jon calculates the "unique-event" risk for either of them to be 0.5%. However, because San Francisco is in an earthquake zone, he estimates the probability of an event that would knock out both suppliers to be 2%. The "North American option" uses one supplier in Canada and another in Mexico. These are upstart firms; John calculates the "unique-event" risk for either of them to be 10%. But he estimates the "super-event" probability that would knock out both of these suppliers to be only 0.1%. Purchasing costs would be $500,000 per year using the San Francisco option and $510,000 per year using the North American option. A total disruption would create an annualized loss of $800,000. Which option seems best?

SOLUTION

Using Equation (S11-1), the probability of a total disruption (i.e., the probability of incurring the $800,000 loss) equals:

$$\text{San Francisco option: } 0.02 + (1 - 0.02)0.005^2 = 0.02 + 0.0000245 = 0.0200245, \text{ or } 2.00245\%$$

$$\text{North American option: } 0.001 + (1 - 0.001)0.1^2 = 0.001 + 0.0099 = 0.01099, \text{ or } 1.099\%$$

$$\text{Total annual expected costs} = \text{Annual purchasing costs} + \text{Expected annualized disruption costs}$$

$$\text{San Francisco option: } \$500{,}000 + \$800{,}000(0.0200245) = \$500{,}000 + \$16{,}020 = \$516{,}020$$

$$\text{North American option: } \$510{,}000 + \$800{,}000(0.01099) = \$510{,}000 + \$8{,}792 = \$518{,}792$$

In this case, the San Francisco option appears to be slightly cheaper.

SOLVED PROBLEM S11.2

Over the past 10 weeks, demand for gears at Michael's Metals has been 140, 230, 100, 175, 165, 220, 200, and 178. Michael has placed weekly orders of 140, 250, 90, 190, 140, 240, 190, and 168 units.

The sample variance of a data set can be found by using the VAR.S function in Excel or by plugging each value (x) of the data set into the formula: Variance $= \dfrac{\Sigma(x - \bar{x})^2}{(n - 1)}$, where $\bar{x}$ is the mean of the data set and n is the number of values in the set. Using Equation (S11-2), calculate the bullwhip measure for Michael's Metals over the 10-week period.

SOLUTION

$$\text{Mean demand} = (140 + 230 + 100 + 175 + 165 + 220 + 200 + 178)/8 = 1{,}408/8 = 176$$

Variance of demand

$$= \frac{(140 - 176)^2 + (230 - 176)^2 + (100 - 176)^2 + (175 - 176)^2 + (165 - 176)^2 + (220 - 176)^2 + (200 - 176)^2 + (178 - 176)^2}{(8 - 1)}$$

$$= \frac{36^2 + 54^2 + 76^2 + 1^2 + 11^2 + 44^2 + 24^2 + 2^2}{7} = \frac{1{,}296 + 2{,}916 + 5{,}776 + 1 + 121 + 1{,}936 + 576 + 4}{7}$$

$$= \frac{12{,}626}{7} = 1{,}804$$

$$\text{Mean orders} = (140 + 250 + 90 + 190 + 140 + 240 + 190 + 168)/8 = 1{,}408/8 = 176$$

Variance of orders

$$= \frac{(140-176)^2 + (250-176)^2 + (90-176)^2 + (190-176)^2 + (140-176)^2 + (240-176)^2 + (190-176)^2 + (168-176)^2}{(8-1)}$$

$$= \frac{36^2 + 74^2 + 86^2 + 14^2 + 36^2 + 64^2 + 14^2 + 8^2}{7} = \frac{1{,}296 + 5{,}476 + 7{,}396 + 196 + 1{,}296 + 4{,}096 + 196 + 64}{7}$$

$$= \frac{20{,}016}{7} = 2{,}859$$

From Equation (S11-2), the bullwhip measure = 2,859/1,804 = 1.58.
Since 1.58 > 1, Michael's Metals is contributing to the bullwhip effect in its supply chain.

SOLVED PROBLEM S11.3

Victor Pimentel, purchasing manager of Office Supply Center of Mexico, is searching for a new supplier for its paper. The most important supplier criteria for Victor include paper quality, delivery reliability, customer service, and financial condition, and he believes that paper quality is twice as important as each of the other three criteria. Victor has narrowed the choice to two suppliers, and his staff has rated each supplier on each criterion (using a scale of 1 to 100, with 100 being highest), as shown in the following table:

	PAPER QUALITY	DELIVERY RELIABILITY	CUSTOMER SERVICE	FINANCIAL CONDITION
Monterrey Paper	85	70	65	80
Papel Grande	80	90	95	75

Use the factor-weighting approach to determine the best supplier choice.

SOLUTION

To determine the appropriate weights for each category, create a simple algebraic relationship:

Let x = weight for criteria 2, 3, and 4.
Then $2x + x + x + x = 100\%$, i.e., $5x = 100\%$, or $x = 0.2 = 20\%$

Thus, paper quality has a weight of 2(20%) = 40%, and the other three criteria each have a weight of 20%.

The following table presents the factor-weighting analysis:

		MONTERREY PAPER		*PAPEL GRANDE*	
CRITERION	WEIGHT	SCORE (1–100) (100 HIGHEST)	WEIGHT × SCORE	SCORE (1–100) (100 HIGHEST)	WEIGHT × SCORE
Paper quality	.40	85	34	80	32
Delivery reliability	.20	70	14	90	18
Customer service	.20	65	13	95	19
Financial condition	.20	80	16	75	15
Total	1.00		77		84

Since 84 > 77, Papel Grande should be the chosen supplier according to the factor-weighting method.

SOLVED PROBLEM S11.4

A French car company ships 120,000 cars annually to the United Kingdom. The current method of shipment uses ferries to cross the English Channel and averages 10 days. The firm is considering shipping by rail through the Chunnel (the tunnel that goes through the English Channel) instead. That transport method would average approximately 2 days. Shipping through the Chunnel costs $80 more per vehicle. The firm has a holding cost of 25% per year. The average value of each car shipped is $20,000. Which transportation method should be selected?

SOLUTION

Daily cost of holding the product = (.25 × $20,000)/365 = $13.70
Total holding cost savings by using the Chunnel = (10 − 2) × $13.70 = $110 (rounded)

Since the $110 savings exceeds the $80 higher shipping cost, the Chunnel option appears best.
This switch would save the firm (120,000)($110 − $80) = $3,600,000 per year.

Problems

Problems S11.1–S11.5 relate to Evaluating Disaster Risk in the Supply Chain

•**S11.1** How would you go about attempting to come up with the probability of a "super-event" or the probability of a "unique-event?" What factors would you consider?

••**S11.2** Following the incident of a furnace fire in the semiconductor plant in Albuquerque, New Mexico, Wellington Company decided to change its single-sourcing strategy of major components to multi-sourcing. The top management of Wellington Company believes that the probability in any year of a "super-event" that might shut down Albuquerque plant again for at least 2 weeks is 0.3%; causing financial strains of €600,000. However, the probability of a "unique event" risk for any of the suppliers is estimated to be 2%. Evaluate the number of suppliers Wellington Company should select, assuming that the marginal cost of managing each supplier will not exceed €10,000 per year and that up to three nearly identical suppliers are available.

••**S11.3** Refer to Problem S11.2,Wellington Company re-estimated the probability of a "super- event" to 0.2%, due to some heavy safety investment carried out in the Albuquerque plant. In addition, they replaced their second and third suppliers, for quality reasons, with another two whose annual management cost would be €20,000 each (compared to €10,000 previously). Assuming that the first supplier would be the first choice, how many suppliers should Wellington Company use?

••**S11.4** Johnson Chemicals is considering two options for its supplier portfolio. Option 1 uses two local suppliers. Each has a "unique-event" risk of 5%, and the probability of a "super-event" that would disable both at the same time is estimated to be 1.5%. Option 2 uses two suppliers located in different countries. Each has a "unique-event" risk of 13%, and the probability of a "super-event" that would disable both at the same time is estimated to be 0.2%.

a) What is the probability that both suppliers will be disrupted using option 1?
b) What is the probability that both suppliers will be disrupted using option 2?
c) Which option would provide the lowest risk of a total shutdown?

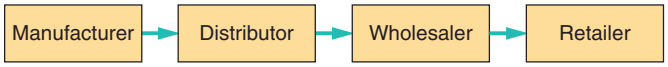
••**S11.5** Kryoneriperfume company is considering the following two alternatives for the supply of vetiver oil (an essential oil used in high-end perfumes). Alternative one is to use two suppliers located in Haiti where half of the world's vetiver oil comes from. Each has a "unique-event" risk of 5%, and the probability of a "super-event" that would disable both at the same time is estimated to be 15%, due to Haiti's vulnerability to earthquakes (remember the earthquake in 2010). Alternative 2 is to use two suppliers located in Japan (another main producer of vetiver oil) where each has a "unique-event" risk of 1%, and the probability of a "super-event" that would disable both at the same time is estimated to be 2%, due to Japan's exceptionally great infrastructure developed after 1995 Kobe earthquake. Estimate which alternative seems best?

Problems S11.6–S11.9 relate to Managing the Bullwhip Effect

••**S11.6** Consider the supply chain illustrated below:

Last year, the retailer's weekly variance of demand was 200 units. The variance of orders was 500, 600, 750, and 1,350 units for the retailer, wholesaler, distributor, and manufacturer, respectively. (Note that the variance of orders equals the variance of demand for that firm's supplier.)

a) Calculate the bullwhip measure for the retailer.
b) Calculate the bullwhip measure for the wholesaler.
c) Calculate the bullwhip measure for the distributor.
d) Calculate the bullwhip measure for the manufacturer.
e) Which firm appears to be contributing the most to the bullwhip effect in this supply chain?



••**S11.7** Over the past 5 weeks, demand for wine at Winston's Winery has been 1,000, 2,300, 3,200, 1,750, and 1,200 bottles. Winston has placed weekly orders for glass bottles of 1,100, 2,500, 4,000, 1,000, and 900 units. (Recall that the sample variance of a data set can be found by using the VAR.S function in Excel or by plugging each x value of the data set into the formula: Variance $= \frac{\Sigma(x - \bar{x})^2}{(n - 1)}$, where $\bar{x}$ is the mean of the data set and n is the number of values in the set.)

a) What is the variance of demand for Winston's Winery?
b) What is the variance of orders from Winston's Winery for glass bottles?
c) What is the bullwhip measure for glass bottles for Winston's Winery?
d) Is Winston's Winery providing an amplifying or smoothing effect?

•••**S11.8** A manufacturer produces asingle product which is sold abroad to an industrial company through the followingchannel.

	VARIANCE OF DEMAND	VARIANCE OF ORDERS
Manufacturer	1000	1100
Agent	1100	2000
Distributor	2000	4000
Industrial company	4000	9000

a) Calculate the bullwhip effect for each stage of the supply chain.
b) What kind of actions management can take to smooth the bullwhip effect.

•••**S11.9** Consider a three-firm supply chain consisting of a retailer, manufacturer, and supplier. The retailer's demand over an 8-week period was 100 units each of the first 2 weeks, 200 units each of the second 2 weeks, 300 units each of the third 2 weeks, and 400 units each of the fourth 2 weeks. The following table presents the orders placed by each firm in the supply chain. Notice, as is often the case in supply chains due to economies of scale, that total units are the same in each case, but firms further up the supply chain (away from the retailer) place larger, less frequent, orders.

WEEK	RETAILER	MANUFACTURER	SUPPLIER
1	100	200	600
2	100		
3	200	400	
4	200		
5	300	600	1400
6	300		
7	400	800	
8	400		

Recall that the sample variance of a data set can be found by using the VAR.S function in Excel or by plugging each x value of the data set into the formula: Variance $= \frac{\Sigma(x - \bar{x})^2}{(n - 1)}$, where $\bar{x}$ is the mean of the data set and n is the number of values in the set.

a) What is the bullwhip measure for the retailer?
b) What is the bullwhip measure for the manufacturer?
c) What is the bullwhip measure for the supplier?
d) What conclusions can you draw regarding the impact that economies of scale may have on the bullwhip effect?

Problems S11.10–S11.13 relate to Supplier Selection Analysis

••**S11.10** As purchasing agent for Eynan Enterprises in Richmond, Virginia, you ask your buyer to provide you with a ranking of "excellent," "good," "fair," or "poor" for a variety of characteristics for two potential vendors. You suggest that the "Products" total be weighted 40% and the other three categories totals be weighted 20% each. The buyer has returned the rankings shown in Table S11.2.

Which of the two vendors would you select? PX

••**S11.11** Using the data in Problem S11.10, assume that both Donna, Inc. and Kay Corp. are able to move all their "poor" ratings to "fair." How would you then rank the two firms? PX

••**S11.12** Develop a vendor-rating form that represents your comparison of the education offered by universities in which you considered (or are considering) enrolling. Fill in the necessary data, and identify the "best" choice. Are you attending that "best" choice? If not, why not?

Additional problem **S11.13** *is available in* MyOMLab.

Problems S11.14–S11.17 relate to Transportation Mode Analysis

••**S11.14** Your options for shipping $100,000 of machine parts from Baltimore to Kuala Lumpur, Malaysia, are (1) use a ship that will take 30 days at a cost of $3,800 or (2) truck the parts to Los Angeles and then ship at a total cost of $4,800. The second option will take only 20 days. You are paid via a letter of credit the day the parts arrive. Your holding cost is estimated at 30% of the value per year.

a) Which option is more economical?
b) What customer issues are not included in the data presented?

••**S11.15** If you have a third option for the data in Problem S11.14 and it costs only $4,000 and also takes 20 days, what is your most economical plan?

••**S11.16** A company with a plant in Basel can be served by both rail and truck at a cost of €250 and €1500 per load, respectively. The transit time for the train is 15 days while for the truck is 5 days. (a) If the daily cost of transit inventory is €100, which transportation mode is more economical attractive? (b) What will be the costs involved, if the daily inventory carrying cost is €50? (c) Identify related principles need to consider when designing a transportation system.

TABLE S11.2 Vendor Rating for Problem S11.10

VENDOR RATING

Company	Excellent (4)	Good (3)	Fair (2)	Poor (1)
Financial Strength			K	D
Manufacturing Range			KD	
Research Facilities	K		D	
Geographical Locations		K	D	
Management		K	D	
Labor Relations			K	D
Trade Relations			KD	
Service				
Deliveries on Time		KD		
Handling of Problems		KD		
Technical Assistance		K	D	

Products	Excellent (4)	Good (3)	Fair (2)	Poor (1)
Quality	KD			
Price			KD	
Packaging			KD	
Sales				
Product Knowledge			D	K
Sales Calls			K	D
Sales Service		K	D	

DONNA INC. = D
KAY CORP. = K

•••**S11.17** Recently, Abercrombie & Fitch (A&F) began shifting a large portion of its Asian deliveries to the U.S. from air freight to slower but cheaper ocean freight. Shipping costs have been cut dramatically, but shipment times have gone from days to weeks. In addition to having less control over inventory and being less responsive to fashion changes, the holding costs have risen for the goods in transport. Meanwhile, Central America might offer an inexpensive manufacturing alternative that could reduce shipping time through the Panama Canal to, say, 6 days, compared to, say, 27 days from Asia. Suppose that A&F uses an annual holding rate of 30%. Suppose further that the product costs $20 to produce in Asia. Assuming that the transportation cost via ocean liner would be approximately the same whether coming from Asia or Central America, what would the maximum production cost in Central America need to be in order for that to be a competitive source compared to the Asian producer?

Problems S11.18–S11.20 relate to Warehouse Storage

• **S11.18** The items listed in the following table are stored in a warehouse.

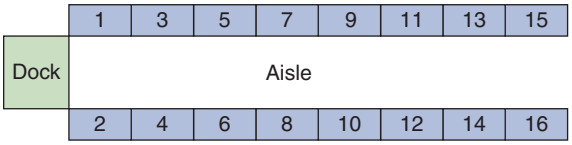
ITEM	WEEKLY TRIPS	AREA NEEDED (BLOCKS)
A	300	60
B	219	3
C	72	1
D	90	10
E	24	3

a) Which item should be stored at the very front (closest to the dock)?
b) Which item should be stored at the very back (furthest from the dock)?

••**S11.19** Amy Zeng, owner of Zeng's Restaurant Distributions, supplies nonperishable goods to restaurants around the metro area. She stores all the goods in a warehouse. The goods are divided into five categories according to the following table. The table indicates the number of trips per month to store or retrieve items in each category, as well as the number of storage blocks taken up by each.

ITEM CATEGORY	MONTHLY TRIPS	AREA NEEDED (BLOCKS)
Paper Products	50	2
Dishes, Glasses, and Silverware	16	4
Cleaning Agents	6	2
Cooking Oils and Seasonings	30	2
Pots and Pans	12	6

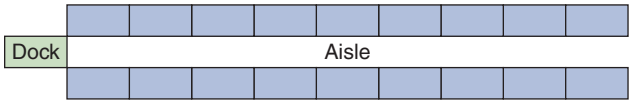
The following picture of the warehouse provides an identification number for each of the 16 storage blocks. For each item category, indicate into which blocks it should be stored.



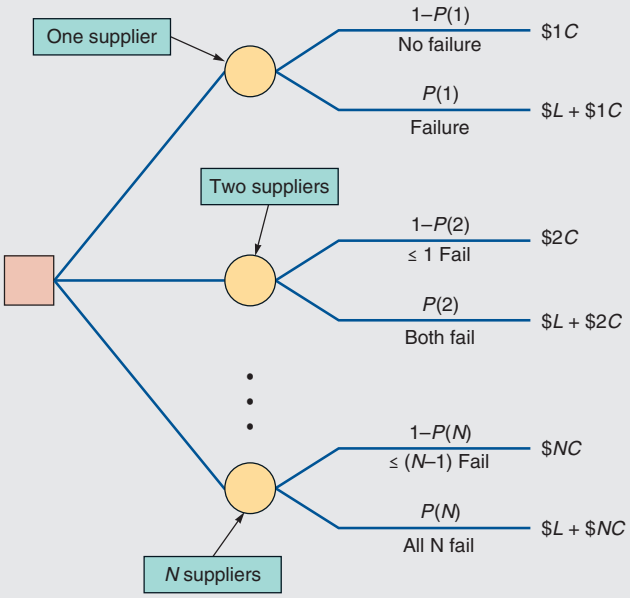
••**S11.20** The items listed in the following table are stored in a warehouse.

ITEM	WEEKLY TRIPS	AREA NEEDED (BLOCKS)
A	2	1
B	160	8
C	16	1
D	40	4
E	24	2
F	15	1
G	4	1

Using the following figure, indicate the best storage location for each item to minimize average distance traveled.



Supplement 11 *Rapid* Review

Main Heading	Review Material	MyOMLab
TECHNIQUES FOR EVALUATING SUPPLY CHAINS (p. 472)	Many supply chain metrics exist that can be used to evaluate performance within a company and for its supply chain partners. The 2011 Tōhoku earthquake and tsunami devastated eastern sections of Japan. The economic impact was felt around the globe, as manufacturers had been relying heavily, in some cases exclusively, on suppliers located in the affected zones. Manufacturers in several industries worldwide took 6 months or longer before they saw their supply chains working normally again.	Concept Question: 1.1
EVALUATING DISASTER RISK IN THE SUPPLY CHAIN (pp. 472–474)	Disasters that disrupt supply chains can take on many forms, including tornadoes, fires, hurricanes, typhoons, tsunamis, earthquakes, and terrorism. Firms often use multiple suppliers for important components to mitigate the risks of total supply disruption. *The probability of all* n *suppliers being disrupted simultaneously*: $$P(n) = S + (1 - S)U^n \quad \text{(S11-1)}$$ where: S = probability of a "super-event" disrupting all suppliers simultaneously U = probability of a "unique-event" disrupting only one supplier L = financial loss incurred in a supply chain if all suppliers were disrupted C = marginal cost of managing a supplier All suppliers will be disrupted simultaneously if either the super-event occurs or the super-event does not occur but a unique-event occurs for all of the suppliers. As the probability of a super-event (S) increases, the advantage of utilizing multiple suppliers diminishes (all would be knocked out anyway). On the other hand, large values of the unique event (U) increase the likelihood of needing more suppliers. These two phenomena taken together suggest that when multiple suppliers are used, managers may consider using ones that are geographically dispersed to lessen the probability of all failing simultaneously. A decision tree can be used to help operations managers make this important decision regarding number of suppliers.  	Concept Questions: 2.1–2.4 Problems: S11.1–S11.5 Virtual Office Hours for Solved Problem: S11.1
MANAGING THE BULLWHIP EFFECT (pp. 474–476)	*Demand forecast updating, order batching, price fluctuations*, and *shortage gaming* can all produce inaccurate information, resulting in distortions and fluctuations in the supply chain and causing the *bullwhip effect*. ■ **Bullwhip effect**—The increasing fluctuation in orders that often occurs as orders move through the supply chain. "Bullwhip" fluctuations create unstable production schedules, resulting in expensive capacity change adjustments such as overtime, subcontracting, extra inventory, backorders, hiring and laying off of workers, equipment additions, equipment underutilization, longer lead times, or obsolescence of overproduced items. The bullwhip effect can occur when orders decrease as well as when they increase. Often the human tendency to overreact to stimuli causes managers to make decisions that exacerbate the phenomenon.	Concept Questions: 3.1–3.4 Problems: S11.6–S11.9 Virtual Office Hours for Solved Problem: S11.2

Main Heading	Review Material	MyOMLab
	The overarching solution to the bullwhip effect is simply for supply chain members to share information and work together. *Specific remedies for the four primary causes include:* Demand forecast errors → *Share demand information throughout the chain* Order batching → *Think of the supply chain as one firm when choosing order sizes* Price fluctuations → *Institute everyday low prices* Shortage gaming → *Allocate orders based on past demand* A straightforward way to measure the extent of the bullwhip effect at any link in the supply chain is to calculate the *bullwhip measure*: $$\text{Bullwhip} = \frac{\text{Variance of orders}}{\text{Variance of demand}} = \frac{\sigma^2_{\text{orders}}}{\sigma^2_{\text{demand}}} \quad \text{(S11-2)}$$ Variance *amplification* (i.e., the bullwhip effect) is present if the bullwhip measure is greater than 1. That means the size of a company's orders fluctuate more than the size of its incoming demand. If the measure equals 1, then no amplification is present. A value less than 1 would imply a *smoothing* or *dampening* scenario as orders move up the supply chain from the retailer toward suppliers.	
SUPPLIER SELECTION ANALYSIS (pp. 476–477)	Choosing suppliers simply based on the lowest bid has become a somewhat rare approach. Various, sometimes competing, factors often play a role in the decision. Buyers may consider such supplier characteristics as product quality, delivery speed, delivery reliability, customer service, and financial performance. The *factor-weighting* technique simultaneously considers multiple supplier criteria. Each factor must be assigned an importance *weight*, and then each potential supplier is *scored* on each factor. The weights typically sum to 100%. Factors are scored using the same scale (e.g., 1–10). Sometimes a key is provided for supplier raters that converts qualitative ratings into numerical scores (e.g., "Very good" = 8).	Concept Questions: 4.1–4.2 Problems: S11.10–S11.11, S11.13 Virtual Office Hours for Solved Problem: S11.3
TRANSPORTATION MODE ANALYSIS (pp. 477–478)	The longer a product is in transit, the longer the firm has its money invested. But faster shipping is usually more expensive than slow shipping. A simple way to obtain some insight into this trade-off is to evaluate holding cost against shipping options. *Daily cost of holding the product*: (Annual holding cost × Product value)/365 There are many other considerations beyond holding vs. shipping costs when choosing the appropriate transportation mode and carrier, including ensuring *on-time delivery* (whether fast or slow), coordinating shipments to maintain a schedule, getting a new product to market, and keeping a customer happy. Estimates of these other costs can be added to the estimate of the daily holding cost.	Concept Questions: 5.1–5.2 Problems: S11.14–S11.17 Virtual Office Hours for Solved Problem: S11.4
WAREHOUSE STORAGE (pp. 478–479)	When determining storage locations for items in a warehouse, rank the items according to the ratio: (Number of trips/Blocks of storage needed) Place the items with the *highest* ratios closest to the dock.	Concept Questions: 6.1–6.2 Problems: S11.18–S11.20

Self Test

■ **Before taking the self-test,** refer to the learning objectives listed at the beginning of the supplement.

LO S11.1 A system to ensure that an organization can resume business after a disruption is called:
a) Crisis avoidance planning
b) Crisis continuation planning
c) Crisis disaster planning
d) Business continuity planning
e) Business crisis and continuity management

LO S11.2 Typically, the bullwhip effect is most pronounced at which level of the supply chain?
a) consumers **b)** suppliers
c) wholesalers **d)** retailers

LO S11.3 Which of the following is not a characteristic of the factor-weighting approach to supplier evalution?
a) it applies quantitative scores to qualitative criteria
b) the weights typically sum to 100%
c) multiple criteria can be considered simultaneously
d) subjective judgment is often involved
e) it applies qualitative assessments to quantitative criteria

LO S11.4 Catastrophic ("super") events:
a) affect many suppliers (sometimes all)
b) can affect an entire nation even the entire world
c) would include such events as an entire set of airlines being grounded
d) large-scale natural disasters
e) widespread communications failure
f) all the above.

LO S11.5 Which of the following items is most likely to be stored at the back of a warehouse, furthest away from the shipping dock?
a) low number of trips and low number of storage blocks
b) low number of trips and high number of storage blocks
c) high number of trips and low number of storage blocks
d) high number of trips and high number of storage blocks

Answers: LO S11.1. d; LO S11.2. b; LO S11.3. e; LO S11.4. f; LO S11.5. b.