CHAPTER

3

(More) Sustainable Supply Chains and Humanitarian Logistics

Learning Objectives
After reading this chapter, you will be able to:

LO1 define the three bottom lines that contribute to more sustainable supply chains.

LO2 define and explain the activities necessary for a reverse supply chain, and how this is a critical part of a closed-loop supply chain.

LO3 describe how firms can use multiple methods to improve the energy efficiency of their supply chains; use a heuristic to formulate an efficient vehicle delivery route.

LO4 explain how social performance encompasses customer and workplace safety, and what actions managers can take to improve both.

LO5 describe how supply chains can be designed to provide relief in humanitarian disasters, and then how supply chains must change as recovery proceeds.

Across the Organization
More sustainable supply chains are important to:

- purchasing, which must monitor the processes used by suppliers to reduce the use of toxic substances, to reduce wastes, and to ensure fair working conditions.

- distribution, which must work with retail partners or government agencies to collect and recycle used products.

- operations, which must examine internal processes to increase material conservation and energy efficiency, and also to look for ways to convert wastes into useful by-products.

- finance, which must assess the implications of potential disruptions and risks as the supply chain grows, particularly on a global basis.

- marketing, which must protect the firm’s brands by ensuring that services, processes, and products do not pose health or safety hazards to customers.
Many Canadian companies source garments and other apparel from suppliers located around the world. Much like other global retailers, these companies do so to lower prices and to increase their flexibility to follow new fashion trends. And sourcing from countries such as Bangladesh provides jobs to local workers who otherwise have few opportunities. Unfortunately, the conditions faced by some of these workers can be both harsh and unsafe, with suppliers facing little accountability.

These problems occur for many reasons. Retailers often place orders with suppliers who, in turn, can outsource their work to sub-contractors. Within Bangladesh, according to one expert, “An order could be produced in 20 different units and it comes to one place for final inspection.” Even if retailers have strict rules about authorizing subcontracting, some suppliers that are running late ignore these rules to save time and avoid being penalized for late deliveries. As a result, Canadian firms are unable to trace where all of their clothing was made, and they struggle to monitor and manage distant suppliers and sub-contractors.

Recent media coverage of poor safety and worker deaths in developing countries has provoked a global outcry. Most notably, in April 2013, more than 1100 workers in a Dhaka-area garment factory were killed when the eight-storey Rana Plaza building collapsed. The building lacked emergency exits and had several floors that had reportedly been added illegally, weakening the structure.

In response, many firms in the garment industry have been pushed to take dramatic steps to improve suppliers’ safety standards. For example, Loblaw was the only Canadian signatory to a European-led accord of over 70 multinational retailers that established a timetable for inspecting and renovating factories in Bangladesh. Other Canadian retailers, such as Canadian Tire and HBC, joined a U.S.-led alliance aimed at increasing safety and working conditions in Bangladesh factories. The primary difference between the two is that the latter alliance expects the Bangladeshi government to play a greater role through upgrading national fire and building standards.

Signing such agreements is only one of several options. At one extreme, a firm can simply stop sourcing from countries that have very poor working conditions, or where safety improvements have been difficult to put in place and monitor. Disney is one firm that has chosen to take this approach, and has publicly stated that it will not longer buy from suppliers located in Bangladesh.

Alternatively, firms can choose to buy apparel only from certified suppliers, such as those with SA8000:2014. Unfortunately, certification is not an ironclad guarantee for worker safety; these suppliers can also experience major problems. For example, almost 300 workers in Pakistan died in a fire that occurred in a certified garment factory in 2012.

At the other extreme, Gildan Activewear, a large Canadian maker of T-shirts, bought a factory in Bangladesh that supplied its garments. This vertical integration allowed senior executives to directly control worker safety, wages, and building safety, although this must be balanced against the reduced flexibility that owning factories creates. Thus, there is no perfect option. Instead, managers must work to build long-term relationships with reputable like-minded suppliers, who are monitored to ensure safety and supported to improve competitiveness.1
Define the three bottom lines that contribute to more sustainable supply chains.

**financial bottom line** An organization’s performance related to the economic needs of the shareholders, lenders, employees, and customers, who each rely on the firm to generate a reasonable return on invested capital after paying for needed resources and labour.

**environmental bottom line** An organization’s performance related to the responsible stewardship of ecological resources used in the production of services and products, and mitigation of any adverse ecological impact.

**social bottom line** An organization’s performance related to the moral, ethical, and philanthropic expectations of the communities and society in which it operates.

**humanitarian logistics** The process of planning, implementing, and controlling the efficient, cost-effective deployment of materials, resources, and information from donors to vulnerable people, with the objective of alleviating human suffering.

loblaw offers an example of how a firm can work with partners to react to new consumer demands and change its supply chain practices. These capabilities can be used to be more competitive, and also to improve a firm’s social and environmental performance. Until recently, little attention was given to these last two dimensions of performance. Now a growing theme of sustainability has pushed many corporations toward the more responsible stewardship of ecological resources and human capital that they and their suppliers use in the production of their services or products. Some managers are striving to have services, products, and processes that are sustainable, which means that they meet humanity’s needs today without hurting future generations. To be fair, describing a business as “sustainable” is a misnomer; no supply chain is truly sustainable because so many complex interactions may improve one measure of social performance, but possibly hurt another of environmental performance. Instead, managers strive to design and operate more sustainable supply chains.

More sustainable supply chains encompass improvements to all three of the firm’s bottom lines, as depicted earlier in Figure 1.6. First, the **financial bottom line** addresses the needs of shareholders, lenders, employees, and customers, who each rely on the firm to provide valuable goods and services, while generating a reasonable return on invested capital after paying for needed resources and labour. Improving profits through better supply chain management can increase the chances of survival in a competitive setting. Historically, this bottom line has received most of the attention of managers.

Second, the **environmental bottom line** captures the ecological needs of the community and the planet through the firm’s responsible stewardship of natural resources used to produce services and products. The goal is to leave a small environmental footprint and conserve where possible, so that future generations can make use of abundant natural resources. The design and integration of supply chains can play a major role in preserving resources. We shall examine how supply chains can be extended to both produce goods and services, then reprocess used goods at the end of their lives to yield value in the form of remanufactured products or recycled materials. We will also examine how supply routes can be planned to reduce the amount of energy consumed in delivering materials or products to customers.

Finally, the **social bottom line** encompasses the customer safety, ethical, and philanthropic expectations of the communities and society in which a firm operates. While this responsibility covers a broad range of activities, supply chains are a critical factor in meeting such expectations. For example, carefully designing products to minimize potential harm to customers and developing supply chains that enable product traceability are important measures of the social bottom line. Ethical considerations also arise with the choice of suppliers (and their workplace practices and use of natural resources), the relationship between buyers and sellers, and the location of facilities.

Firms also can respond to natural and human-made disasters using their expertise in supply chain management. **Humanitarian logistics** is the process of planning, implementing, and controlling the efficient, cost-effective flow of materials and resources from donors to vulnerable and displaced people, with the objective of alleviating human suffering. Table 3.1 provides some examples of well-known firms actively developing more sustainable operations and supply chains.

A recent survey of CEOs of major corporations revealed that 93 percent believed that sustainability issues are critical to the future success of their companies, and 91 percent will employ new technologies (e.g., renewable energy, energy efficiency, information and communication) over the next five years. Yet, while 88 percent of these executives believe that they should be integrating sustainability through their supply chains, only 54 percent think that it has been achieved. Why is there a gap? While intuitively appealing, sustainability is tough to do well. Managing a single financial
bottom line is much easier, and does not require managers to understand complex trade-offs and synergies among three bottom lines. Sustainability efforts often require a long-term view that might require both patience and initial acceptance of lower short-term financial returns as supply chains are redesigned and improved.

**ENVIRONMENTAL PERFORMANCE**

Environmental concerns about business are voiced every day in the popular media. Service providers are examining ways to increase efficiency and reduce the impact of their operations on the environment. Manufacturers are feeling pressure to take responsibility for their products from production to their final fate after use, sometimes termed “cradle to grave.” In this section, we will discuss some environmental concerns, and how smart thinking by managers about their supply chains can help to address them. We will discuss the managerial implications for implementing an approach called “reverse supply chain,” which responds to the need to maximize the value of products at the end of their useful life. We will also show how the need for energy efficiency impacts decision making in supply chains.

**REVERSE SUPPLY CHAIN**

To address environmental concerns and to manage their products throughout their life cycles, firms such as HP, Labatt, Interface, and Caterpillar are developing supply chains with greater focus on sustainability. This focus has led to a shift in thinking about the end of a product’s useful life and the need to consider strategies for recycling, reusing, or disposing of products in an environmentally responsible manner. This approach, known as reverse supply chain, seeks to maximize the value of products at the end of their useful life, thereby reducing waste and environmental impact.

**TABLE 3.1**

**Examples of Initiative to Make Supply Chains More Sustainable**

<table>
<thead>
<tr>
<th>BOTTOM LINE</th>
<th>EXAMPLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental</td>
<td>Energy efficiency</td>
</tr>
<tr>
<td>Green design</td>
<td>Walmart Canada: New forklift trucks in the Alberta fresh food distribution centre operate on hydrogen fuel cells, eliminating carbon emissions.</td>
</tr>
<tr>
<td>Recycle/Reverse supply chain</td>
<td>Caterpillar: Its remanufacturing facilities recycle over two million pieces and 140 million pounds of materials annually in state-of-the-art factories worldwide.</td>
</tr>
<tr>
<td>Social</td>
<td>Product safety</td>
</tr>
<tr>
<td>Working conditions</td>
<td>Chiquita: More than a decade ago, adopted SA8000 for all of its owned farms. Many suppliers are now certified as well.</td>
</tr>
<tr>
<td>Disaster relief</td>
<td>DHL: Uses its comprehensive logistics network and worldwide presence to help people and communities affected by major sudden-onset natural disasters.</td>
</tr>
<tr>
<td>Financial</td>
<td>Cost effectiveness</td>
</tr>
<tr>
<td>Risk</td>
<td>Nikon: International expansion for DSLR cameras focused on Thailand. However, severe flooding halted all production. Local supply chain partners allowed Nikon to maintain output.</td>
</tr>
</tbody>
</table>

Define and explain the activities necessary for a reverse supply chain, and how this is a critical part of a closed-loop supply chain.
chains that not only manufacture and distribute new products, but also take back and recycle used products and packaging. The reverse supply chain is the process of planning, implementing, and controlling the efficient, cost-effective flow of used materials and products from the point of consumption to reuse, repair, remanufacture, or recycle. Major process activities include collection, inspection, and disassembly.

The process of planning, implementing, and controlling the efficient, cost-effective flow of used materials and products from the point of consumption to reuse, repair, remanufacture, or recycle. Major process activities include collection, inspection, and disassembly.

A supply chain that integrates the forward and reverse supply chains, thereby developing a complete chain of operations from cradle to cradle.

products sustainability

Information about product sustainability

Improved design

Early returns & end-of-life failure

Disassembly

Inspection & sorting

Collection

Raw materials

Components

Assembly

Distributor/retailer

Customer

Recycle

Recondition

Repair and reuse

Remanufacture

Legend

- Forward supply chain
- Reverse supply chain

Products flow to and from consumers, potentially offering multiple points to benefit from consumed materials. Wastes also could be generated at each tier in the supply chain.

also, information about a product or service’s sustainability performance, if measured across the supply chain, can be sent back to the new service/product development process to introduce improvements in future generations and new services. For example, environmental performance includes waste created by the product throughout the forward and reverse supply chains, as well as during customer use. Careful process analysis (see Chapter 4, “Process Configuration”) can redesign the product and supply chain processes to yield a smaller impact. Xerox has leveraged information from its used products and customers’ experience to develop more reliable and durable
products that have less waste, which, in turn, also can be remanufactured and leased for multiple cycles.

Although often overlooked, services can generate large amounts of waste, and reverse supply chains are not well-established. For example, operating rooms in hospitals use many disposable supplies that might be recycled (or if autoclaved, even reused). Medical supply firms are beginning to explore options to safely, yet responsibly, develop closed-loop supply chains, which can also provide new business opportunities. Finally, some charitable organizations, such as Habitat for Humanity’s ReStore, resell donated windows, doors, paint, hardware, lumber, tools, lighting fixtures, furniture and appliances.

**Processes to Close the Loop.** It is clear that the reverse supply chain processes are considerably different from those for forward flows, and considerably more expensive. A firm must establish convenient collection points to receive the used goods from the final customer and transport the goods to a *returns processor*, which is a facility owned by the manufacturer or outsourced to a supplier that is proficient at gleaning value from them. Several options are possible after inspection and sorting, which can use sophisticated tests to detect the for electronic or mechanical components.

First, if the item no longer works, it might be *repaired* and then returned to the customer or sold in another market. A second option is to partially disassemble, clean, and *recondition* the product, either to be sent to the distribution channel, which is the case with leased products, or back to customers, which is the case with a maintenance warranty. Third, the product could be *remanufactured* by tearing it down and rebuilding it with new parts as needed. Unlike reconditioning, a remanufactured product loses its original identity as new materials and components are mixed with quality-checked used parts. Finally, used parts or packaging that cannot be salvaged can be recycled for their material value (e.g., aluminum). In addition, some waste is often created at each step in the forward or reverse supply chain.

Reverse supply chains can be particularly important in the electronics industry. Have you ever wondered what happens to your old computer after you purchase a new one? You may have given it to the store where you purchased your new one, or taken it to a municipal recycling centre. Old computers and used electronic devices, termed e-waste, contain electronic components with materials that can be recycled. They also have toxins that leach into the soil if these components are left unprocessed; for example, lead and cadmium in computer circuit boards, mercury in switches and flat screens, and fire retardants on printed circuit boards and plastic casings.

Many recycling processors are typically low-tech and located in developing countries. When processing e-waste in these settings, workers usually wear little protective gear; toxins often are emitted to air when waste is burned; and liquid waste leaches into the ground from illegal dumps. This disregard for the environment prompted a backlash against the improper disposal of electronic equipment from developed countries. To address this, Canada was one of the signatories to the Basel Convention in 1992 (www.basel.int) that limited the import and export of hazardous waste, including e-waste, to enforce cleaner recycling practices. The Managerial Practice provides an example of how two companies use recycling to be environmentally responsible.

**Customers as Suppliers.** Firms, as well as individuals, participate in the reverse supply chain by supplying their used products and materials for processing. A continuous supply of these unused products and materials is needed to make the reverse supply chain
Financially viable. Various incentives may be used to influence the quantity, quality (condition), and timing of supply from customers. Examples of incentives include the following:

- **Fee.** A fee is paid to the user when a used product or recyclable material is delivered for recovery. Usually the fee depends on the condition of the product or material because this may determine the possibilities for its reuse. For example, scrap metal recyclers have offered a small payment to customers for end-of-life automobiles for many decades.

- **Deposit fee.** Such fees provide incentive for the user to return packaging or products to be reimbursed for an initial deposit fee. This fee may relate to the product itself, such as a rented musical instrument, which must be refurbished (cleaned, maintained) before allowing the next customer to use it. Alternatively, a small fee is applied when a consumer buys a consumable product in a returnable container, such as the deposit fee applied on beer and wine bottles in Ontario.

- **Take back.** A company may offer to collect its products from its customers for no charge when those customers want to dispose of them. Dell, for example,
charges no fees to recycle old computers from customers. Dell has designed its computers to make them easier to disassemble and recycle.

- **Trade-in.** One can get a new copy of a product if another copy is returned. For example, purchasing a refurbished engine for an automobile often requires the owner to turn in the old one, which might be disassembled for its parts or refurbished for sale to another customer.

- **Community-based recycling programs.** Often communities or groups will set aside special days for the disposal of items that are hazardous or difficult to dispose of, such as automobile tires, paint, metal, etc.

Many firms and individuals submit their used products and materials to be recycled for no other reason than it is the environmentally best option. Nonetheless, without the incentives, many reverse supply chains would dry up.

### ENERGY EFFICIENCY

Supply chains involve the flow of materials and services from their origin to their ultimate destination. As such, supply chains consume energy. Energy consumption not only is expensive from a business perspective, but it can also have negative effects on the environment because much of our energy is derived from fossil fuels, such as oil, coal, and gasoline, which emit carbon dioxide ($CO_2$) when burned. As a result, many firms are measuring their **carbon footprint**, which is the total amount of greenhouse gases (GHG) produced to support their operations, usually expressed in equivalent tonnes of $CO_2$. Supply chain logistical operations can be a major contributor to a firm’s carbon footprints. As a result, managers are increasingly focusing on using energy efficiently across their supply chains. Five levers related to logistics and transportation are (1) distance, (2) frequency, (3) freight density, (4) shipment mode, and (5) transportation technology.

#### TRANSPORTATION DISTANCE

Supply chain managers can decrease the amount of energy consumed in moving materials or supplying services by reducing the distance travelled. There are two ways this can be accomplished. The first involves the design of the supply chain itself. Locating service facilities or manufacturing plants close to customers reduces the distance required to supply the service or product. Furthermore, selecting local suppliers reduces the amount of fuel (and time) needed to procure materials and services. Of course, these suppliers must meet the firm's quality and performance needs.

A second way to improve energy efficiency involving transportation distances is **route planning**, which seeks to find the most efficient route to deliver a service or product to one or more customers. One approach, called the **shortest route problem**, seeks to find the shortest distance between multiple locations on a map or in a network. While elegant mathematical methods have been developed for solving this problem, today we are fortunate to have GPS systems for vehicles and websites, such as Google Maps, to quickly obtain good, energy-efficient routes. Manufacturers with their own delivery fleets or third-party logistics providers (3PLs) also can use these routes to minimize their costs of making the deliveries.

Another more complex approach is known as the **travelling salesman problem**, which seeks to find the shortest possible route that visits multiple locations: each location is visited exactly once before returning to the starting location. This problem is much more difficult one to solve, yet one that delivery services face every day. Starting from a central location, such as a warehouse, distribution centre, or hub, orders headed for multiple destinations are loaded into a truck in the right sequence for upcoming deliveries to customers. The same approach can be used to arrange the order in which materials are picked up from suppliers, before returning to a central location. The
problem is to find the best sequence of locations, such that the total distance travelled is minimized. (Of course, other factors such as traffic congestion, location of refueling stations, and road conditions can serve as additional criteria to minimize cost and environmental footprint, but we will focus just on distance here.)

By way of a simple example, Figure 3.2 illustrates a four-location travelling salesman problem with the driving distance between each location (e.g., customer facility) shown on the arc connecting them. How many different routes are there in Figure 3.2? Because we are dealing with driving distances between the locations (and assuming that there are no one-way streets or road blockages), the route from the Central Hub, to A, then C, then B, and finally returning to the Central Hub, has the same total distance as the reverse of that route. Consequently, there are only three different routes:

1. Central Hub – A – B – C – Central Hub, which is $90 + 100 + 120 + 80 = 390$ km.
2. Central Hub – B – C – A – Central Hub, which is $85 + 120 + 130 + 90 = 425$ km.
3. Central Hub – C – A – B – Central Hub, which is $80 + 130 + 100 + 85 = 395$ km.

Thus, the optimal route for the example is Central Hub – A – B – C – Central Hub.

It may look easy to find the shortest route; simply evaluate each possible route as we just did. However, if the truck must visit $n$ locations (e.g., customers), there are $(n-1)!/2$ different routes to consider. For example, if there are eight customers to visit, we have a total of 2520 possible routes to consider. While considering every feasible route is one way to solve this problem, the computational effort quickly becomes tiring. So, one simple heuristic (i.e., rule of thumb) is to do the following: Start with the Central Hub and go to the closest unvisited location; from that location find the next closest unvisited location, and repeat until you get back to the Central Hub. This approach is called the nearest neighbour (NN) heuristic, and has the following steps:

1. Start with an initial site, such as the warehouse or depot. Call this site the “current location.” Place all other sites in an “unvisited” set.
2. Choose the site in the unvisited set that is closest to the current location, and remove it from the unvisited set. This new site is now the current location.
3. Repeat step 2 with each new site.
4. When all sites have been removed from the unvisited set, return to the initial site. You now have a feasible solution that forms an ordered route of sites.

5. Compute the total distance travelled along the route.

6. Redo steps 1–5, trying each site as the initial site.

7. From the ordered routes, choose the one with the shortest total distance. Because you can start at any point on that route (and the total distance is unchanged), in practice, delivery always originates from the warehouse or depot.

Using the NN heuristic for the problem in Figure 3.2 yields the following route: Central Hub – C – B – A – Central Hub, for a total distance of 390 km. Notice that this is the optimal solution to the problem. The NN heuristic does not always yield the optimal solution; however, it is fast and generally provides reasonable solutions to a very complex problem. Example 3.1 shows the application of the NN heuristic for the delivery of food products.

**EXAMPLE 3.1** Finding an Energy-Efficient Route Using the Nearest Neighbour Heuristic

Hillary and Adams, Inc. is a privately owned firm located in Atlanta that serves as the regional distributor of natural food products for Georgia, Kentucky, North Carolina, South Carolina, and Tennessee. They are particularly well known for their unique blend of fiery hot Habanera sauces. Every week, a truck leaves the large distribution centre in Atlanta to stock local warehouses located in Charlotte NC, Charleston SC, Columbia SC, Knoxville TN, Lexington KY, and Raleigh NC. The truck visits each local warehouse only once, and returns to Atlanta after all the deliveries have been completed. The distance between any two cities in kilometres is given below.

<table>
<thead>
<tr>
<th>FROM/TO</th>
<th>ATLANTA</th>
<th>CHARLESTON</th>
<th>CHARLOTTE</th>
<th>COLUMBIA</th>
<th>KNOXVILLE</th>
<th>LEXINGTON</th>
<th>RALEIGH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atlanta</td>
<td>0</td>
<td>518</td>
<td>397</td>
<td>366</td>
<td>348</td>
<td>609</td>
<td>707</td>
</tr>
<tr>
<td>Charleston</td>
<td>518</td>
<td>0</td>
<td>340</td>
<td>189</td>
<td>606</td>
<td>878</td>
<td>453</td>
</tr>
<tr>
<td>Charlotte</td>
<td>397</td>
<td>340</td>
<td>0</td>
<td>151</td>
<td>375</td>
<td>647</td>
<td>275</td>
</tr>
<tr>
<td>Columbia</td>
<td>366</td>
<td>189</td>
<td>151</td>
<td>0</td>
<td>429</td>
<td>699</td>
<td>366</td>
</tr>
<tr>
<td>Knoxville</td>
<td>348</td>
<td>606</td>
<td>375</td>
<td>429</td>
<td>0</td>
<td>276</td>
<td>570</td>
</tr>
<tr>
<td>Lexington</td>
<td>609</td>
<td>878</td>
<td>647</td>
<td>699</td>
<td>276</td>
<td>0</td>
<td>809</td>
</tr>
<tr>
<td>Raleigh</td>
<td>707</td>
<td>453</td>
<td>275</td>
<td>366</td>
<td>570</td>
<td>809</td>
<td>0</td>
</tr>
</tbody>
</table>

John Jensen, vice president of logistics at Hillary and Adams, Inc., is worried about rising fuel costs. With a reduction in operating budgets, he is interested in finding a route that would minimize the distance travelled by the truck.

Use the nearest neighbour heuristic to identify a route for the truck and compute the total distance travelled.

**SOLUTION**

The application of the NN heuristic results in the following steps:

1. Start with Atlanta and place all other cities in the unvisited set: Charleston, Charlotte, Columbia, Knoxville, Lexington, and Raleigh.

2. Select the closest city to Atlanta in the unvisited set, which is Knoxville. Remove Knoxville from the unvisited set. The partial route is now Atlanta – Knoxville, which is 348 km.
SHIPMENT FREQUENCY. To reduce the total inventory in a supply chain, many businesses have adopted policies that encourage small, frequent shipments of materials and products. Commonly termed just-in-time (JIT), this approach aims to meet customer needs at exactly the time that shipments are needed, not before, as discussed in greater detail in Chapter 8, “Lean Systems.” In terms of performance, at this point, we will simply note that JIT delivery can provide great customer service, although the number of orders per year and carbon footprint increase.

Imagine a large metropolitan area where most businesses are using JIT systems and the traffic congestion that results from delivery trucks carrying the small order quantities. For example, much of the congestion in Tokyo is attributed to JIT deliveries. While responsiveness can be better and the cost of the inventory also can be lower, noise pollution, energy consumption, air pollution, and travel time increase for the community at large. A balancing act occurs between financial responsibility and environmental responsibility. However, careful planning can reduce these problems,
including consolidating shipments of items to nearby customers, or shifting the timing of deliveries away from peak rush hours.

**FREIGHT DENSITY.** Truck vans, containers, and rail cars all have limits with respect to cargo volume and weight. By reducing the volume that a product displaces while staying within the weight limits of the conveyance, the firm can use fewer trucks, containers, or rail cars to ship the same number of units. For example, 1000 kg of ping-pong balls occupy much more room in a trailer than 1000 kg of bowling balls. Firms can increase the freight density by reducing the volume of packaging, redesigning the product to have less volume, or postponing the assembly of the product until the customer takes possession. IKEA offers an excellent example of the last option.

**TRANSPORTATION MODE.** The four major modes of transportation are (1) air, (2) truck, (3) ship, and (4) rail. From an energy perspective, freight transported by air or truck is much less energy efficient than by ship or rail. On average, railroads are three times more fuel-efficient than trucks, thereby reducing the carbon footprint by roughly one-third. Further, freight moved by rail helps to relieve congestion on the highways; a typical train takes freight equivalent of several hundred trucks.

Trucks, nonetheless, are more flexible and can make deliveries right to the customer’s door. Shippers also can have the door-to-door convenience of trucks with the long-haul economy of railroads or ocean containers by employing **intermodal shipments**, which involves mixing the modes of transportation for a given shipment. By using standard-size containers, shipments can use rail cars for long distances, with subsequent transfer of the containers to truck trailers for regional delivery. A huge range of consumer goods, from bicycles and lawn mowers to greeting cards and clothing, and an increasing amount of industrial and agricultural products, are being transported by intermodal shipments. All of these factors should be considered when designing an environmentally responsible supply chain.

**TRANSPORTATION TECHNOLOGY.** Each transportation modes offers opportunities for improving energy efficiency through improved designs. Design factors include the following:

- Relative drag—the energy needed for propulsion of a vehicle of a given size at a given speed
- Payload ratio—the cargo-carrying capacity of the vehicle relative to the vehicle’s weight when fully loaded
- Propulsion systems—the technology used to move the vehicle

Walmart, for example, purchased diesel-electric and refrigerated trucks with a power unit that could keep cargo cold without the engine running, saving nearly $75 million in fuel costs and reducing the carbon footprint by roughly 400,000 tonnes of CO₂ annually. More recently, Walmart has been testing a new trailer design in Ontario that would increase the volume of goods shipped by 30 percent. Combined with a safer design, this innovative trailer captured space that was formerly wasted under the bed of the trailer and behind the cab of the truck. While receiving positive reviews from environmentalists for a lower carbon footprint, truckers have been more skeptical, likely because fewer shipments are needed for low-density cargo.

Elsewhere in the world, manufacturers and transportation services companies such as FedEx, UPS, and DHL also actively replace old equipment with newer, energy-efficient equipment to greatly reduce their carbon footprints. Liquefied
natural gas (LNG) is starting to replace diesel fuel in trucks on some shipment routes in the U.S. Going one step further, all commercial vehicles in New Delhi, India, were mandated to use LNG in order to reduce the air pollution levels in the capital city.

**SOCIAL PERFORMANCE**

Beyond financial and environmental performance, firms and organizations are increasingly recognizing the need to better manage social performance as a means to protect their brand names, ensure access to key consumer markets, and expand revenues. Supply chain managers are in a unique position to be catalysts to improve social performance because they are boundary spanners: They interact both internally with key functional areas in the firm, as well as externally with suppliers and customers. Nonetheless, supply chain managers cannot do it alone. Social responsibility should be the focus of the entire organization, including the top management. In this section, we discuss customer safety, working conditions, and humanitarian logistics (i.e., disaster response), three areas in which supply chain managers can make a major contribution.

**CUSTOMER SAFETY**

Both the design of the product or service, and the network of suppliers play critical roles in customer safety.

**SAFER DESIGNS.** Customer safety relies on, first, a careful and thoughtful service or product design and, second, many different partners in the supply chain working in a well-coordinated fashion. Specific design parameters must take into account the choice of materials, development of packaging, and the pattern of use and potential misuse by a customer. (The design process itself is detailed elsewhere; see Chapter 9, “Managing Projects”).

For material selection, companies are reducing the use of substances that have been shown to have potential health risks. Of course, some of these changes are driven by regulations. For example, in 2010, after an exhaustive four-year study, the Canadian government declared bisphenol A (BPA)—used for such consumer goods such as water bottles and the protective lining inside metal food cans—a toxic substance. BPA was subsequently banned from use in baby bottles.  

Taken further, some managers view the careful choice of materials and development of alternative components as a means of increasing value. For example, Brita notes that its water pitchers are BPA-free, something not required by regulation, yet attractive to consumers. But making such changes is rarely simple. Another example is Herman Miller, a global maker of office furniture who wanted to market a PVC-free chair because of environmental and health concerns raised over this plastic. Managers had to collaboratively work with suppliers to identify alternative materials and make other process adjustments. Since then, the number of PVC-free products that Herman Miller offers continues to expand.

Unfortunately, communicating to consumers the safety of products can often be bewildering, with different firms trumpeting confusing claims. To sort out this confusion, firms within an industry can work together to develop standards that have clear criteria. Several firms in the cosmetics industry have tried to do this with the term “natural.” Currently, there is no regulatory definition in Canada. However, Burt’s Bees spearheaded a consortium that worked collaboratively to define “natural products.” In short, these must comprise at least 95 percent ingredients from nature (and manufactured to maintain ingredient purity), avoid any ingredient suspected to pose a
human health risk, use no animal testing in their development, and use biodegradable ingredients and environmentally sensitive packaging.  

**SUPPLY CHAIN PARTNERS.** Suppliers, manufacturers, distributors, and retailers all have responsibilities to ensure that safe products reach customers. Customers also can play a critical role in the process. To help customers detect problems and ensure product integrity, industries such as pharmaceuticals use packaging that provides clear evidence of tampering. Product expiry dates and clearer labelling also have become more common to give customers information to avoid toxins or allergens.

For many products, managers must develop designs that minimize the risk of harm or reduce the likelihood that customers will misuse products. Thus, we see equipment guards that cover cutters on power tools; and aircraft manufacturers must frequently update their aircraft designs to take into account findings from recent accident investigations. With many of these changes, suppliers must adapt and improve their own designs for materials or components.

Despite efforts like these, large-scale problems that endanger customers still can occur. Product recalls have attracted an increasing amount of customer and media attention across a wide range of categories, including contaminated foods, lead-laced toys, or faulty automobiles. To be fair, the underlying problems might be only partially under the control of the firm originating the recall; supply chain partners, both upstream and downstream, can contribute to product failure. Timely and accurate product traceability is essential to minimize harm, reduce liability, and limit the amount of product that must be collected and destroyed. **Product traceability** follows the path of defective products back upstream from detection through multiple tiers of the supply chain to the specific source of the problem based on serial numbers, or date and batch codes. Ideally, traceability captures many specific aspects, including specific suppliers, materials, processes, facility locations, and conditions under which the recalled good or service is produced.

Traceability has been emphasized for years in food and pharmaceuticals. More recently, many other products with global supply chains that reach into developing countries have discovered that tracing materials and parts to specific suppliers, dates, and locations can be very difficult. This problem is very important for firms trying to assure customers that their products are manufactured under safe, humane working conditions, as noted in the opening vignette. Rigorous attention to detailed record keeping and significant investments in information technology, sometimes combined with tracking using bar coding or RFID tags, lay the foundation for the effective protection of customer safety.

**WORKING CONDITIONS**

The labour practices employed in developing countries by global firms—either directly in their own plants, or more often, in those of their suppliers—have received much attention from non-governmental organizations (NGOs), the media, and ultimately, customers. Concerns raised include worker safety, working conditions, the right to join unions, and child labour, to name several. For example, controversy over working conditions and suicides at an Apple supplier in China and Nike’s treatment of workers in its own facilities or those of subcontractors pushed both firms to respond with supplier audits and changes to counteract public and customer concerns. While these steps can translate into higher costs, they were essential to protect each firm’s brand name and improve the working conditions at suppliers.

Selecting suppliers that adhere to an ethical code of conduct is a critical aspect of designing a supply chain. This is a difficult task, and a number of NGOs have developed...
certification standards that allow for independent third-party verification. One such organization, Social Accountability International, has developed SA8000:2014, comprising nine dimensions that define a decent workplace:

1. **Child Labour.** Employ no underage workers, usually taken to be under 15 years of age.
2. **Forced or Compulsory Labour.** Prohibit the use of forced labour, including prison or debt bondage labour.
3. **Health and Safety.** Provide a safe and healthy work environment; take steps to prevent injuries; provide regular health and safety worker training; have system to detect threats to health and safety; provide access to bathrooms and potable water.
4. **Freedom of Association and Right to Collective Bargaining.** Respect the right to form and join trade unions and bargain collectively.
5. **Discrimination.** Avoid discrimination based on race, caste, origin, religion, disability, gender, sexual orientation, union or political affiliation, or age; no sexual harassment.
6. **Disciplinary Practices.** Use no corporal punishment, mental or physical coercion, or verbal abuse.
7. **Working Hours.** Comply with the applicable law but, in any event, set working hours at no more than 48 hours per week, with at least one day off for every seven-day period; voluntary overtime is to paid at a premium rate and not to exceed 12 hours per week on a regular basis.
8. **Remuneration.** Wages paid for a standard workweek must meet the legal and industry standards and be sufficient to meet the basic need of workers and their families.
9. **Management System.** Policies and procedures must be in place, for example, to maintain records related to SA8000, identify and assess risks, monitor workplace activities, and allow external auditors to conduct both announced and unannounced audits.

While certification neither guarantees that the supplier adheres to every regulation nor that accidents won’t happen, it does improve the likelihood that workers have a fair and safe workplace. Once certified, a supplier must be recertified every three years.

**POWER IN BUYER-SUPPLIER RELATIONSHIPS.** One aspect of buyer-supplier relationships deserves special mention: purchasing power can play a strong role in many supply chains. Suppliers who generate much of their revenue from a single powerful customer can be bullied into accepting concessions that might hurt the supplier in the short term, and possibly in the long term as well. (Similar issues arise for customer with a few dominant suppliers.) This was the perception by some when Walmart required all suppliers to invest in RFID technology to track inventories and shipments. Some suppliers, especially those selling commodities with small profit margins, initially were forced to take a loss to remain a supplier to Walmart. However, after supplier resistance caused the program to falter, Walmart shifted to focus on a narrower range of products, and moved to share the costs with suppliers.

**LOCATION OF FACILITIES AND SOURCING.** The construction and operation of new facilities can affect the local communities in many important ways. Pollutants and noise can
hurt the health of nearby residents, and managers might be tempted to locate facilities with these concerns in neighbourhoods that have little political power. While some argue that these communities benefit from greater levels of employment, managers must be careful to protect both the health of workers and the environment in the surrounding area. Such concerns extend to the sourcing of raw materials and agricultural commodities. For example, NGOs have voiced strong concerns about the sourcing of palm oil from suppliers that clear rainforests to create plantations. In response, some corporate users of palm oil, such as McDonalds, worked to bring together a coalition of suppliers, processors, customers and NGOs to define good practices, improve material traceability, and exclude questionable suppliers. This type of approach is often critical to address the complex trade-offs that link social, environmental, and economic issues.

HUMANITARIAN LOGISTICS

When natural disasters strike, it is often critical that life-saving resources arrive within hours. According to the United Nations, a disaster is any event that seriously disrupts the functioning of society and causes widespread human, material, or environmental losses that exceed the ability of the affected people to cope using only their own resources. Recent disasters, such as the earthquake in Haiti (2010), the earthquake and tsunami in Japan (2011), and Typhoon Haiyan in the Philippines (2013) are cases in point. Between 400 and 500 natural disasters strike annually, affecting more than 250 million people. Unfortunately, natural events are not the only causes of disasters; many are human-related, such as epidemics, war, genocide, and terrorism. The civil war in Syria, which began in 2011, is one such example, with millions of displaced people requiring aid and relief.

Thus, while some disasters are more predictable than others, all disasters put immense pressure on the operations of international relief organizations and governments, and 80 percent require supply chains of some sort. Responses to major disasters involve many organizations, often led by the United Nations, the International Federation of Red Cross and Red Crescent Societies, and other philanthropic and faith-based NGOs. Government organizations, such as Canadian Forces Disaster Assistance Response Team (DART), also can provide crucial services, such as clean drinking water and medical personnel, in the initial days after disaster strikes. Logistics firms, such as Agility, TNT, and UPS, have partnered with the UN to provide additional transportation capacity in the event of large-scale international disasters and to provide warehousing services in multiple locations around the world, such as Italy, United Arab Emirates, Panama, and Ghana. The warehouses, referred to as strategic hubs, stockpile vital supplies in anticipation of major disasters in those areas of the world.

Figure 3.3 shows the three major supply chain processes relating to disaster response—preparation, relief, and recovery.

1. Preparation. Forecasts and early warning systems can sometimes provide enough lead time to assemble needed resources and organize relief efforts. Often, however, disasters happen with little or no warning. Regardless of the warning for a specific disaster, relief agencies can do advance planning and readiness preparation to reduce the response time. Communication protocols and the information technology infrastructure can be prepared. Strategic partnerships with other agencies and companies can be formalized, and training of agency personnel can be undertaken before the next disaster. Kits of standardized, non-perishable items can be pre-assembled and stocked, and some items can be placed in strategic hubs to reduce the delivery time when the need arises.
2. **Relief.** After a disaster strikes, resources must be mobilized and transported to the disaster location by air, water, and land as soon as possible. Ideally, small multidisciplinary teams of experienced humanitarian workers and logistics experts quickly make a preliminary assessment of needs. Unfortunately, coordination among international suppliers of needed items and the local authorities is often difficult because ports of entry are inaccessible, and local authorities are often overwhelmed by events, inexperienced in events of this magnitude, and lacking in sufficient resources. Ambiguous lines of communication further complicate relief efforts. After the initial procurement of food, water, materials, and medicines is made, personnel who provide assistance and humanitarian aid are dispatched to the region.

3. **Recovery.** As time progresses, the crisis mode of relief gives way to a focus on rebuilding infrastructure and rehabilitating the affected society. Supplies, food, and medicines can be ordered with more normal lead times as quantities can be better estimated. More focus is placed on the cost of these items. Collaboration and cooperation improves; however, supplies from all over the world likely have been sent during the relief phase, often lacking consultation with teams on site, causing over-supply of some commodities and shortages of others.

**ROLE OF SUPPLY CHAIN MANAGEMENT.** From the perspective of disaster relief agencies, supply chains must be designed to link the preparation activities to initial relief activities and, later, recovery operations. The procurement of materials, food, and medicines must be matched with their distribution to the affected areas, often involving trade-offs in delivery speed, cost, and quality with regard to the type of goods and their quantities. However, key differences emerge from traditional supply chains in two aspects, namely the timetable is event driven and “customer” needs change rapidly, which creates a life cycle for the design of a supply chain to respond to disasters.

The two processes of relief and recovery shown in Figure 3.3 can be broken down into four life cycle stages: (1) brief assessment of critical needs, (2) speedy distribution of life-saving resources (both human and physical) to the affected region, based on
forecasted needs using a flexible supply chain, (3) increased emphasis on an efficient supply chain as time progresses, whereby the needed supplies arrive by a fixed schedule or on request, and (4) dismantling or turning over of the supply chain to local agencies. Suppliers need to understand the evolving nature of the supply chain after a disaster, while accommodating the specific timeframe and resource needs expressed by the affected communities.

After an earthquake, for example, drinking water, medical supplies for trauma treatment, and temporary shelters must be available immediately. However, as time progresses, the needs of the affected populations shift toward materials for reconstruction of permanent housing, routine shipments of foodstuffs, rebuilding of infrastructure like roads and schools, and a greater range of medical care. In the longer term, supplies for temporary shelters and water purification stations must be dismantled and recycled. The materials, equipment, and human resources needed for each of these four stages must change accordingly, which points to several important management challenges.

**MANAGEMENT CHALLENGES.** The unpredictability and severity of disasters pose difficult challenges to supply chain managers. First, many disaster relief supply chains exist for only short times. At the onset of a disaster, the supply chain could require a new design that takes into account the unique characteristics of the location, size of affected populations, and severity of the needs. Relief is all about speed and agility in delivering the right items. Creative approaches might be encouraged because the priority is quick access. Later, recovery operations must use a more scheduled approach, favouring an efficient supply chain design.

Second, for large-scale disasters, the United Nations typically has a leadership role. Disaster relief agencies work to supply the items and services they have access to. However, the national and local governments of the affected region must be recognized and included in decision making. Sometimes the national government will not grant access to the area for political reasons. In other words, critical supplies may not be deployed as soon as they are available because of national or local roadblocks. And even when deployed, security for the shipment of supplies, as well as relief personnel, can be difficult to maintain because of looting and theft.

Third, donor agencies often respond independently, with little coordination. In essence, many disaster relief agencies have the best of intentions to help relieve pain and suffering, and they send what they think is needed. However, the lack of inter-organizational communication and sharing can result in confusion, congestion, and overstocking of some items in some areas, while other critical supplies experience shortages.

Fourth, during the response, supplies are initially sent without waiting for demand to be accurately determined. This “push” flow of supplies makes sense during this start-up time, because the need far outstrips available supplies. However, once relief operations shift into recovery, actual needs must be more carefully matched to the volume of supplies, and the supply chains should switch to a “pull” flow.

Fifth, because disasters often cause major damage to the infrastructure, such as roads, ports, railways, and airports, the movement of needed supplies is severely restricted and hampered. Lines of communication, such as telephone lines and mobile phone services, are limited at best. Initially, high-cost, low-volume logistics are necessary because they are the only options. For example, helicopters can transfer supplies from ships at sea to inland areas. However, infrastructure needs to be improved rapidly to enable higher volumes of relief supplies to be moved more efficiently.

Finally, disaster relief often mobilizes large numbers of temporary workers, including many skilled workers such as medical personnel. Providing them with the right resources in a timely way is key. But different skilled personnel and supplies are needed as recovery progresses, for example, related to construction, education, and
other important infrastructural services. Putting these in place after the initial media attention has disappeared can be challenging. And as noted earlier, these must be developed in partnership with the affected local community. Consequently, each disaster requires a unique supply chain solution.

**CHAPTER HIGHLIGHTS**

- More sustainable supply chains must strive to have services, products, and processes that meet humanity’s needs today without hurting future generations. In practice, sustainability is translated into the triple bottom line, whereby firms must measure and improve financial, environmental, and social performance. The environmental bottom line captures the responsible stewardship of ecological resources used throughout the supply chain, as well as the mitigation of any adverse ecological impact. The social bottom line captures customer safety and ethical expectations of the communities and society in which the firm operates.
- The reverse supply chain considers how used products are dealt with, either after being returned from customers or at the end of their useful life. Used products must be collected, inspected, and sorted and, finally, disassembled. Competitive benefits, as well as cost savings, are possible through better service and product design.
- In order to connect the reverse and forward supply chains, managers have four process options: repairing, reconditioning, remanufacturing, or recycling. Each requires unique processes and operational capabilities.
- Energy efficiency can reduce a firm’s carbon footprint, defined as total amount of greenhouse gases (GHGs) produced to support operations and supply chain management, usually expressed in equivalent tonnes of carbon dioxide. One means is to minimize transportation distances through efficient route planning, using approaches such as the nearest neighbour heuristic. Other actions to improve efficiency include adjusting shipment frequencies and scheduling, and increasing freight density. Lower carbon footprint transportation modes and technologies also can be employed.
- For supply chains, social performance focuses on customer safety, working conditions, and humanitarian logistics. Customer safety can be improved through safer designs of products and services, as well as working with strong supply chain partners that ensure products reach customers without tampering or mishandling.
- In many industries, such as apparel, firms must increasingly account for the working conditions that suppliers use to produce their goods or services. Certifications, such as SA8000:2014, provide one means of ensuring that audits are routinely performed against multiple criteria.
- Humanitarian logistics respond to natural and human-made disasters through preparation, relief, and recovery. Supply chains link these activities together, although the design of the supply chain must change dramatically as disaster response proceeds. Four life cycle stages are (1) brief assessment of critical needs, (2) speedy distribution of life-saving resources to the affected region based on forecasted needs using a flexible supply chain, (3) increased emphasis on an efficient supply chain to deliver a broader range of needed supplies for reconstruction, and (4) dismantling of the supply chain and recovery of spent resources.

**SOLVED PROBLEM**

Greenstreets Recycling, Inc., collects used motor oil from several collection sites across the greater Vancouver area. In order to minimize the use, and thereby the cost, of its labour, vehicle, and energy resources, the company is interested in locating the shortest route that will allow its collection vehicle to visit each collection site exactly once. The following table provides the travel distances in kilometres between each site.

<table>
<thead>
<tr>
<th>TO/DOM</th>
<th>DEPOT</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depot</td>
<td>–</td>
<td>25</td>
<td>50</td>
<td>48</td>
<td>41</td>
<td>60</td>
</tr>
<tr>
<td>B</td>
<td>25</td>
<td>–</td>
<td>35</td>
<td>22</td>
<td>23</td>
<td>43</td>
</tr>
<tr>
<td>C</td>
<td>50</td>
<td>35</td>
<td>–</td>
<td>25</td>
<td>47</td>
<td>65</td>
</tr>
<tr>
<td>D</td>
<td>48</td>
<td>22</td>
<td>25</td>
<td>–</td>
<td>24</td>
<td>40</td>
</tr>
<tr>
<td>E</td>
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<td>23</td>
<td>47</td>
<td>24</td>
<td>–</td>
<td>21</td>
</tr>
<tr>
<td>F</td>
<td>60</td>
<td>43</td>
<td>65</td>
<td>40</td>
<td>21</td>
<td>–</td>
</tr>
</tbody>
</table>

Provide an efficient route for the collection vehicle.
a. Begin at the Recycling Depot and proceed to its nearest neighbour (site B), which is 25 km away.
b. From site B proceed to its nearest unvisited neighbour. Proceed from B to D—distance 22 km.
c. From site D proceed to site E—distance 24 km.
d. From site E proceed to site F—distance 21 km.
e. From site F proceed to site C (the only remaining unvisited site)—distance 65 km.
f. From site C return to Depot—distance 50 km.

The completed route is Depot – B – D – E – F – C – Depot, with a total distance travelled of 207 km (25 + 22 + 24 + 21 + 65 + 50).

To see if a better solution exists, the nearest neighbour heuristic should be repeated using each city in turn as the starting point.

City B: B – D – E – F – Depot – C – B, with a total distance of (22 + 24 + 21 + 60 + 50 + 35) = 212 km
City C: C – D – B – E – F – Depot – C, with a total distance of (25 + 22 + 23 + 21 + 60 + 50) = 201 km
City D: D – B – E – F – Depot – C – D, with a total distance of (22 + 23 + 21 + 60 + 50 + 25) = 201 km
City E: E – F – D – B – Depot – C – E, with a total distance of (21 + 40 + 22 + 25 + 50 + 47) = 205 km
City F: F – E – B – D – C – Depot – F, with a total distance of (21 + 23 + 22 + 25 + 50 + 60) = 201 km

Note that the solutions to the nearest neighbour heuristic that started with sites C, D, and F all provide an equally short route. Thus, from the Recycling Depot, the collection vehicle should proceed to F then E then B then D then C and finally back to Depot, with a total distance travelled of 201 km. (Of course, the reverse route is the same distance.)

Additional student problems and supporting software are available on the companion website for study preparation, in-depth analysis, and assignments.

1. On a daily basis, a medical services van is dispatched from Maplewood Hospital to pick up blood and platelet donations made at its local donation centres. The distances in kilometres between all locations may be found in Table 3.2.
   a. The medical services van travels from Maplewood Hospital (A) to (B) to (C) to (D) to (E) and then returns to the Hospital (A). What is the total number of kilometres that the van must travel using this route?
   b. Using Maplewood Hospital as the beginning location, create a route using the nearest neighbour heuristic. What is the total number of kilometres that the van must travel using this route?
   c. Using Valley Hills (E) as the beginning location, create a route using the nearest neighbour heuristic. What is the total number of miles that the van must travel using this route?

2. Royal Seafood delivers fresh fin and shellfish to specialty grocery stores in the Greater Toronto Area (GTA). The company packs a delivery truck in Toronto and then drives in a
single route to its five major customers spread throughout the region. The distances in kilometres between all locations may be found in the table below.

<table>
<thead>
<tr>
<th>DISTANCE (KM)</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warehouse [A]</td>
<td>–</td>
<td>93</td>
<td>102</td>
<td>268</td>
<td>219</td>
<td>220</td>
</tr>
<tr>
<td>Roseburg [B]</td>
<td>93</td>
<td>–</td>
<td>116</td>
<td>296</td>
<td>167</td>
<td>216</td>
</tr>
<tr>
<td>Bend [C]</td>
<td>102</td>
<td>116</td>
<td>–</td>
<td>181</td>
<td>138</td>
<td>117</td>
</tr>
<tr>
<td>Baker [D]</td>
<td>268</td>
<td>296</td>
<td>181</td>
<td>–</td>
<td>223</td>
<td>106</td>
</tr>
<tr>
<td>Lakeview [E]</td>
<td>219</td>
<td>167</td>
<td>138</td>
<td>223</td>
<td>–</td>
<td>118</td>
</tr>
<tr>
<td>Burns [F]</td>
<td>220</td>
<td>216</td>
<td>117</td>
<td>106</td>
<td>118</td>
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</tr>
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</table>

a. Propose an efficient route by using the nearest neighbour heuristic with the warehouse as the starting city. What is the total distance travelled?
b. Use the nearest neighbour heuristic to calculate the five other routes, each starting from one of Royal Seafod’s customer’s location. What is the best route for Royal Seafod?

3. On Thursdays, Traxis Consolidated delivers liquid oxygen to its industrial customers in Alberta. The following table provides the driving time in minutes among all customers and the Traxis liquid oxygen depot location in Calgary.

<table>
<thead>
<tr>
<th>DRIVING TIME (MINUTES)</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
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</thead>
<tbody>
<tr>
<td>Depot [A]</td>
<td>–</td>
<td>26</td>
<td>38</td>
<td>31</td>
<td>49</td>
<td>33</td>
<td>40</td>
<td>52</td>
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<td>B</td>
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<td>54</td>
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<td>56</td>
<td>73</td>
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<td>C</td>
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<td>53</td>
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<td>D</td>
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<td>54</td>
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<td>32</td>
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<td>E</td>
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<td>44</td>
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<td>51</td>
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</table>

a. Currently, Traxis travels from the Depot (A) to (F) to (G) to (D) to (E) to (H) to (B) to (C), then returns to (A). What is the total driving time using this route?
b. Using the Depot (A) as the beginning location, create a route using the nearest neighbour heuristic. What is the total driving time using this route?
c. Use the nearest neighbour heuristic to calculate seven other routes, each starting from one of Traxis’s customers’ locations. What are your conclusions?

NOTES FOR CHAPTER


Companion Website

To access valuable study tools including Self-Study Quizzes, Glossary Flashcards, virtual tours, videos, experiential exercises, OM Explorer Tutors, Extend LT, and more, Visit the Companion Website at www.pearsoncanada.ca/ritzman!