1

Introducing Logistics

1.1 Definition of Logistics

According to a widespread definition, *logistics* is the discipline that studies, in an *organization* (such as a private company, a public administration, a non-profit association, a military corps), the management and implementation of the operations concerning the flow of tangible goods (materials, food and medical supplies, refuse, equipment, weapons, etc.) from their sources (suppliers, mines, crop fields, etc.) to their points of utilization or consumption or disposal (retailers, landfills, army units, etc.) to meet the objectives of the organization. To this end, logistics requires the collection, integration, and processing of data from several sources in order to plan, organize, and control activities such as material handling, production, packaging, warehousing, and distribution.

The words “logic” and “logistics” both come from the Greek term *lógos*, which means, among other things, “order”. However, while “logic” derives directly from Greek, “logistics” first passed into Middle French as “logis”, meaning “lodging”, and then into English.

Defence Logistics. The origins of logistics are of a strictly military nature. In fact, the discipline arose as the study of methodologies to guarantee the correct supply of troops with victuals, ammunitions, fuel, etc. Indeed it was the Babylonians, in the distant twentieth century BCE, who first created a military corps specialized in the supply, storage and delivery of soldiers’ equipment. The relevance of logistics became apparent during the American Revolutionary War (1775–1783) when the lack of adequate supplies for the 12 000 British soldiers overseas during the first six years devastated the troop morale and contributed to their final defeat. In modern times, logistics played a key role in World War II where it helped the Allied powers to succeed. In modern times, the key concept in defence logistics is that of *supply chain*, defined as the set of processes, infrastructure, equipment and personnel ensuring that a specific vehicle or weapon is fully functioning in the theatre of operations.

Industrial Logistics. Only in the twentieth century, were logistics principles and techniques extended to manufacturing companies. In industrial logistics, a supply chain resembles a military one and is defined as the network of organizations (suppliers, carriers, logistics providers, wholesalers, and retailers, etc.), resources, activities, and

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information built around a company to produce and distribute a specific product to a specific market. Here, the goal of logistics is to manage the flow of materials and information from the extraction, harvesting or purchase of raw materials and components up to the delivery of the finished products to customers. In this sector, logistics activities are traditionally classified depending on their location with respect to the production and distribution processes. In particular, *procurement logistics* comes before the manufacturing process and consists of supplying raw materials and components to support the company's production plan. *Internal logistics* is about material handling and storage in production plants in order to feed production lines and the subsequent product packaging and shipment. Finally, *distribution logistics* falls after the production plants and before the market, and aims to supply sales points or customers. In this framework, procurement logistics and distribution logistics are collectively called *external logistics*.

Service Logistics. Logistics issues are also increasingly present in the service sector, for example in postal services, in urban solid waste collection, in the post-sales activities of manufacturing companies as well as in humanitarian organizations. *Logistics service providers* (LSPs), performing transportation or warehousing activities for other organizations, including manufacturing companies, also fall into this category.

Integrated Logistics and Logistics Alliances. Logistics activities may be carried out entirely by a specific function of the organization (see Section 1.5 for details). Otherwise, they may be jointly performed by multiple departments of the organization such as production, marketing, etc. (*integrated logistics*) or even in collaboration with different partner organizations (*logistics alliances*). Logistics alliances can be implemented in two different forms. The *efficiency-oriented approach* relies on contracts of a strictly operative nature that do not modify the organization's own strategy but simply tend to create synergies or economies of scale with the primary objective of minimizing costs. On the other hand, in the *differentiation-oriented approach* the company tries to forge exclusive alliances with some partners, not replicable by competitors, to generate an added value with respect to the competition.

An efficiency-oriented logistics alliance was implemented by SkyTeam, the second global airline alliance in the world, that in 2021 counted 19 members (Aeroflot, Aerolíneas Argentinas, Aeroméxico, Air Europa, Air France, Ita Airways, China Airlines, China Eastern, Czech Airlines, Delta Airlines, Garuda Indonesia, Kenya Airways, KLM Royal Dutch Airlines, Korean Air, Middle East Airlines, Saudi Arabian Airlines, TAROM Romanian Air Transport, Vietnam Airlines, and Xiamen Airlines). The alliance allows the collaboration among airlines in different forms: creating synergies in timetable design and ticket pricing, sharing information about customers, operating ground services, managing frequent flyer programmes, and airplane maintenance. In addition, customers of the SkyTeam airlines can benefit from a larger number of flights, with more destinations and connections as well as a larger number of lounges located within the network's airports. In 2021 SkyTeam transported about 675 million passengers over

15 500 daily flights reaching about 1000 destinations in 170 countries. The cargo branches of 11 of the 19 air companies cited above have also signed a strategic alliance, called SkyTeam Cargo, for freight transportation. The members of SkyTeam Cargo share airplanes and cargo buildings (see Section 6.3.2) located in 76 air cargo terminals worldwide (e.g., the cargo building located in the Vienna Airport is shared among China Airlines Cargo, Korean Air Cargo and Aerflot Cargo).

An example of a differentiation-oriented logistics alliance has been set up in 2019 between Unilever, a global Dutch–British consumer goods company owning the Algida ice cream brand, and Ferrero, a world-renowned Italian manufacturer of branded chocolate and confectionery products, including the Kinder brand of chocolate products and Nutella. The agreement concerned the launch of a new Kinder Ice Cream (whose recipe was created by Ferrero), produced and distributed by Unilever in various European markets (Germany, France, Italy, Austria, etc.). The partnership has clear mutual benefits. Ferrero may take advantage of Unilever's experience in the ice cream sector to take its Kinder brand to new attractive markets, without the cost of investing in a frozen food supply chain. On the other hand, Unilever may take advantage from the Kinder brand power to increase its sales and enlarge its product portfolio.

1.2 Logistics Systems

A *logistics system* is a set of interacting infrastructures, equipment, and human resources whose objective is, as a whole, the execution of all the functional activities determining the flow of materials among a number of *facilities*. Facilities may be plants, warehouses, landfills, sorting centres, air, and ground hubs where either production or assembly, disposal, consolidation, storage, packaging, distribution, etc. is carried out.

It is concerned with the flow of materials among facilities. For example, in a waste collection system, materials flow from households to waste recycling plants and landfills through a number of facilities such as transfer points and mixed waste sorting plants. In a postal system, letters and packages flow from the pickup points to the delivery addresses through mail sorting sites, air and ground hubs, regional distribution centres (DCs), etc. In a manufacturing system, materials flow from suppliers to production plants and then reach the distributions system and the retailers (or directly the final customers). The distribution phase may rely, depending on the cost structure and customer expectations, on a single layer of DCs or on a central distribution centre (CDC) and a number of regional distribution centres (RDCs). In any case, at each facility the flow of materials is temporarily interrupted, generally in order to change their physical or chemical composition (production, assembly), appearance (packaging), availability (storage), or ownership. Such logistics activities, along with transportation and material handling, constantly add value to the product, as it draws nearer the final customer.

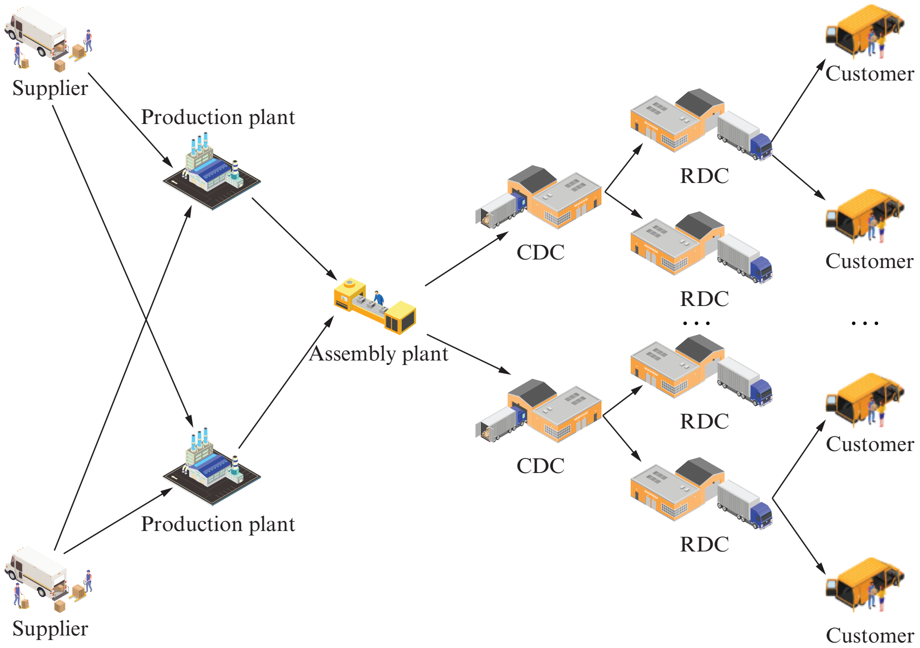

Figure 1.1 Example of a logistics system.

An exception to the downstream flow from suppliers to markets is when a defective product, or a product at the end of its life cycle, is returned to be repaired or disposed of (see Section 1.7.1).

Figure 1.1 shows a schematic representation of a logistics system in which the manufacturing process of the finished goods is divided into a transformation phase and an assembly phase, performed in different facilities. At the start are the suppliers of materials and components which feed the final manufacturing process. The end part represents a two-level distribution system with a tree structure. The CDCs are directly supplied by the production plants, while each RDC is connected to a single CDC which has the task of serving the retailers or directly the customers.

A logistics system can be represented as a directed graph $G = (V, A)$, where V is the set of facilities, and A is a set of arcs representing material flows. In a multi-graph there can be several arcs between a pair of facilities, representing alternative transportation services or different routes or products.

In addition to materials, there is a flow of information between facilities. This can happen in different ways, including emails or more sophisticated data exchange platforms. In general, information can flow in both directions between two facilities even if material flows are unidirectional. A logistics system including information flows is also called a *logistics network* and can be itself represented as a directed graph, in which some arcs represent information flows (e.g., sales figures, orders, inventory updates, etc.) between a pair of nodes. Figure 1.2 provides a logistics network representation of the logistics system illustrated in Figure 1.1.

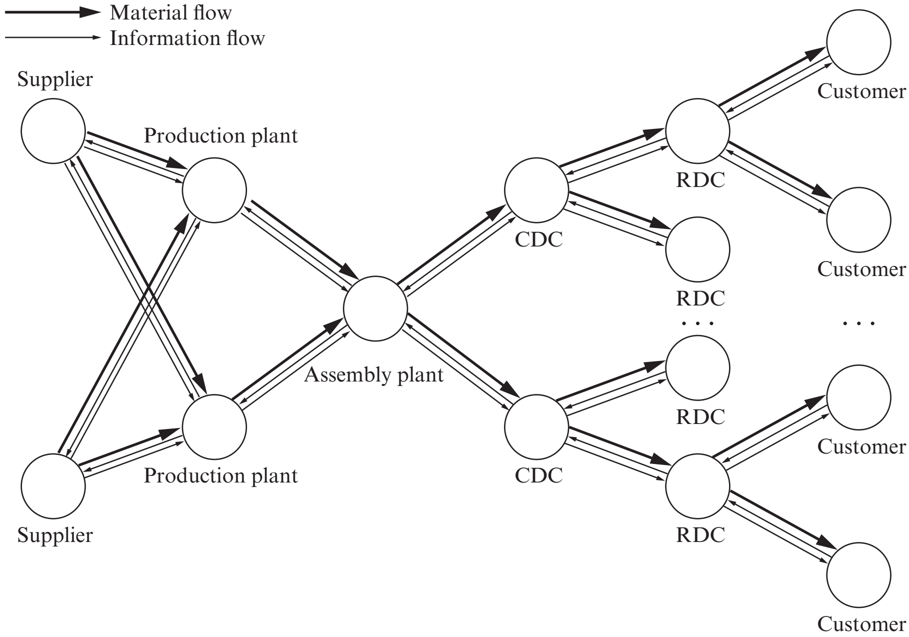

Figure 1.2 Network representation of the logistics system illustrated in Figure 1.1.

1.3 Supply Chains

Supply Chain Management (SCM) is concerned with the coordination and management of the supply chains of an organization. Note the plural in "chains": organizations may operate multiple supply chains that work together to serve different segments. For example, in defence logistics, the *maintenance, repair, and overhaul* (MRO) of the military systems in a theatre of operations can be managed through distinct supply chains. Similarly, in industrial logistics, there may be a specific supply chain for different combinations of markets, consumers, products or even seasons.

1.3.1 Logistics Versus Supply Chain Management

The difference between logistics and SCM is subtle (and controversial among scholars and practitioners). Based on the definition adopted in the book, logistics has a wider scope than SCM, since it also encompasses logistics systems that are not supply chains (e.g., solid waste collection systems or postal delivery systems).

1.3.2 A Taxonomy of Supply Chains

As shown schematically in Figure 1.3, in industrial logistics, supply chains may be configured in a variety of shapes. When the demand of single products can be predicted accurately, all the activities of procurement, manufacturing, assembly, and distribution can be planned in advance, based on forecasts of finished product demand (*make-to-stock* (MTS) supply chain). On the other hand, when finished products come in a very

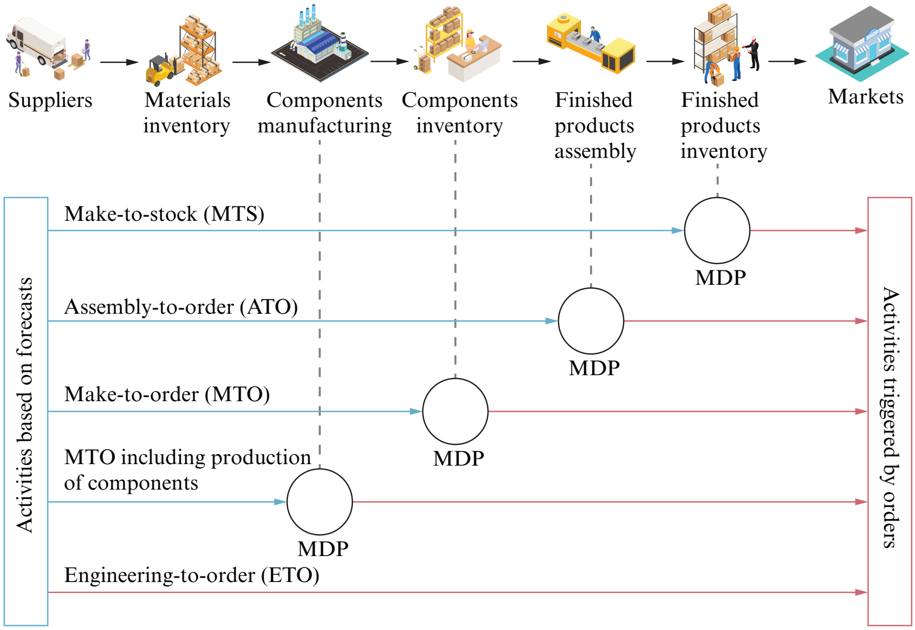

Figure 1.3 Supply chain taxonomy.

large number of variants and only the aggregate demand can be predicted accurately, it is reasonable to produce common components in advance (based on aggregate forecasts) and then assemble the products when orders arrive (*assembly-to-order* (ATO) supply chains). Of course, a hybrid MTS–ATO supply chain can also be implemented by holding a small inventory of the most demanded finished products in either DCs or retailers if customers expect to receive the goods in a timely fashion. If even the aggregate demand of an entire range of products is hard to be predicted, all the activities of manufacturing, assembly and distribution (and sometimes procurement) should be triggered by customers' orders (*make-to-order* (MTO) supply chains). Again, a hybrid MTO–ATO–MTS supply chain may prove a good compromise between the needs to keep inventories low and to provide a reasonable level of service. Finally, some products are so unique that even the design of the product is done on the basis of the customers' specifications (*engineering-to-order* (ETO) supply chains). The separation between the activities based on planning (*push* subsystem) and the activities triggered by orders (*pull* subsystem), which is often a significant stock-holding point, is called *material decoupling point* (MDP). Products are pushed to the MDP and pulled from it.

1.3.3 The Bullwhip Effect

Managing a supply chain is relatively simple for standard products with a stable demand. This is the case, for example, for some household cleaning products that come in a small number of variants with a predictable demand. On the other hand, SCM can be complex when dealing with short life cycle products having a highly uncertain demand. This is the case, for example, of the fashion apparel and consumer electronics industries. Forecasting errors in the fashion industry may have an order of magnitude of 10% at the start of season, 20% 16 weeks ahead and 40% 26 weeks ahead. Similarly, in consumer electronics the equivalent rule of thumb is that the forecasting error is 5% one month ahead, 20% two months ahead and 50% three months ahead. Since manufacturing is not instantaneous, poor planning can result in a stockout or in a very large surplus (followed by a seasonal sale at knock-down prices) or, even more dramatically, in the so-called *bullwhip effect*: many stockouts alternating with very large surpluses in the same selling season.

SCM is even more challenging when facilities are located thousands of kilometres away from each other, in different countries or even in different continents. The mass migration of manufacturing from the developed world to emergent economies is motivated mainly by fewer regulatory controls and significantly lower wages. This has significantly increased the global trade. While sea cargo shipments are relatively cheap, they are also relatively slow. For instance, the shipment of a container from a supplier in China to an assembly plant in the USA by a combination of truck, train, and sea shipments may take weeks. These longer lead times (see Table 1.8 and Section 5.12) may amplify the bullwhip effect.

The beer distribution game, also known as the *beer game*, is an educational game invented in 1960 by J. W. Forrester at the MIT Sloan School of Management. It is commonly used to teach supply chain principles and, in particular, to demonstrate the bullwhip effect. In the game, more teams composed of four players each, acting as the factory manager, the distributor, the wholesaler and the retailer, respectively, are involved in a role-play simulation of a beer supply chain (see Figure 1.4).

The common goal of the participants is to produce and deliver beer to the final consumers at minimum cost (total cost being the sum of reorder, shortage, and holding costs along the entire planning horizon, see Section 5.12.1 for more details). The team that achieves the minimum total cost in the simulation of the supply chain wins. The game is played by each team in a certain number of rounds and in each round:

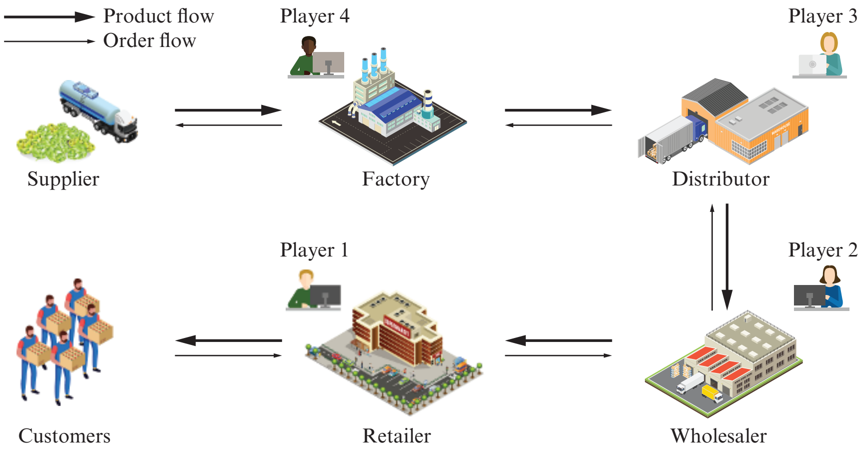

Figure 1.4 Supply chain of the beer distribution game.

- the number of beer packs demanded by the consumers in the last period becomes known to the retailer;
- the retailer updates its inventory and may decide to issue an order to the wholesaler;
- the wholesaler is instantaneously informed about the new (possible) order, updates its inventory and may decide to issue an order to the distributor.

A distinctive feature of the beer game is that orders are not delivered instantaneously, but only after a given number of time periods (corresponding to the lead time).

It is worth noting that, in the original game, players do not have a full picture of what is happening in the supply chain, each player being only aware of the orders received from the downstream player of the same team and its inventory. When playing the game under such conditions, the simulation shows a considerable inventory oscillation (i.e., a bullwhip effect) even for small variations of market demand (see Problem 5.17 for further insight). On the other hand, supply chain performance is greatly improved if the players are allowed to share information and coordinate their decisions.

1.4 Logistics Service Providers

While some manufacturers operating in geographically concentrated markets may still possess and operate their own logistics resources (facilities, vehicles, crews, etc.), nowadays the complex needs of global supply chains are often contracted out to external service providers. LSPs, introduced in Section 1.1, allow manufacturing companies to outsource some specific logistics operations (warehousing, sea freight forwarding, rail freight transportation, intermodal transportation, last-mile distribution, etc.), or even the entire SCM, to external organizations. Outsourcing may involve only a subset of the logistics activities, leaving some products or operations to the in-house logistics (if this works better or is cheaper than an external provider). There are five main logistics outsourcing paradigms:

- *First-party logistics* (1PL). Logistics needs, such as the transportation and the storage of goods, are fulfilled by using the organization's internal resources (e.g., trucks and warehouses bought or rented by the company). Hence, a 1PL provider is a department or a division (see Section 1.9.2) of the organization itself.
- *Second-party logistics* (2PL). Transportation and warehousing activities are outsourced to an external LSP that possesses and manages its own assets. A key aspect of 2PL is that the provider's service is limited to a portion of a supply chain without including integrated logistics solutions.
- *Third-party logistics* (3PL). A LSP guarantees an integrated logistics solution that may include not only transportation and warehouse management, but also terminal operations, customs clearance as well as package tracking. A 3PL provider is not involved in the design of the supply chains. Examples of 3PL providers include freight forwarders and courier companies.

- *Fourth-party logistics* (4PL). A 4PL provider deals with all the aspects of the client's supply chains, including their design. Hence, the client company simply communicates to the 4PL provider the needs of its supply chain (e.g., amount of goods to be stored and delivered). Then, the 4PL provider manages the entire supply chain process for the client company. As a rule, 4PL providers entrust the execution of operational activities to subcontractors (3PL providers). For this reason, sometimes they often do not own physical assets. Due to its technological and integration capabilities, a 4PL provider is also called a *logistics integrator*.
- *Fifth-party logistics* (5PL). 5PL providers are the same as 4PL providers, except that they have an extensive focus on e-business solutions and provide additional services such as *customer relationship management* (CRM), online payments and so on.

Finally, it is worth noting that, broadly speaking, any company offering some type of logistics service for hire defines itself a 3PL provider.

UPS Supply Chain Solutions is an American 4PL company which offers, in partnership with its customers, a variety of services including global supply chain design, logistics and distribution, customs brokerage, and international trade organization. In particular UPS, through its warehousing and freight distribution services, promotes the adoption of an outsourced solution for e-commerce business that eliminates the need for its partners to hold inventory or pick, pack, and ship freights.

1.5 Logistics in Service Organizations

Logistics principles may be even more important in service organizations than in production firms. The following subsections provide two relevant examples.

1.5.1 Logistics in Solid Waste Management

Solid waste management (SWM) is concerned with the collection, treatment and disposal of solid materials that have served their purpose or are no longer useful. Municipal solid waste includes waste from residential, commercial, and institutional (e.g., schools, government offices) sources. Other materials that are frequently disposed in landfills include construction and demolition waste as well as non-hazardous industrial process waste.

Every citizen generates a fairly large amount of solid waste every day (on average, 2.58 kg in the USA, 2.11 kg in Germany, 0.52 kg in Indonesia, just to mention a few statistics). This creates the need to manage a complex logistics system that can be often divided into two major subsystems: a municipal collection system and a regional management system.

Each municipality is in charge of its own curbside garbage collection, using either its own fleet or a contracted service. The collection is done on the basis of a weekly schedule, depending on the type of refuse (organic waste, paper, plastic, etc.) and district. Depending on the local regulations and policy, the residential waste is collected directly at home (*door-to-door collection system*), or has to be taken to a collection site by

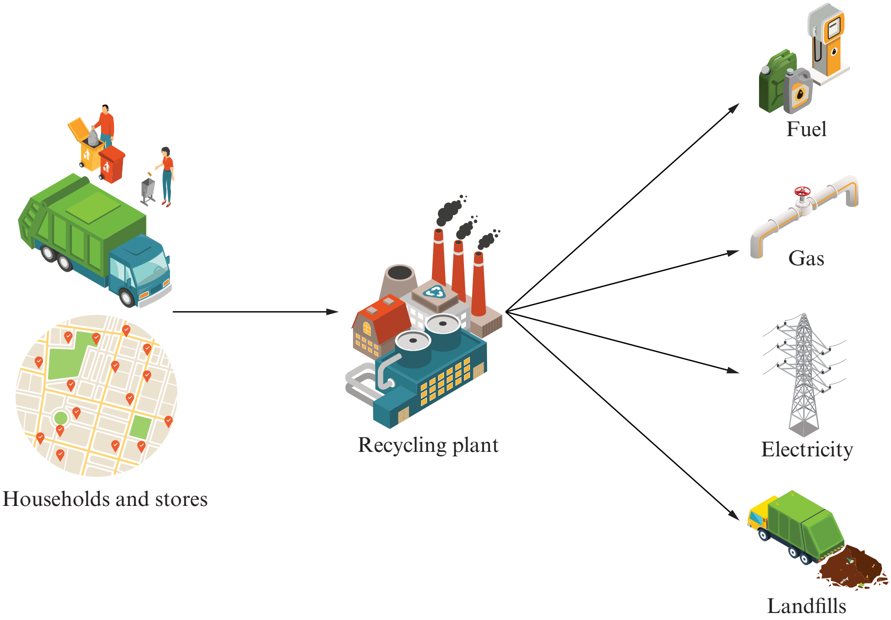

Figure 1.5 Logistics in a Solid Waste Management System.

the citizens (where it is later collected by specialized vehicles). Once the waste has been collected, it is possibly shredded and taken directly to a recycling plant or to a intermediate transfer station. Finally, fuel, gas and electricity (as well as other materials such as compost) are generated from the waste. The residuals of the process are then disposed in a landfill (see Figure 1.5).

Building a new treatment or disposal facility may take one to four years, while its operating life is around 15–30 years. Consequently, designing or redesigning a regional SWM system is a strategic decision having long-lasting effects.

Another issue to be considered is the large percentage of total solid waste management cost related to waste collection (about 75%) due to the equipment and the workforce. Therefore, partitioning the service territories into districts, allocating waste flows among the facilities selected at the strategic level, choosing collection days for each district and for each waste type, determining the composition of the fleet and the crew assignment could result in significant cost savings.

1.5.2 Humanitarian Logistics

Every year, there are approximately 150 000 deaths and 200 million people affected by sudden onset disasters, such as hurricanes, tsunami or earthquakes, and slow onset disasters, such as famine or droughts. Humanitarian logistics aims to provide support in the form of medicines, water, food, and shelter to the affected population in a timely and cost-effective fashion.

As far as sudden onset disasters are concerned, humanitarian logistics is fundamentally different from commercial SCM. Some warehouses, often located in donor countries or at strategic points in the world, such as the United Nations Humanitarian Response Depot (UNHRD) in Brindisi (Italy), store goods (blankets, spare parts, equipment, tools, etc.) for a long time (months or even years) until they are needed. Only then, are they transported near the heart of affected zones, displaced or distributed to the population.

Transportation plays a fundamental role in making search and rescue teams, doctors, equipment and supplies available in a timely way to the affected regions. Its use must consider the level of urgency, the total cost as well as the geographical characteristics of target areas. Another peculiar feature of humanitarian logistics is the need to coordinate several players, including governments, military forces, aid agencies, donors, non-governmental organizations, suppliers, and private service providers (e.g., airlines for freight transportation).

1.6 Case Studies

This section aims at introducing, through case studies, the fundamentals of logistics systems management. In each case study, a logistics system is sketched based on articles published in either general or specialist media. It is out the scope of this book to be exhaustive (especially because some information is kept confidential by companies and may change rapidly over time). Rather, a flavour of the variety of challenges and problems faced by logistics managers in today's global economy is given. The purpose is to make the methodological treatment of the subsequent sections easier to understand. In no way are the following case studies intended to be accurate and updated business reports.

1.6.1 Apple

Apple is an American multinational company, headquartered in California (USA), that designs, develops, and sells consumer electronics, computer software, and online services. Apple markets high-end high-value electronic devices (including the *iPhone* smartphones, the *iPad* tablet computers, the *Mac* personal computers, the *iPod* portable media players, the *Apple Watch* smart-watch, the *Apple TV* digital media player), as well as software (including the *OS X* and *iOS* operating systems, the *iTunes* media player and the *Safari* Web browser). The company also operates online services such as the iTunes Store, the App Store and the iCloud operating system.

As a competitive strategy, Apple constantly seeks a high rate of innovation in product and service design, as well as excellence in customer service, which allows it to charge customers relatively high selling prices. In 2019, the iPhone generated $ 142.3 billion in revenue, which is approximately 55% of the company's total revenue for that year. A look at the supply chain (see Figure 1.6) shows that the company makes very little of its own hardware products: components and subsystems are manufactured by dozens of suppliers around the globe and sometimes even from direct competitors. In particular, for the iPhone, Texas Instruments (USA) makes the touch screen controller, Micron (USA) the flash memory, Cirus Logic (USA) the audio controller, Dialog Semiconductors (Italy) the power management components, ST Microelectronics (Taiwan) the accelerometers and gyroscope, Infineon (Germany) the phone network components, Murata (Japan) Bluetooth and Wi-Fi components while Samsung makes the memory and application processor. This approach lowers

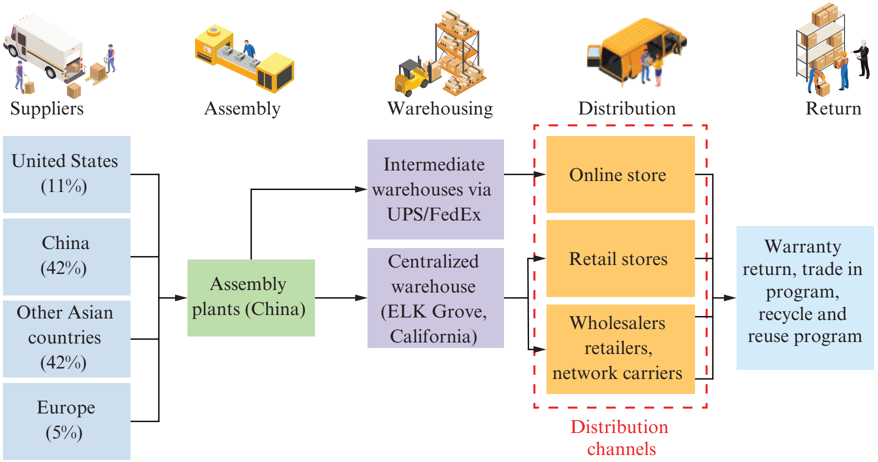

Figure 1.6 Apple iPhone supply chain.

the capital investment for Apple but requires a strict coordination of the contractors along the supply chain. In extreme cases, when a supplier proved unreliable, the company cut it off and quickly procured the same components from another manufacturer. Components are shipped by air from the suppliers to China where the finished products are assembled by the Taiwanese company Foxconn. Air transportation is substantially more expensive than sea shipments: around $ 1.21 per ton-mile versus $ 0.04 per ton-mile (see Chapter 6 for more details). However, this is not a major problem for Apple: profit margins are relatively high and the supply chain priority is being responsive opposed to being efficient. A look at a few figures will clarify this point. The retail price of the *iPhone 11 Pro Max* is nearly $ 1099 while the estimated cost of its components is approximately $ 490.50 per phone (the Samsung battery unit costs around $ 10.50, the triple camera $ 73.50 while other equipment such as the processor, modem, and circuit boards costs approximately $ 159 per phone). While it is difficult to determine the actual profit per unit (R&D, marketing, sales, and administrative costs are not included in the $ 490.50 estimate), it is clear that a pricey but timely air shipment service is worth using.

To mitigate the risk of supply shortage or disruption, Apple pools inventory and other capacity resources. The Apple's chief executive officer, Tim Cook, is convinced that the inventory of high-end high-value electronic devices depreciates very quickly, losing 1–2% of their value each week. "Inventory is fundamentally evil", he stated in a famous interview, "you kind of want to manage it like you're in the dairy business".

Apple operates multiple distribution channels: an online store, wholesalers, retail stores and network carriers (such as Bell, Verizon, Vodafone, Wind 3). Products bought from the Apple's online store are shipped to the customers via couriers (such as FedEx and UPS) on the basis of an outsourcing service level agreement (SLA). These companies hold their own iPhone stocks in order to provide timely shipments. For the other distribution channels, Apple ships products from its centralized warehouse in Elk Grove (California, USA). Finally, at the end of product's life, customers can return their devices to the nearest Apple stores or to dedicated recycling facilities.

1.6.2 Adidas AG

Adidas AG is a German multinational corporation that designs and produces sport shoes, sport clothing (including men's and women's t-shirts, jackets, hoodies, pants, leggings) and accessories (such as eyewear, bags, caps, socks as well as deodorants, perfumes, aftershave, and lotions). It is the largest sportswear manufacturer in Europe and the second largest in the world, after Nike. It is part of the Adidas Group which also includes the Reebok sportswear company and Runtastic, a fitness technology company. Adidas' revenue was around $ 21 billion in 2018.

In 2017 the supply chain of Adidas included 296 suppliers, 79% of which where in Asia while 11% were in the Americas, 9% in Europe, and 1% in Africa. In particular, 97% of the total footwear volume (nearly 403 million pairs) was made in Asia (44% in Vietnam, 25% in Indonesia, and 19% in China). As for apparel production, the total production equalled 404 million units that were manufactured mainly in China (23%), Cambodia (22%), and Vietnam (18%). Finally, the total volume of hardware (such as balls and bags) amounted to 110 million units and were produced mainly in China (40%), Pakistan (18%), and Turkey (15%). Adidas uses ocean freight to transport goods to distributions centres around the world. The company owns more than 2500 retail shops and sells through approximately 13 000 mono-branded franchise stores and 150 000 wholesalers around the globe.

To cope with this complexity, retailers are segmented into homogeneous groups and several supply chain models are used. As far as sportswear is concerned, the retailer segments are the following:

- *"Mi Adidas" e-commerce segment*. The Adidas online shop is devoted to those looking for a high performance gear. Consumers can design their sporting goods (e.g., running shoes) to meet their expectations, choosing from a variety of colours, styles, and features. Products are then manufactured and delivered to consumers in 21 days.
- *Specialist store segment*. Customers shopping at a specialist retailer are serious about their sport and are willing to pay a premium price for the latest products. Unsurprisingly, price is not considered an order winner in this segment.
- *Sports generalist segment*. These retailers are patronized by customers who want to keep fit and look for reasonably priced products of acceptable quality.
- *Lifestyle generalist segment*. The fourth retailer segment sells the latest fashion items at premium prices. It guarantees high margins based on brand perception, innovation, and exclusivity of the product range.

Adidas uses the following supply chain models to cope with the short-life cycles and unpredictable demand of its sportswear garments.

- *Never out of stock (NOOS) model*. Small retailers can place any size order and have the stock delivered from a DC in two to three days. Adidas combines the orders from the

NOOS retailers to reach minimum order quantities with the producers and benefit from volume discounts. This supply chain model proved to be able to increase sales by a factor of five with retailers in the lifestyle generalist segment.

- *Special handling at source (SHAS) model.* For major customers, batches are prelabelled at production sites and shipped in ocean containers directly to DCs and then sent to stores with no rework.
- *Consignment model.* The consignment model allows retailers to return unsold product to Adidas without charge, thus removing retailer risk. This approach allowed Adidas to improve its market position in specialist running stores.
- *FLASH model.* The FLASH model aims to revive consumer interest by constantly refreshing products at retail shops. Packages are shipped to stores every six weeks while unsold stocks are returned to Adidas. This model was first used by the Spanish apparel retailer Zara, who developed new ranges of products every six to eight weeks to create a sense of urgency with consumers and encourage them to buy before the stock disappears.
- *"Mi Adidas" model.* The large number of design variations required by customers in the "Mi Adidas" segment needs buffers of raw materials and components to be maintained in the factories. Semi-finished products are kept in stock and are completed according to the customers' desired colour, size, and features, only when orders are received. Products bought online can be returned to nearby stores in order to get a refund or a different product.

1.6.3 Galbani

Galbani, a company of the French Lactalis group, is a leader in Italy in the dairy products sector and one of the main actors in the pressed pork market. Galbani is currently made up of three independent operational branches. One of them, biG Logistics, has the mission to manage the logistics activities of the whole company. The logistics system is organized in such a way as to guarantee an efficient synchronization of the internal production and distribution processes of the products, both for *mass market retailers* (MMRs) and traditional retail shops. The distribution network of the company is organized on two levels: there are, between the production plants and the destination markets, a central warehouse and 11 distribution platforms. This solution promotes a rapid delivery of the products (within 12 hours in Italy and 24 hours abroad), strictly respecting the requirements of the *cold chain*. The daily products are dispatched directly by the production plants to the central warehouse, located in the area of Ospedaletto Lodigiano, considered a barycentric position with respect to the national market. The central warehouse of 185 000 m^3, highly automated and constantly kept at a temperature of 4 °C, serves, in turn, the second level platforms with the orders mixed according to their destination (see Figure 1.7). The platforms receive the incoming flow of goods from the central warehouse and supply both the DCs of the MMRs and the so-called satellites. The satellites are small-size warehouses from which a fleet of distinctive yellow vans (operating as truly travelling stores) delivers to retailers. There are 108 satellites distributed throughout the national territory, each covering roughly a province.

Galbani determines the daily production plan for each plant on the basis of forecasts derived from historical data. These data are gathered at the 11 logistics platforms,

Figure 1.7 Location of the central warehouse and the 11 distribution platforms in the logistics system of Galbani.

MMRs and the satellites. Then this information is shared with the central warehouse and the production plants.

1.6.4 Pfizer

The Pfizer Pharmaceuticals Group is the largest pharmaceutical corporation in the world. Its mission is "to discover, develop, manufacture and market innovative, value-added products that improve the quality of life of people around the world and help them enjoy longer, healthier, and more productive lives". The Pfizer range of products also includes self-care and well-being products for livestock and pets.

Founded in 1849 by Charles Pfizer, the company was first located in a modest red-brick building in the Williamsburg section of Brooklyn, New York (USA), that served as office, laboratory, factory, and warehouse. The firm's first product was Santonin, a palatable antiparasitic which was an immediate success. In 1942 Pfizer responded to an appeal from the US Government to expedite the manufacture of penicillin, the first real defense against bacterial infection, to treat Allied soldiers fighting in World War II. Of the companies pursuing mass production of penicillin, Pfizer alone used the innovative fermentation technology. Pfizer manufactures some of the most effective and innovative active ingredients including atorvastatin, whose medicine is the most prescribed cholesterol-lowering one in the USA, amlodipine, belonging to the calcium channel blocker dihydropyridine class, used as an anti-hypertensive, azithromycin, the most-prescribed brand-name oral antibiotic in the USA, and sildenafil citrate, a breakthrough treatment for erectile dysfunction. With a portfolio that includes five of the world's 20 top-selling medicines (including Advil, Viagra, Xanax, Zoloft and the Comirnaty COVID-19 vaccine), Pfizer sets the standard for the pharmaceutical industry. Ten of its medicines are ranked first in their therapeutic class in the US market, and eight earn a revenue of more than one billion dollars annually. Research, development and innovation represent the lifeblood of Pfizer business that supports the world's largest biomedical research laboratory, with 12 000 scientists worldwide and a financial investment of six billion dollars annually.

The Pfizer logistics system comprises 58 manufacturing sites around the world (see Table 1.1), producing pharmaceutical, veterinary, and cosmetic products for more than 150 countries. Because manufacturing pharmaceutical products requires highly specialized and costly machines, each Pfizer plant produces a large amount of a limited number of pharmaceutical products for the international market (see Table 1.2).

The attention will be now focused on the Pfizer supply chain of a cardiovascular product, fictitiously named Alpha10. The product is packaged in blisters, each containing 20 tables of five or 10 mg. Alpha10 is produced in a unique European plant (EUPF) for an international market including 90 countries (see Figure 1.8). Every year the plant produces over 117 million blisters. The product expires 60 months after its production and must be stored at a temperature varying between 8 °C and 25 °C. The main component of Alpha10 is a particularly active pharmaceutical ingredient, based on a Pfizer property patent, manufactured in a North American plant. Its packages are transferred

Table 1.1 Geographical distribution of the manufacturing sites of Pfizer.

Continent	Number of sites
Africa	7
Asia	13
Australia	2
Europe	16
America	20

Table 1.2 Features of some Pfizer plants in Europe. The productivity rate is measured in millions of items per year.

Country	Number of plants	Number of products	Productivity rate
Belgium	1	29	6.5
France	1	14	2.4
Germany	1	3	11.4
Italy	3	182	87.1
United Kingdom	1	8	5.0

Figure 1.8 Markets for Pfizer product Alpha10.

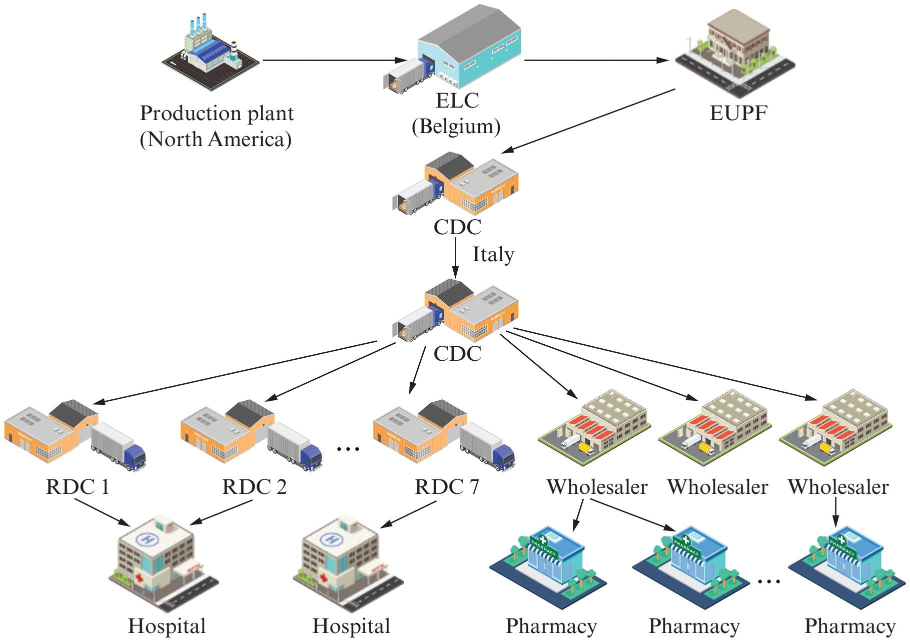

Figure 1.9 Pfizer supply chain for product Alpha10 in Italy.

by air to the European logistics centre (ELC), located in Belgium, which in turn replenishes the EUPF on a monthly basis (see Figure 1.9). Freight transportation between the ELC and the EUPF is performed by overland transportation providers (e.g., Danzas). The EUPF plant manufactures Alpha tablets which are subsequently packaged into 120 blister boxes and sent weekly to a third-party CDC.

In Italy, Alpha10 is distributed, together with other products of Pfizer, both to hospitals and pharmacies, using two different channels (see Figure 1.9). Hospitals (about

2000) are supplied directly by the company, throughout a CDC and seven RDCs. Hospitals may be supplied by more than one warehouse, depending on stock levels available at the RDCs. Transportation is performed by specialized haulers in refrigerated vans. Pharmacies (about 16 000) are supplied through (about 200) wholesalers. Wholesaler orders are collected directly by Pfizer and shipped weekly by the CDC. The CDC is able to deliver the product to any Italian location within at most 60 hours. Wholesalers receive orders from pharmacies very frequently (up to four times a day). Pharmacies expect the wholesalers to deliver medicines within four to 12 hours (it is worth noting that, in Italy, pharmacies have a high contractual power over the wholesalers). Therefore, the average revenue of the wholesalers is low, due to the high logistics costs that are incurred to guarantee a high service level to pharmacies. The Pfizer logistics network and its wholesalers share data (orders, delivery times, etc.) with an information system named Manugistics.

1.6.5 Amazon

Amazon is an American multinational technology company headquartered in Seattle (USA). Its core business is based on cloud computing, digital streaming and, above all, e-commerce. Initially born as a online marketplace for books, Amazon now sells a multitude of product categories in more than 200 countries, including electronics, hardware, software, video games, apparel, furniture, food, toys, accessories, and jewellery. Amazon carries its business on an international scale, operating complex logistics activities 24–7 to guarantee fast deliveries to its customers all over the world (see Section 1.7.2). The logistics system is composed of three main levels: *procurement & fulfilment*, *distribution*, and *last mile* (see Figure 1.10). The three levels are described in the following with reference to North America.

- *Procurement & fulfilment*. The first level is focused on procurement, with the main objective of stocking products to fulfil customer orders promptly even if demand is uncertain, as well as the preparation of packaging and parcels for the subsequent delivery stages. In North America, this level is composed of 10 *inbound crossdocking points* (ICPs) and 187 *e-fulfilment centres* (EFCs), each of which named after the International Air Transport Association (IATA) code of the closest airport, followed by a digit (e.g., MIA5 is the code adopted for the e-fulfilment centre located in Miami, Florida). The ICPs are usually located in proximity of major intermodal terminals and corridors to facilitate trans-shipment. The EFCs, having an average size of 79 500 m^2 each, are usually located in suburban areas with an easy access to highways. In order to face the high variability and frequency of online orders, a great part of the EFCs is completely automated, guided by algorithms (developed by *Amazon Robotics*, a subsidiary company of Amazon) that optimize the routes and schedules of pickers and *automated guided vehicles* (AGVs, see Section 5.6.2). The procurement strategy is based both on low-cost manufacturers making products offered under the Amazon brand, and *associated* vendors that sell their own products on the Amazon e-marketplace. The associated vendors usually have to send a share of their inventory to the EFCs before the actual sale, in order to guarantee a fast-delivery service (e.g., *Amazon Prime* deliveries).

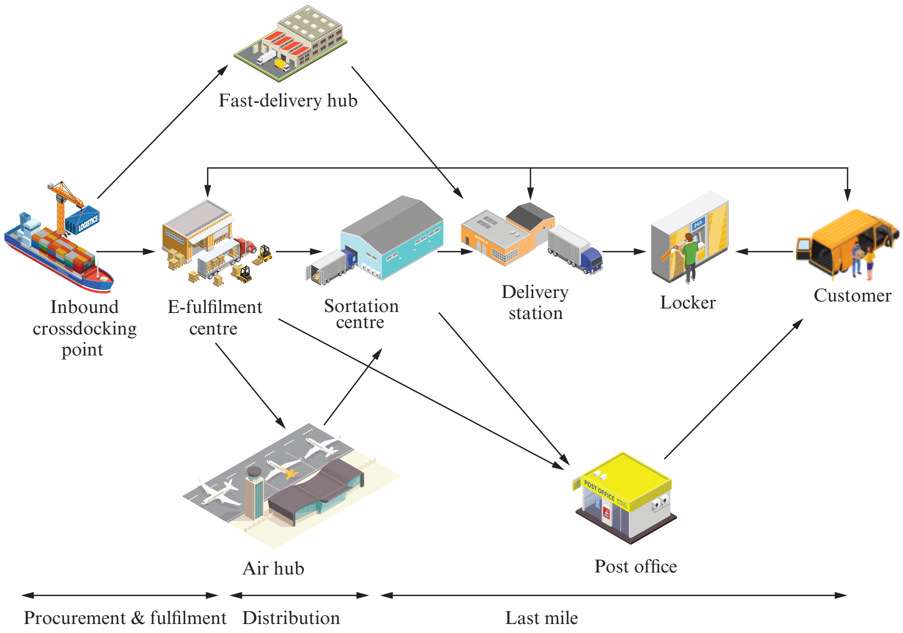

Figure 1.10 Amazon's supply chain. For simplicity, only one node for each type of facility is depicted.

- *Distribution*. The second level involves the distribution of parcels to downstream facilities, up to a centre close enough to the final destination. The two main facilities at this level are *air hubs* (AHs) and *sortation centres*. The distribution through AHs is performed by *Amazon Air*, a cargo airline, set up in 2015 to transport Amazon parcels, operating a fleet of 42 airplanes. Amazon Air serves six AHs and 23 airports in North America, with a *hub-and-spoke* structure. The airports are chosen for their proximity to metropolitan areas, in order to move freight directed to the sortation centres with the use of trucks. Sortation centres represent the first layer of a city logistics framework (see Section 1.7.3). Nowadays, there are 47 sortation centres in North America, with an average size of 29 900 m^2 each. A sortation centre is located in an area with a minimum level of demand and its role is to split the loads into parcels to be delivered directed to *delivery stations* (see the *last mile* level) or to other destinations, such as post offices and households.
- *Last mile*. The third level involves the transportation of parcels to final destinations. In this case the challenges faced by the company are those of city logistics (see Section 1.7.3) with a variety of operational constraints related to traffic congestion, presence of limited traffic zones, lack of parking spaces, etc. Excluding 3PL services, this level is managed by using two different types of facilities: *fast-delivery hubs* and *delivery stations*. Fast-delivery hubs are facilities which specialize in the fast-delivery market segment, for managing specific company services like: Amazon Prime deliveries within the same day or 48 hours, depending on the destination), Amazon Fresh (grocery and perishable) and Amazon Pantry (household and cleaning). The network is made up of 53 Amazon Prime hubs of an average size of 3700 m^2 each, that represent a compromise between reduced lead time and costs; 24 Amazon Fresh and Pantry

hubs usually co-located with Prime hubs. A delivery station is the most common type of facility. Indeed there are around 250 delivery stations inside North America with an average size of 8500 m^2. In this case, the main strategy for the last mile is building a series of horizontal collaborations. In particular, Amazon defined a series of pickup points located in affiliated physical bookshops, news vendors, shopping centres and drug stores. In particular, in September 2011 the company launched the Amazon Locker program in major US cities where self-service kiosks (called *lockers*, see Section 1.7.2) were installed in affiliated stores. The service was then extended to Canada, France, Spain, Germany, and Italy. In June 2018, Locker was available in over 2800 locations in 70 cities around the world. Finally, Amazon is experimenting with other innovations for last-mile delivery: Amazon Prime Air and Amazon Flex services. Amazon Prime Air is a drone delivery service launched in 2013 specifically for parcels of at most 5 kg that have to be delivered over small distances in around 30 minutes. The Amazon Flex platform was launched in 2015 in 14 American metropolitan areas, introducing one of the first crowdshipping services (see Section 1.7.2) to encourage ordinary citizens to carry out deliveries on the last mile.

As is common in the e-commerce sector, Amazon stipulates specific contracts with 3PL service providers such as DHL, FedEx, and UPS (see Section 1.4) to operate long-haul transportation from EFCs directly to customers, or to move freight by truck among the different nodes of the supply chain.

1.6.6 FedEx

FedEx is an American multinational delivery and SCM company servicing more than 220 countries and territories with over 500 000 team members, 180 000 cars, vans, tractors, motorcycles, 670 cargo planes, and hundreds of freight terminals around the world. Every day the company delivers more than 16 million packages.

Major competitors include the United States Postal Service (USPS) and UPS, along with national postal services and carriers such as Canada Post (and its subsidiary Purolator), Deutsche Post (and its subsidiary DHL), Royal Mail, and Poste Italiane.

FedEx deals with two distinct (air and ground) networks (see Figure 1.11). Both are based on a hub-and-spoke strategy in which parcels are consolidated through hub terminals connected with multiple decentralized terminals (spokes) along the network. Conversely, a transportation network may connect directly every pair of origin-destination pairs (*point-to-point network*) but this is only rarely economically viable.

Air parcels (often classified as urgent shipments) are driven to a nearby airport facility (*express station*), successively flown to an air hub (either the major hub in Memphis, USA, or to a regional hub), transported to the destination airport, and then delivered by truck. It is worth observing that FedEx air shipments are typically overnight. This allows a customer to ship a package, for example, from Grenoble (France) on Wednesday to Seattle (USA) by 8:30 on Thursday. To achieve this result, FedEx operates one of the largest cargo airlines in the world, with more than 1950 express stations at 13 air hubs, and flies to over 800 destinations worldwide.

Non-urgent packages in North America or in Europe, when the distance is compatible, are picked up, dropped off at a ground centre, sent out to a ground hub, forwarded

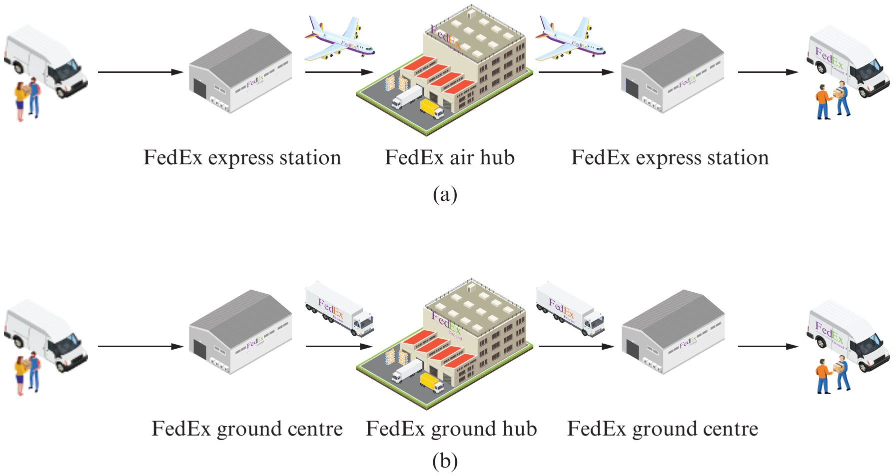

Figure 1.11 FedEx's multiple hub-and-spoke (a) air and (b) ground networks.

to a destination hub by truck, driven to a destination centre and finally shipped by truck to the final destination. FedEx operates more than 600 ground facilities in 39 ground hubs.

FedEx uses independent contractors for many deliveries (depending on the country and service level) while other competitors (such as UPS) use their own employees for all services. The company deals daily with all the facets of international logistics, including customs regulations.

1.6.7 A.P. Moller-Maersk

A.P. Moller-Maersk (APM) is a Danish company operating in the transportation, logistics and energy sectors, with subsidiaries and offices in 130 countries. Its operating units include APM Terminals and Maersk Line. Both operate in the sea freight transportation sector (see Section 6.2.2).

Since the 1970s, the majority of long-haul transportation makes use of *containerization*, a system based on the use of intermodal containers of standardized dimensions (see Section 5.4.5 for more details). This allows productivity gains to be achieved through simplified cargo handling: containers are loaded and unloaded, stacked and transported efficiently over long distances. In particular, containers are moved from one mode of transportation to another (e.g., container ships, rail flatcars, and semi-trailer trucks) without being opened. Container ship capacity is measured in *twenty-foot equivalent units* (TEU), representing the volume of a 20-foot-long (around 6.1 m) container.

With a staff of 83 000 employees worldwide, APM owned 307 ships and was chartering some 417 ships in 2021. It accounted for around 17% of the world's merchant container fleet. In terms of TEUs, APM is the world's largest container-shipping company. It has ships with an overall capacity of around 4 000 000 TEU (2 300 000 TEU of owned capacity and about 1 800 000 TEU of chartered capacity).

Maersk operates a global container network with a hub-and-spoke topology: medium-size freight ships usually under 3000 TEU (called *feeder ships*, see Section

6.2.2) transport containers from different ports (*spokes*) to central container terminals (*hubs*) to be loaded onto larger vessels (*mother vessels*) with a capacity up to over 20 000 TEU. The hub-and-spoke configuration, introduced in 1985, avoids very large mother ships deviating from their round-the-world routes to visit ports whose volumes are not large enough to justify direct calls. In particular, hub ports link the major East–West services with one another, and to the North–South services (see Figure 1.12). Some *transshipment* hubs, such as Algeciras (Spain) and Gioia Tauro (Italy), serve no hinterland, their only attraction being their location close to the shortest intercontinental routes. The update of the Maersk's hub-and-spoke container network is constantly in progress. In 2021 the network was based on 343 ports and terminals operating in 121 countries, and the routes were split over six areas: Africa, Asia Pacific, Europe, Latin America, North America, and West Central Asia. By using the company website, it is easy for potential customers to recover detailed shipping information for any route to and from each area. For example, for the FEW1 route (see Figure 1.13), corresponding

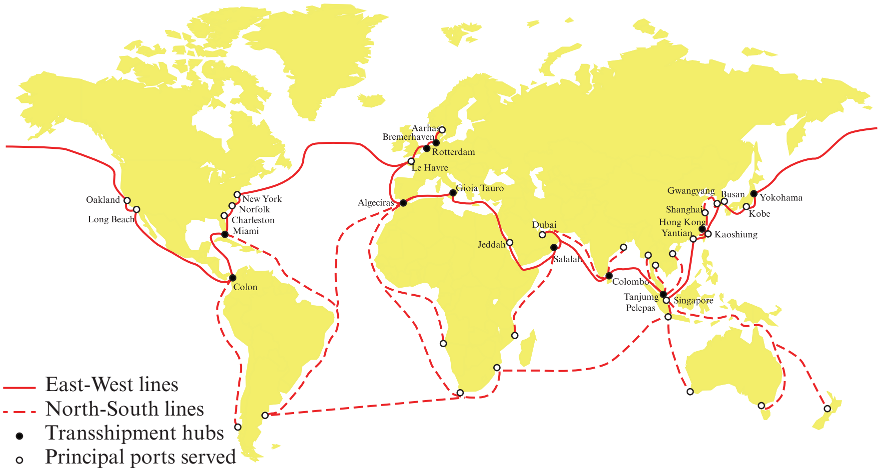

Figure 1.12 Maersk's hub-and-spoke container network in 2003.

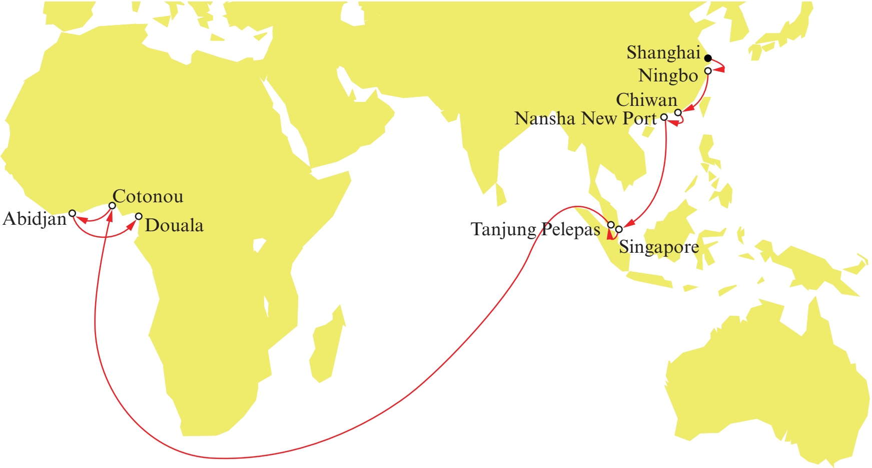

Figure 1.13 Maersk's FEW1 westbound route.

Table 1.3 Timetable of the Maersk's FEW1 westbound route.

Port	Country	Transit time	Arrival day	Departure day
Shanghai	China	–	–	day 1
Ningbo	China	1 day	day 2	day 2
Chiwan	China	3 days	day 4	day 4
Nansha New Port	China	3 days	day 4	day 4
Tanjung Pelepas	Malaysia	10 days	day 11	day 11
Singapore	Singapore	11 days	day 12	day 12
Cotonou	Benin	33 days	day 34	day 34
Abidjan	Ivory Coast	36 days	day 37	day 37
Douala	Cameroon	41 days	day 42	day 42

to the westbound service from Asia Pacific to Africa, and in particular, from Shangai port (China) to Douala port (Cameroon), the timetable in Table 1.3 is shown.

1.6.8 Canadian Pacific Railway

Canadian Pacific Railway (CPR) hauls freight over 20 100 km of track in six provinces of Canada and into the USA. Its transcontinental railroad system stretches from Montreal to Vancouver, from Edmonton to Milwaukee, Detroit, Chicago, and Albany (see Figure 1.14).

Rail is the cheapest freight transportation mode in inner territories which makes it the mode of choice for low-value and less time-sensitive goods. In North America it costs approximately $ 0.025 to move a tonne of freight over one kilometre, which means that a tonne of freight can be moved on a train from New York to Los Angeles for about $ 100. In Europe the cost is nearly double. The competitors to trains are trucks that can haul a tonne of freight for about $ 0.13 per km.

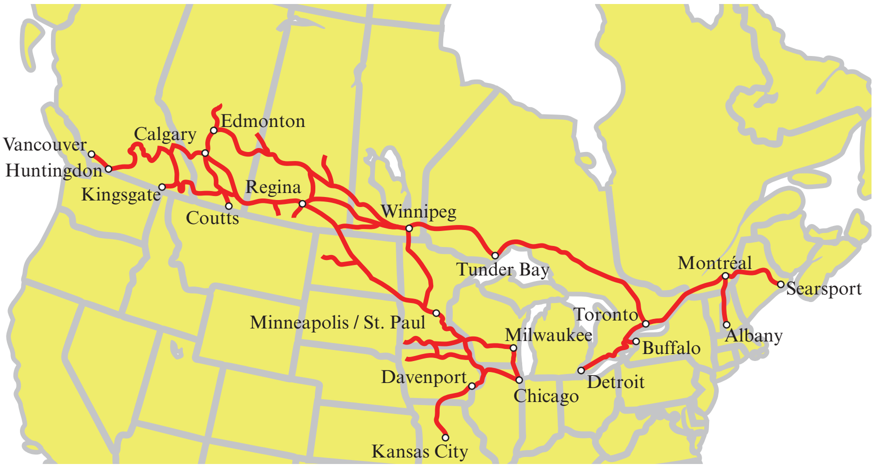

Figure 1.14 Canadian Pacific Railway network.

In North America the rail network is quite extensive and is owned mostly by private companies. The governments subsidize passenger transportation. Seven major rail operators, each with its own territory, exist: Union Pacific Railroad, BNSF Railway, CSX Transportation, Kansas City Southern Railway, Norfolk Southern Railway, Canadian National and CPR. None of these companies covers the entire continent. So for most journeys a single operator cannot get a load shipped from origin to destination. Hence, rail companies need to cooperate: rail cars are trans-shipped from the convoys of an operator to the convoys of others at special terminals.

CPR primary business is transporting intermodal grain (24% of 2016 freight revenue), intermodal freight (22%), and coal (10%) as well as chemicals (12%), automotive parts and automobiles. Coal is shipped in unit trains from coal mines to terminals in British Columbia, from where it is shipped inland. Grain is hauled from the prairies to ports on the Atlantic and Pacific coasts, where it is then shipped overseas. Over half of CPR's freight traffic is in western Canada. The company also provides logistics services via partners. Passenger services were terminated in 1986.

CPR runs very long freight trains (as long as 4000 m). It usually takes a crew of only two people to run such a train. Long routes are divided into segments: for example, the route from Chicago to Seattle is partitioned into 10 segments, each of which assigned to a different crew. Crews get on a train at the origin point of a segment (coinciding with the endpoint of the preceding segment), run the train (for at most 12 hours in the USA) up to the other endpoint where they are taken over by another crew. They then drop off and rest in a hotel, and drive another train along the same segment in the opposite direction.

1.7 Trends in Logistics

This section reviews the trends that are expected to transform the global logistics industry in the near future.

1.7.1 Reverse and Sustainable Logistics

The life cycle of a product does not finish with its delivery to the end consumer. In fact, it may be that the product is unsold, or becomes damaged or obsolete, and must, therefore, be sent back to its origin for possible recycling, repair, or disposal.

Reverse logistics comprises all the operations needed to move such products from their final destination to another location to recapture value or for final disposal. Examples of reverse logistics activities are verifying whether a product is damaged or not; transporting obsolete and damaged items to disposal centres or to secondary markets. A possible schematization of the direct and reverse material flows in a logistics system is shown in Figure 1.15.

A customer buys a washing machine from a sales point of the German chain MediaMarkt which they subsequently find to be defective. Hence, the customer takes it back to the sales point which acknowledges the defect and then substitutes the product with a new one. The retailer then returns the malfunctioning

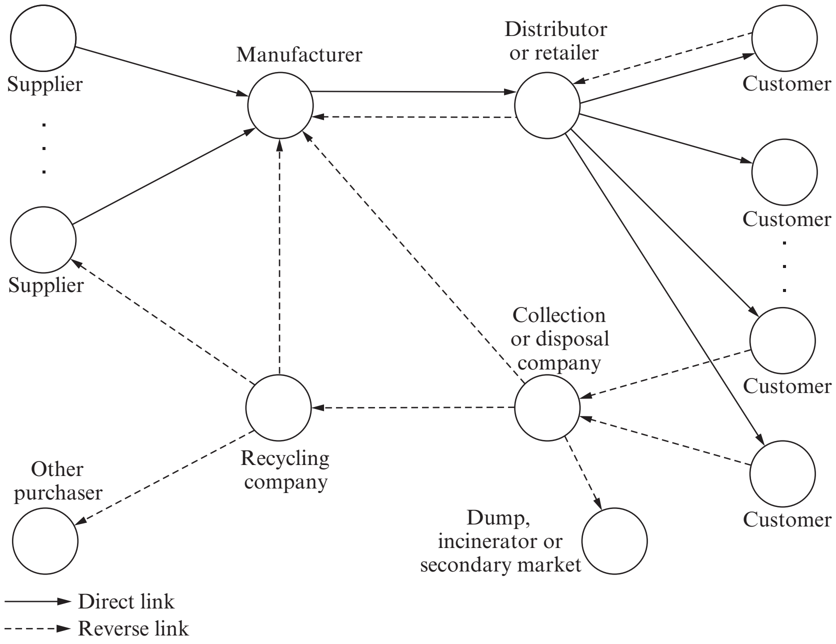

Figure 1.15 Graph representation of a reverse logistics system.

machine to an appropriate collection centre. The product is finally sent to the manufacturer which repairs it and sends it to a secondary market. In this way the manufacturer obtains an added value from the defective product.

Reverse logistics is intrinsically aligned with environmental sustainability and can therefore be seen as an important part of *sustainable logistics* which aims to lower the ecological footprint of logistics operations, such as CO_2 emissions, noise pollution, consumption of raw materials and energy, etc., balancing financial performance measures and environment care.

Hennes & Mauritz AB (more commonly referred to as H&M) is a Swedish multinational retail company known for its fast-fashion clothing. In 2012, H&M innovated the concept of reverse logistics by collecting old and unwanted clothes of any brand in any condition. The initiative started in Sweden and was later extended worldwide through the “Garment Collecting Program”, a global initiative for a sustainable future of fashion. In 2019, the company collected 29 005 tons of fabrics, equivalent to approximately 145 million T-shirts. The garments collected are divided into three different categories: items that can be reworn; items reused for the production of new clothes; items recycled in order to make fabrics for non-fashion markets. The initiative rewards participating customers with a discount on their next purchase with the aim to make customers respectful of the environment as well as reducing the cost of raw materials. The ultimate goal of H&M is to manufacture all its products with 100% recycled materials by 2030.

1.7.2 E-commerce Logistics

Retail e-commerce sales have reached $ 4 trillion in 2020 and are expected to constantly increase during the next few years. The massive use of e-commerce implies a lot of advantages: reaching customers living in remote areas, the creation of new markets for niche products, the possibility to sell products 24 hours per day, etc. On the flip side, managing logistics assets becomes much more complex. For this reason, e-commerce companies are required to have a distribution system that is as organized, fast, efficient, rational, and as optimized as possible.

E-commerce logistics is obviously very different from traditional logistics because the dynamics of physical stores differ from those of e-shops in many aspects. Indeed, a large number of activities like procurement, shipping, storage, deliveries, reverse logistics, and customer care cannot be managed in the same way inside the two channels. For example, traditional LSPs try to ship many parcels within the same delivery in order to exploit reductions in transportation costs deriving from economies of scale. On the other hand, in e-commerce distribution, logistics providers need to manage lots of shipments individually which may require a completely different approach. Broadly speaking, e-commerce changed the dynamics both in *business-to-consumer* (B2C) and *business-to-business* (B2B) sectors.

In e-commerce, the speed and reliability of the shipments are crucial: customers who buy online expect a delivery within a short amount of time, without additional costs, and with a high level of personalization (e.g., the possibility to choose the delivery place and time). Other aspects that increase the complexity of e-commerce logistics are the extreme variability and uncertainty of the demand as well as the complexity of the whole logistics process (which includes online ordering, billing, shipment tracking, and providing updates to customers).

Impact of E-commerce on Logistics Performance Measures

The adoption of the e-commerce paradigm has a significant impact on all the logistics performance measures (Section 1.8), including costs and service level provided to customers. In general, e-commerce largely improves product availability and variety since companies can concentrate their inventories in a few centralized warehouses, without the need to distribute them across a large number of stores. This implies lower overall inventory levels as well as larger facilities, usually automated, with reduced unit warehousing costs. The benefits derived from this aggregation are lower for products with high demand and low variability, while they are higher for low demand products with a high level of variability. E-commerce also allows quick adaptation to changing market conditions (e.g., demand lower than expected) by means of real-time changes in pricing and promotions. Moreover, direct deliveries allow costs to be cut by removing intermediaries from the value chain and, in the case of new products, to reduce the time-to-market, that is the length of time required from a product being conceived until its commercialization.

The other side of the coin is that delivery time may become longer than the travel time to a shop. In addition, the impossibility of trying the products can be, in some sectors, a minus. Except for digital goods, the aggregation of stocks generates longer trips to reach the customers with higher delivery costs. Moreover, an e-company needs to build and maintain a suitable *information and communication technology* (ICT) infrastructure (an online store, a payment system, a tracking or tracing system, etc.). Finally, in the e-commerce sector, the return of unsatisfactory products is much higher than in traditional supply chains (even 25–40% in the fashion and hi-tech sectors versus 8–9% in traditional stores). Hence, reverse logistics (see Section 1.7.1) has to handle a very large number of small parcels. Since the return process is often free of charge for the final customer (companies that decide to charge their customers for returning goods have a significant reduction in revenue) and returned products can rarely be resold at the original price, reverse logistics can generate large profit losses.

Issues in E-commerce Logistics

E-commerce companies face a number of peculiar issues.

- *Outsourcing of logistics activities*. Several companies outsource their e-commerce logistics to 3PL, 4PL, or even 5PL providers (see Section 1.4). These providers have the resources and expertise to face the challenges posed by e-commerce supply chains. Of course, this approach requires a high level of integration between the information systems of the providers and the company's order-entry system and *warehouse management system* (WMS).
- *Big data analytics*. E-commerce allows companies to collect a very large amount of data about their customers' buying behaviour. These data can be used to enhance customer service, define personalized pricing strategies and promotions, facilitate collaboration with logistics partners, produce accurate forecasts, etc. (see Section 1.10 for more details).
- *Horizontal, vertical, and lateral integration*. These supply chain collaboration strategies allow costs and risks to be shared with different partners. *Horizontal integration* consists in sharing resources (such as warehouse space or production capacity) at the same level in the supply chain. *Vertical integration* occurs at different levels of the supply chain (such as the integration between a producer and a retailer chain) in order to optimize service level or cost. *Lateral collaboration* combines the benefits of both vertical and horizontal integration (such as intermodal transportation).
- *Last-mile logistics*. The last mile is the least efficient part of most supply chains and generates costs which account for up to 30% of the total transportation cost. Many factors generate inefficiencies, such as traffic in urban areas and the absence of customers at the destination to receive parcels. For this reason, e-commerce companies have developed alternative approaches to the classical home delivery: pickup points and *crowdshipping*. In the first case, the company delivers the goods to specific pickup points where the customer can go and collect the order at a later time. This solution saves transportation costs (as the company delivers parcels to a limited number of points) and allows customers to collect the goods during their leisure time. A variant of this approach makes use of lockers as pickup points. Lockers are automated distribution machines that allow the collection and delivery of goods 24 hours a day. When a parcel has been placed in a locker by a delivery crew, the company sends a

code to the customer which can be used to open the locker. In the second case, companies rely on a distribution strategy based on the principles of *sharing economy*. Crowdshipping can be defined as a system in which delivery is outsourced to occasional drivers who travel inside an area as a part of their daily routine. Crowdshipping uses an internet-based platform to match the needs of customers with drivers having some spare capacity in their schedule or in their vehicles. Drivers are rewarded by the company for their service.

WalMart, an American retail company operating worldwide, launched in 2013 a plan to improve its transportation operations for delivering online orders. The company offered to in-store customers the possibility to deliver packages to other customers located along their route home. The system implemented by WalMart can be considered one of the first examples of crowdshipping. As an incentive, WalMart offered a discount on the customers' shopping bill covering the cost of their gas in return for the delivery of packages.

1.7.3 City Logistics

City logistics is concerned with freight distribution in urban areas with the aim of mitigating externalities such as congestion, emissions, and noise pollution, in addition to pursuing the traditional objectives of logistics (see Section 1.8). City logistics, which can be seen as a part of sustainable logistics (see Section 1.7.1), has gained increasing relevance in the past few decades due to the progressive population migration from small towns to large cities and the rise of e-commerce (see Section 1.6.5). Nowadays, the distance covered by delivery vehicles in urban areas represents 15–20% of all road freight transportation. The first city logistics initiatives have been taken in Europe and Japan, followed more recently, by North America and Australia.

A key feature of city logistics is a new organizational model, not considering each player (logistics providers, customers, municipal police, etc.) individually. Rather, all the stakeholders and activities are seen as part of a unique and integrated logistics system within the city. As a consequence, city logistics focuses on a strong coordination between players at all levels and, in particular, consolidation of the loads of different customers and shippers inside the same (low-emission) vehicles. In the following, the distinctive features of city logistics are reviewed.

City DCs. City DCs are intermodal platforms whose aim is to provide coordination in freight movements inside the urban area. City DCs work as crossdocking points or warehouses, receiving the inbound freight that has to be delivered within the city from long-haul multimodal transportation. In the city DC the orders are consolidated and loaded onto smaller vehicles to their final destination in the urban area. The city DCs also deal with the outbound freight flows (e.g., those generated by returned items) from the city to destinations outside the urban area. Systems where freight flows from a single city DC directly to the city centre are defined as *single-tier*. In large cities, a central city DC located in the outskirts of the urban area may serve a set of smaller city DCs (defined as *satellites*) in different city neighbourhoods (*two-tier* systems).

Ad hoc and clean vehicles. City logistics makes use of different types of vehicles. In a two-tier system, urban trucks move freight from the city outskirts to the satellites and vice versa, along selected corridors around the urban area, traversing the city centre only when necessary (e.g., when vehicles are close to their destinations). Then, smaller vehicles (called *city freighters*) are used to deliver goods from satellites to the final destinations. City freighters may be zero-emission vehicles, cargo bikes, electric vehicles, drones, etc.

Massive use of ICT. The complexity of city logistics may take advantage of ICT to coordinate the various players and control operations. Such systems create an ecosystem of connected devices and computing mechanisms to exchange data and information. Collected data include:

- vehicle positions through GPS-based devices;
- the status of deliveries through barcode (see Section 5.7.3) or *radio-frequency identification* (RFID) systems (see Section 5.7.6);
- traffic updates from sensor networks or mobile phone networks;
- planned shipments.

These data are then used to make forecasts, extract demand patterns, control operations, and update customers. Moreover, a Web-based platform is often used to plan vehicle routes and loading operations, reoptimizing routes in real time when traffic conditions vary or accidents occur, tracking last-mile deliveries, booking loading and unloading bays. In the near future, the adoption of the *Internet of things* (IoT) paradigm will make this approach more and more pervasive.

The municipality of Donostia-San Sebastián (Spain) has recently carried out a city logistics project to make city freight distribution more environment-friendly. A cycle logistics micro-hub has been located in the city centre (with an area of 500 m^2) as a city DC from which a fleet of pedal-assisted electric cargo bikes, with a cargo capacity of 180 kg for each, serve the urban area. In addition, a Web-based platform has been set up to allow logistics providers to reserve loading and unloading bays in the city centre, to plan shipments at night and to coordinate distributors, local shops and municipal police. In a single year, the cargo bikes performed about 21 000 deliveries, saving around 27 000 km in van and truck routes and highly reducing vehicle emissions.

Alternative delivery schemes. In a city logistics context, other paradigms based on the concept of sharing and integration have gained in popularity. These approaches aim to reduce costs, to increase the vehicle utilization rate, and to optimize routes. One of the most common approaches is the implementation of a *van-sharing* system, operated by specialized companies or consortia of logistics providers, through Web-based applications. The service allows the creation of a collective rental of minivans. Another common approach is the integration of public and freight transportation. In this case, the spare capacity of transit systems (e.g., metro lines) is used for freight transportation. Other delivery schemes are peculiar to e-commerce (see Section 1.7.2).

ILOS (Intelligent Freight Logistics in Urban Areas) is a city logistics project developed in Vienna (Austria) to reduce traffic congestion and air pollution caused by freight flows inside the city. ILOS has developed a freight routing optimization tool that suggests the best routes to LSPs and provides information about the associated time and cost savings. The system implements a massive collection of data from GPS-based devices on board the vehicles. The data input a simulation model which, based on real time traffic conditions, estimates travel and delivery times. The project has been able to achieve a 60% reduction in travel time, a 15% reduction in distance travelled, a 20% reduction in fuel and a 30% reduction in cost.

1.8 Logistics Objectives and KPIs

The ultimate goal of logistics management is to move goods effectively and efficiently. The concept is often summarized by stating that “logistics aims to get the right goods, in the right quantity, in the right condition, at the right place, at the right time, to the right destination, at the right cost”. Nowadays, logistics is seen by organizations as a fundamental tool to gain a *competitive advantage* and its objectives are more and more closely tied to the global organizational strategy (see Section 1.9.2). This means that logistics is no longer regarded as a mere “cost minimizer” (as it used to be in the past), but rather aims to achieve a suitable trade-off among the following aspects, in accordance with the organization’s mission and plans:

- minimize investment (capital) or maximize return on investment;
- minimize logistics cost;
- maximize customer service level.

In practice, logisticians use a number of *key performance indicators* (KPIs) and *performance measures*. The two terms are sometimes used interchangeably but they are not synonyms. Indeed, the word “key” in KPI is crucial. KPIs express the truly vital and strategic objectives of the organization (see Section 1.9.2). They must be few and well chosen to get focus from top managers. Performance measures, on the other hand, are chosen by departments and may be numerous in order to track specific aspects of operational progress. The main KPIs related to logistics are described in the remainder of this section, while logistics performance measures are illustrated in Section 1.9.3.

1.8.1 Capital-related KPIs

This family of KPIs is related to the amount of capital invested in the logistics system, both as infrastructures, equipment, inventory, or cash. In particular, in commercial supply chains, it includes measures of how well cash flow (money coming in and out) is managed. Its primary objective is to avoid the company running low on (or even out of) cash. The main KPIs of this family are listed in the following.

- *Cash-to-cash time*, C2C. This measures the lag between the time when a company pays its suppliers and when it receives cash from its customers. Several studies have proved empirically the direct correlation between shorter C2C times and greater profitability.
- *Gross margin return on investment*, GMROI. This is defined as the ratio between the gross profit generated by a product and its average inventory investment. GMROI shows which products are poor performers and which are more valuable.
- *Inventory days of supply*, IDOS. This is defined as the number of days it would take a company (or a DC) to run out of stock if it was not replenished. A large value of IDOS indicates that the company has excess inventory with respect to sales.
- *Inventory turnover*, IT. More formally defined and described in Section 5.8, IT measures the number of times a company sells and replaces its stock of goods during a specified time period (e.g., a year). Similarly to IDOS, the IT is an indicator of the logistics management efficiency. In general, the higher the IT, the better. On the other hand, a low inventory turnover shows difficulties in turning the stock into revenue.

1.8.2 Cost-related KPIs

The logistics cost can be broken down into three broad cost components: inventory-carrying costs, transportation costs, and logistics administration costs, each containing several fixed and variable cost subcomponents. Figure 1.16 and Table 1.4 report a summary of the logistics costs in the USA in 2012. The main cost-related KPI is the *logistics cost as a percentage of sales*. It shows the overall relevance of logistics in a given business, or sector, and highlights the potential of improvements in logistics efficiency. If more granularity is needed, this KPI can be split into *warehousing costs as a percentage of sales* and *transportation costs as a percentage of sales*.

Figure 1.16 Magnitude of logistics costs in the USA.

Table 1.4 Incidence of different cost components in inventory-carrying and transportation costs in USA.

Cost category	Components	[%]
Inventory-carrying	Taxes, obsolescence, insurance	66
	Warehousing	26
	Interest	8
Transportation	Truck intercity	50
	Truck local	27
	Railroads	6
	Logistics administration	8
	Water	4
	Air	4
	Oil pipelines	1

1.8.3 Service Level-related KPIs

Broadly speaking, the service level encompasses the overall degree of customer satisfaction and depends on numerous factors (indicated collectively as the 4Ps of *marketing mix*): product features, price, promotional offers, and place (distribution). The latter defines the logistics component of the service level: as a rule, an effective and efficient organization of logistics yields an increase in market share and profits, at least to some extent. However, if the logistics service level further increases, it produces a fast rise in costs while sales and profits grow more slowly, making the profit fall. Hence, logisticians determine the service level for maximum profit (difference between revenues and costs over a given period). An alternative approach is to minimize the logistics cost (e.g., on a yearly basis) while keeping the service level unchanged.

Ecopaper is a Turkish company producing various kinds of paper (glossy paper, newsprint paper, gift wrapping paper, etc.) for specialized shops, mass market retailers, etc. The market is highly competitive and delivery time is seen to be a key factor for the company's success. Ecopaper can act on the distribution system and, in particular, on the number and location of the DCs which affect delivery times. The company's logistics manager has made available some estimates of distribution annual costs and sales as a function of different service levels (see Table 1.5). As shown in the table, profits can be maximized by guaranteeing that 80% of deliveries are completed within three days from order date. This is due to the possible savings obtained by optimizing the number of DCs.

Table 1.5 Annual estimate of sales, costs and profits (in M€) for Ecopaper.

	Orders dispatched within three days [%]				
	60	**70**	**80**	**90**	**95**
Sales	4.00	5.00	7.00	9.00	10.50
Costs	1.80	3.00	3.50	6.00	7.10
Profits	2.20	2.00	3.50	3.00	3.40

The logistics component of the service level is often expressed by means of the following indicators.

- *Fill rate*, FR. Also indicated as *demand satisfaction rate*, FR is the percentage of customer demand that is met through stock availability, without backorders or lost sales. Empirical studies have showed that the FR is strongly correlated to sales volume.
- *Perfect order rate*, POR. This is defined as the percentage of orders delivered incident-free, that is, with no inaccuracies, damages, or delays. This KPI has a direct impact on customer retention and loyalty. The overall POR can be computed by multiplying the POR of each stage of the logistics system. For instance, if four stages are performing at 99%, the entire logistics process will achieve only a $0.99^4 = 96\%$ POR.
- *Order-cycle time*, OCT. This measures the average time required to fulfil a customer order, from a customer placing an order to its delivery. The OCT contains several components depending on the type of business. It may include order processing, producing and assembling the goods (or, more simply, order picking in a warehouse), order packaging, and shipping time. In general, the duration of each of these operations is not known accurately, given that several internal and external random factors affects the company's logistics system. For this reason, each component of the OCT can be seen as a *random variable* of unknown probability distribution, whose *statistics* can be estimated from historical data. Statistics provide information about the distributional tendencies that one encounters when observing samples of random variables. The two most significant statistics are the *expected value* (or *mean*) and the *standard deviation* whose estimates are the *sample mean* and the *sample standard deviation*, respectively. As a sum of random variables, the OCT is a random variable itself and its statistics can be estimated from those of its individual components.

`[MobilTrust.xlsx, MobilTrust.py]` The OCT of the British company MobilTrust is made up of two components: assembly time and transportation time. Five hundred observations of assembly time and 252 samples of transportation time are available. The minimum observed assembly time is 2.3 days while the maximum is 15.9 days. The minimum transportation time is 6.9 days while the maximum is 13.2 days. For simplicity, both parameters are discretized and expressed as an integer number of days (see Table 1.6).

Table 1.6 Historical assembly and transportation times (in days) in the MobilTrust problem.

Assembly		Transportation	
Time (x_i)	**Number of observations (h_i)**	**Time (y_j)**	**Number of observations (k_j)**
2	1	7	19
3	4	8	27
4	4	9	54
5	18	10	65
6	38	11	48
7	56	12	25
8	69	13	14
9	96		
10	72		
11	68		
12	41		
13	18		
14	12		
15	2		
16	1		

Let X and Y be the independent random variables associated with the assembly time and transportation time, respectively. The set of (discrete) realizations of the assembly time is indicated as Ω_X ($\Omega_X = \{2, \dots, 16\}$). Moreover, h_i denotes the number of observations recorded for realization $x_i \in \Omega_X$ (e.g., $h_3 = 4$). Similarly, Ω_Y indicates the observed transportation times ($\Omega_Y = \{7, \dots, 13\}$) and k_j the number of observations recorded for every realization $y_j \in \Omega_Y$. The sample mean $\overline{X}$ and the sample standard deviation S_X of X are

$$\overline{X} = \frac{\sum_{i \in \Omega_X} h_i x_i}{\sum_{i \in \Omega_X} h_i} = 9.13 \text{ days},$$

$$S_X = \sqrt{\frac{\sum_{i \in \Omega_X} h_i (x_i - \overline{X})^2}{\sum_{i \in \Omega_X} h_i - 1}} = 2.3 \text{ days}.$$

Similarly, the sample mean and the sample standard deviation of transportation time are computed as

$$\overline{Y} = 9.9 \text{ days},$$

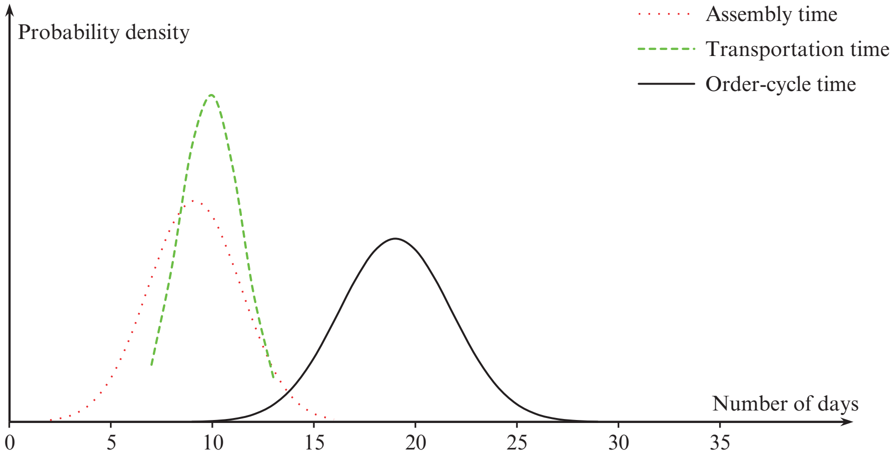

Figure 1.17 Plot of the probability density functions of assembly time, transportation time, and OCT in the MobilTrust problem.

$$S_Y = 1.55 \text{ days.}$$

Hence, the OCT $Z = X + Y$ has mean and standard deviation estimated as

$$\overline{Z} = \overline{X} + \overline{Y} = 19.03 \text{ days,}$$

$$S_Z = \sqrt{S_X^2 + S_Y^2} = 2.77 \text{ days.}$$

Figure 1.17 shows the plot of the probability density functions of assembly time, transportation time, and OCT (in number of days), obtained in `Excel` by using the `NORM.DIST` function, in which the mean and the standard deviation of each random variable are replaced with the corresponding sample mean and sample standard deviation, respectively.

The coefficient of variation of the OCT, which is defined as the ratio of its standard deviation and expected value, can be used as a measure of the *variability* involved in customer service. The lower the value of this coefficient, the lower the variability.

`[Lugan.xlsx, Lugan.py]` Lugan is a Chilean chain of supermarkets aiming to select the carrier with the least variability for its distribution system. For the best two LSPs A and B, Lugan examined 20 observations each, corresponding to travel times (in hours) between a sample sales point and its DC (see Table 1.7). The sample means and the sample standard deviations of the transportation times T_A and T_B of the two providers, computed by using the `Excel` functions named `AVERAGE` and `STDEV.S`, came up to be

Table 1.7 Observed transportation times (in hours) for providers A and B in the Lugan problem.

Provider *A*		**Provider *B***	
7.74	6.63	5.22	7.11
6.20	10.11	3.02	7.98
5.55	7.78	4.85	9.21
7.16	7.56	9.87	7.92
8.61	6.65	7.86	4.14
7.61	7.74	8.06	10.86
7.08	7.28	9.05	7.17
8.30	9.40	5.92	7.66
7.40	7.55	12.17	4.51
8.32	8.80	7.37	6.28

$$\overline{T}_A = 7.67 \text{ hours}, \tag{1.1}$$

$$S_{T_A} = 1.07 \text{ hours}, \tag{1.2}$$

$$\overline{T}_B = 7.31 \text{ hours}, \tag{1.3}$$

$$S_{T_B} = 2.31 \text{ hours}. \tag{1.4}$$

On the basis of the coefficients of variation, estimated as $V_{T_A} = S_{T_A}/\overline{T}_A = 0.14$ and $V_{T_B} = S_{T_B}/\overline{T}_B = 0.32$, respectively, the company decided to select carrier A.

1.9 Logistics Management

The principles of business management comprise four basic steps: planning, organizing, leading, and controlling, commonly known as the *P-O-L-C framework*. *Planning* sets the objectives of the organization and determines a course of action to achieve them. Organizational strategies are then converted into more specific objectives for the various functional areas (including logistics). As far as logistics is concerned, Section 1.8 describes the most common objectives and the associated KPIs. *Organizing* amounts to developing an organizational structure and allocating human resources to guarantee the accomplishment of the objectives set in the planning phase. *Leading* stimulates employees to participate in achieving the organization's goals. *Controlling* is the ongoing process of evaluating the execution of the plan (and making adjustments if necessary) to ensure that the organizational objectives are met. These four functions of management constitute a process where each function builds on the previous one. In the remainder of this section, planning, organizing, and controlling will be described in the context of logistics management, whereas the in-depth study of leadership is left to the reader, since it is beyond the scope of this book.

1.9.1 Logistics Planning

Logistics planning can be organized at three different decision-making levels: strategic, tactical, and operational.

Strategic decisions have a long-term effect (multiple years) on the logistics system and typically involve major financial investments. They are generally based on forecasts relative to aggregated data (e.g., on the predicted demand of groups of similar products at a regional level). A fundamental strategic decision is whether logistics (or parts of it) has to be outsourced to an external service provider (see Section 1.4) on the basis of a suitable SLA. Alternatively, logistics is managed by the organization itself. In this case, a key strategic decision is the design of the logistics system, including the choice of the number, size and location of facilities, and a rough assignment of demand to stocking points, the design of layout and material handling for each facility, the selection of the mode of transportation for each link of the logistics system as well as fleet sizing.

Tactical decisions concern the detailed implementation of the long-term strategy, usually with a medium-term impact (a quarter, six months, a year) on the logistics system. They may include aggregate production planning, seasonal freight flow assignment, the decision to rent space in public warehouses to cover seasonal demand peaks, space utilization and inventory policies in warehouses, the definition of safety stock levels, etc.

Operational decisions concern the definition of short-term (e.g., weekly or daily) work plans for human resources and equipment. They are mainly based on actual data, e.g., orders issued by customers, product inventory levels, real-time location of delivery vehicles, etc. Such decisions include machine scheduling in production plants, order consolidation, vehicle dispatching, repositioning of idle vehicles and containers, etc.

Logistics planning affects five areas: order processing, procurement (see Chapter 4), warehousing and inventory (see Chapter 5), and transportation (see Chapter 6).

1.9.2 Logistics Organizational Structures

The organizational structure is usually represented by an *organizational chart*, also called *organigram*, which provides a graphical representation of the chain of command. It determines the duties and responsibilities of each individual in the organization, as well as the manner in which these duties should be carried out. Organizing at the corporate level amounts to deciding how to departmentalize the organization, i.e., divide the organization into departments to facilitate the achievement of the objectives set in the planning phase. There are many ways to departmentalize an organization, such as organizing by function, product, or geographical area.

The organizational structure determines the distribution of responsibilities and tasks within the company itself. It is influenced by factors such as sector, culture (company's shared values, goals, attitudes, and practices), technology (the greater the use of advanced technology, the slimmer the organizational structure) and size (small companies typically have a sole decision maker, whereas in medium to large ones several responsibilities must be delegated). The organizational structure can be *functional*, *divisional* or *matricial*.

The Functional Model

The functional model is based on principles of labour division and specialization. In such a framework, activities requiring similar skills and resources are grouped within the same *function*. A function is associated with a *department*, headed by a director. In a functional structure, top management deals with strategic decisions, whereas tactical and operational decisions are delegated to departments. The functional structure is particularly suitable for small- and medium-size organizations, especially those with a low degree of diversification that use a consolidated technology in a stable economic environment. The functional model allows an efficient use of the organizational resources (in particular, staff, equipment, and budget). Another strength is the simplicity which facilitates control from top management. In contrast, the interdependence among departments may result in inefficiencies due to contrasts in departments' objectives. Moreover, a functional structure (which by nature is not very flexible) is often incapable of dealing with product diversification and economic turbulences. Finally, an increase in the organization's size may slow down the decision-making process because each department becomes overwhelmed by responsibilities. Figure 1.18 depicts a functional-type organizational chart in which the logistics function is carried out by a corresponding department which depends directly on top management. Each department is directed by a functional manager who reports to the general manager.

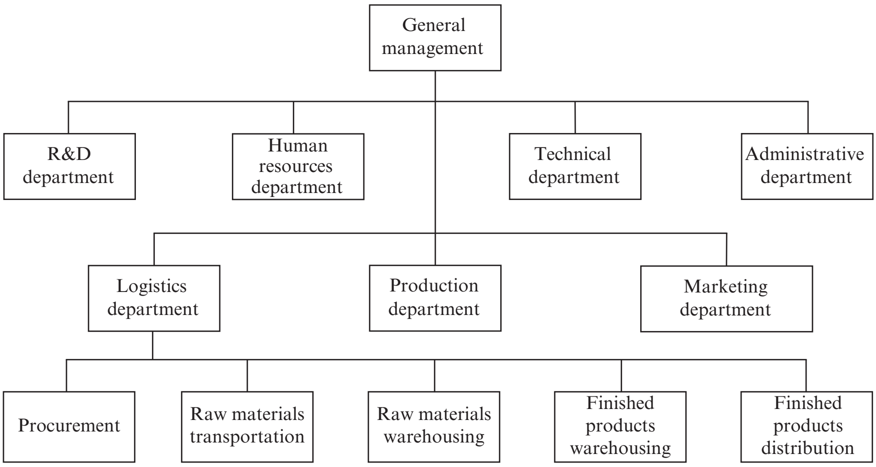

Figure 1.18 Functional-type organizational chart where the logistics department depends directly on general management.

The Swiss company Akira Foods specializes in the production and marketing of food products. The organizational chart resembles that illustrated in Figure 1.18. Because of its great importance for the organization, logistics is autonomous from other functions and coordinates the following activities: raw materials supply, raw materials warehousing, order processing, inventory and production scheduling, packaging, and transportation. This kind of organizational structure allows the company to guarantee a high level of service to its customers in the Swiss market.

The functional structure of a company may not explicitly contain a logistics function, in which case logistics activities are carried out by one or more departments. This solution is adopted by several food, chemical, and clothing companies and, more generally, by those companies for which the distribution of finished products is critical, as it often happens in mature markets.

In another common variant of the functional model, logistics activities are performed by the materials department (see Figure 1.19). This is the preferred choice for companies manufacturing complex products based on orders. After products have been manufactured, distribution simply amounts to shipping them to customers, with no or little warehousing. In contrast, there are plenty of raw materials and components whose supplies have to be synchronized with production and assembly.

The Divisional Model

Divisions are completely autonomous operational structures that behave like independent businesses. They plan, create, and market products or services autonomously. Each division is organized entirely according to a functional-type logic. The subdivision of the organizational chart into divisions can be operated on the basis of products or services, geographical areas, or markets. The general management is responsible for strategic decisions, especially for product portfolio selections. Each single division makes strategic, tactical, and operational decisions for its products or services. This

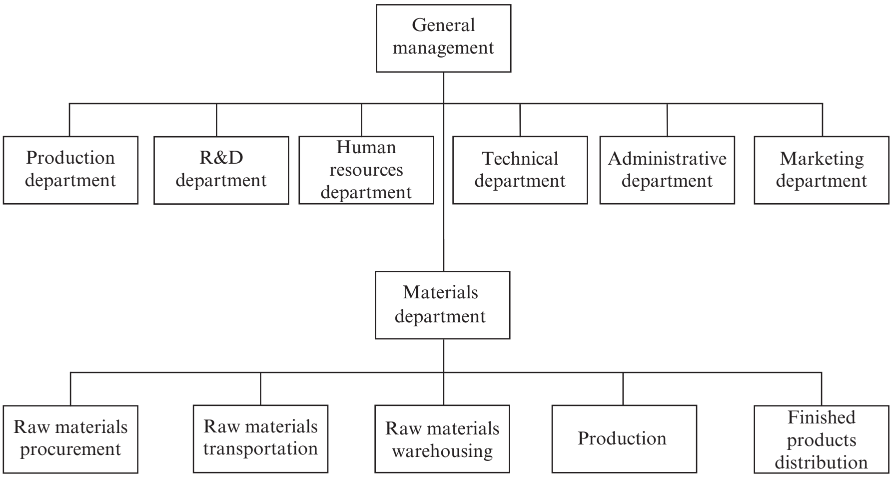

Figure 1.19 Functional-type organizational chart where the logistics activities depend on the materials department.

structure is suitable for large companies, even if the market is turbulent since divisions are able to react quickly to shifts in demand, production costs, availability of raw materials, etc.

On the flip side, this organizational model creates information silos which make it difficult to share knowledge among divisions. Moreover, the duplication of job positions not only generates an increase in fixed costs, but can also stimulate a harmful competition among divisional managers, leading to an excessive focus on short-term (rather than long-term) goals.

As far as the logistics function is concerned, each division adopts its own organizational structure.

Varsth is a multinational company, registered in Denmark, made up of three divisions, one for each the following geographic areas: Europe, North America, and South America. In Europe, the company produces and markets three lines of products: washing machines, television sets, and small electrical appliances (respectively referred to as P_1, P_2, and P_3). Each of the three lines of products is produced independently, whereas the marketing channels and the logistics system are shared (see Figure 1.20).

The Matrix Model

The matrix organizational structure is adopted by large-size companies manufacturing a variety of complex (often high-tech) products with a short- or medium-life cycle. The design, launch, production, and marketing of each product is managed like an individual *project*. The matrix structure combines features of the functional and divisional organizational structures. Technicians and specialists from different functions are in fact assigned to one or more project groups, coordinated by a *project manager*. Each employee involved in a project team reports simultaneously to a functional manager and to a project manager. There are therefore two simultaneous lines of authority (function and project) even if one dimension usually proves dominant.

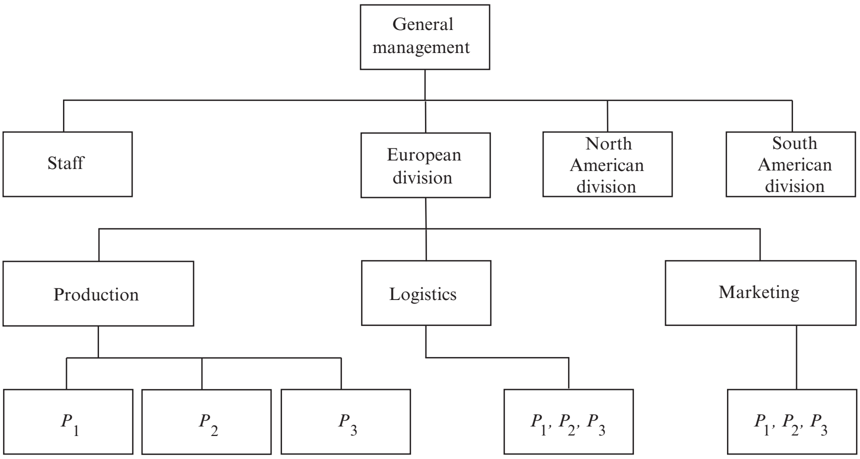

Figure 1.20 Divisional-type organizational chart of Varsth.

The matrix model is well suited for turbulent economic markets and favours elements like motivation and staff development. The dual hierarchical dependence can, however, generate confusion and conflicts because of the presence of different lines of command. Therefore, companies need to establish efficient and effective coordination mechanisms to favour cooperation among managers, which may result in increased operating costs.

In a matrix organization, logistics resources are shared among projects. The functional manager is responsible for the overall logistics system but shares authority with the various project managers.

Elifly is a French–German consortium designing, manufacturing, and delivering industry-leading commercial and military helicopters. The company adopts a matrix organizational model in which a specific project is coordinated by a manager for each product. At present three products (called EXcopter, VLcopter and GRcopter) are marketed. Figure 1.21 depicts Elifly's organizational structure.

1.9.3 Controlling

Controlling deals with monitoring that KPIs and performance measures do not deviate from predefined standards. It consists of three steps, which include: (1) selecting appropriate KPIs and performance measures and establishing their performance standards; (2) comparing actual performance against standards; (3) taking corrective action when necessary. Performance standards are often stated in monetary terms such as revenue, costs, or profits but may also be stated in other terms, such as units produced, number of defective products, or level of service. Effective controlling requires the existence of plans, since planning provides the necessary performance standards. Controlling also requires a clear understanding of where responsibility for deviations from standards lies. For the control of the efficiency and effectiveness of

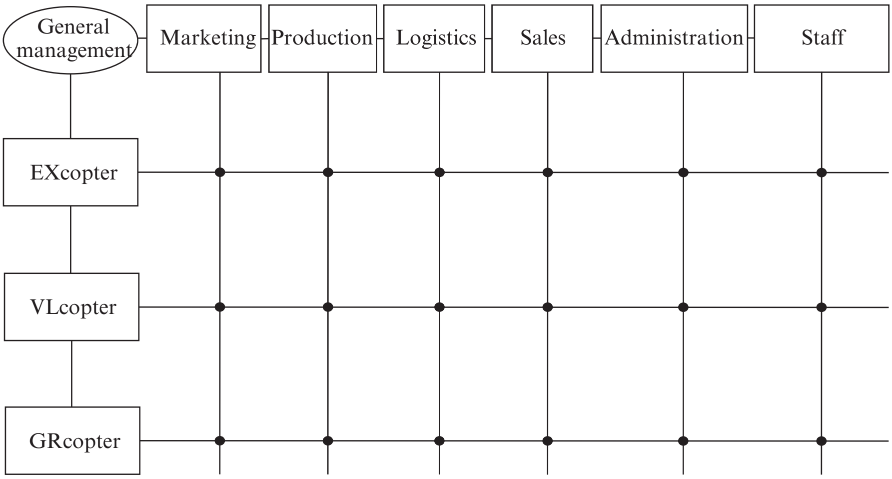

Figure 1.21 Elifly matrix organizational chart.

the logistics system, managers use tailored performance measures described in the following.

Logistics Performance Measures and the Control Panel

As noted in Section 1.8, unlike KPIs, logistics performance measures are used to track specific results related to logistics operations. Each such performance measure generally belongs to two different categories:

- measures of *effectiveness*, that express the capability of the logistics system to achieve the organizational objectives;
- measures of *efficiency*, that express how well logistics resources are utilized to achieve the organizational objectives.

Furthermore, the performance measures are usually classified into *families*, defined in accordance to the company needs, or more generally, corresponding to the decision making areas identified in the planning phase (see Section 1.9.1), such as procurement, storage and distribution (see Table 1.8 for a non-exhaustive list). Some of them correspond to warehouse efficiency measures that will be illustrated in detail in Section 5.8.

The frequency at which performance measures are monitored depends on the logistics decision to be taken: in some cases, the frequency can be monthly or even shorter (e.g., total sales in the last quarter). In other cases, it can be daily or even more frequently: e.g., this may be the case of the sales of a limited-edition series of products on an e-commerce website.

It is good practice to periodically revise the number and type of performance measures used by the logistician by inserting new indicators that capture uncovered relevant aspects or by eliminating obsolete ones. Finally, it is worth noting that an excessive number of performance measures can generate confusion for the decision maker and lead to results that are difficult to interpret (*performance measure overload*).

`[Cardena.xlsx, Cardena.py]` Cardena is a Romanian company producing and commercializing perforated bricks. During the eighth week of the current year, its logistics manager noticed numerous complaints from customers due to delivery delays. For this reason, they decided to monitor the logistics system starting from the first week of the year, through the use of a specific performance measure referred to as *punctuality*, defined as the percentage of weekly orders delivered on time. A sufficient level of punctuality is set by the manager to the value of 95%. The required data for computing the performance measure have been extrapolated from the Cardena database with a weekly frequency and theresults obtained from the first week to the current (twenty-fifth) week are illustrated in Figure 1.22. The performance measure values from the sixth week to the eighth, in fact, confirmed the manager's perception. Consequently, they decided to implement a series of corrective actions to improve fleet size and vehicle routing (see Chapter 6 for more details). The effects of the corrective actions were evaluated in the subsequent weeks. In particular, from the twentieth to the current week, the performance measures were systematically above the fixed threshold, which motivated the logistics manager to confirm the adoption of the corrective actions in the coming weeks.

Table 1.8 List of performance measures related to procurement, storage, and distribution.

Family	Performance measure	Formula	Category
Procurement	Average volume	Total supply volume/ number of orders	Efficiency
	Unit cost per invoice	Total invoice cost/number of invoices	Efficiency
	Rejected supplies	Rejected orders/total orders	Effectiveness
	Supplier compliance	Orders received after due date/ total orders	Effectiveness
	Lead time	Order delivery date − order issuing date	Effectiveness
Storage	Warehouse utilization rate	Occupied storage locations/ total number of storage locations	Efficiency
	Surface utilization rate	Surface used/ total warehouse surface	Efficiency
	Inventory turnover index	Outgoing freight flow/ average inventory level	Efficiency
	Productivity	Orders fulfilled/working days	Efficiency
	Unit inventory cost	Total inventory cost/total number of items at stock	Efficiency
	Obsolescence	Value of obsolete inventory/ total inventory value	Efficiency
	Out-of-stock rate	Unfulfilled orders/total orders	Effectiveness
	Inventory accuracy	Incorrect product codes/total codes	Effectiveness
	Punctuality	Orders delivered on time/ orders delivered	Effectiveness
	Lead time deviation	Actual lead time/expected lead time	Effectiveness
Distribution	Cost per km	Total transportation cost/ km travelled	Efficiency
	Average delivery	Delivered amount/ number of deliveries	Efficiency
	Trip saturation	Amount dispatched per vehicle/ vehicle capacity	Efficiency
	Punctuality	On time deliveries/total deliveries	Effectiveness
	Delivery accuracy	Incorrect deliveries/total deliveries	Effectiveness

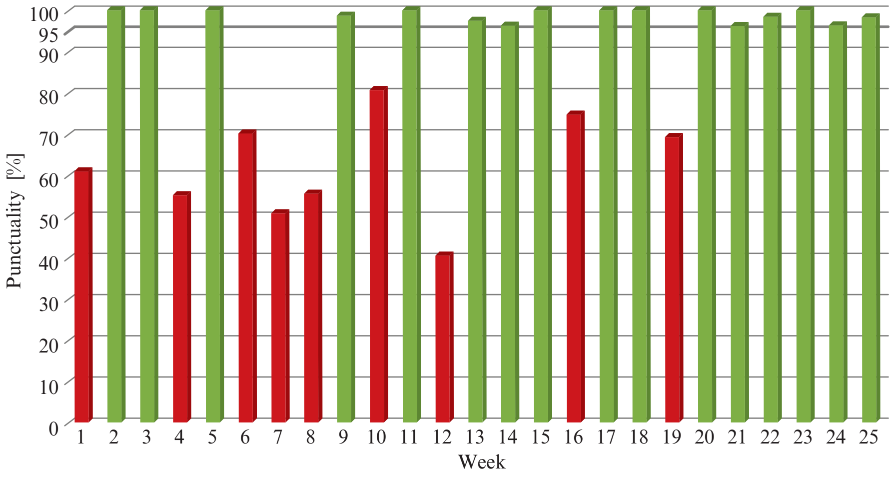

Figure 1.22 Weekly observations measuring delivery punctuality during the last 25 weeks in the Cardena problem.

If a company needs to check multiple performance measures (computed with the same frequency), it is worth using a *control panel*, an information tool which provides a synthetic overview of the entire set of performance measures. Since indicators are measured on different scales, a *min–max normalization* is required to make all the measures homogeneous and easy to compare. With this technique, indicators are shifted and rescaled so that they end up ranging between *min* and *max* (*min* < *max*, see Section 2.5.7 for more details). This operation transforms all the performance measures to a notionally common normalized scale.

`[Borg.xlsx, Borg.py]` Borg is a Canadian company producing wooden utensils. Following a recent organizational restructuring, the new logistics manager is in charge of monitoring the most critical supply chain activities every month. When designing a control panel, it was found that the most significant problems were connected to the large number of complaints received about errors in dispatched orders, frequent delivery delays, an incorrect policy of inventory management, overstaffing in the warehouse and inefficiencies in the transportation system.

The logistics manager therefore identified 19 performance measures, subdivided into five families calculated with a monthly frequency: two of them (storage and delivery) are representative of typical logistics activities; the others (order dispatch, etc.) are defined considering the Borg specific needs. These measures are described in Table 1.9, in which the calculation method used for each of them is also indicated.

Table 1.9 Performance measures for the Borg logistics system.

Family	Performance measure	Computing method
Dispatch of orders	Number of orders	Orders received in a month/working days in the month
	Complaints	Number of complaints in a month
	Extent of completeness	Order lines dispatched in a month/order lines received in the month
	Errors in order lines	Order lines with errors in a month/order lines inserted in the month
	Errors in orders	Number of orders with errors in a month/orders fulfilled in the month
Staff	Warehouse employees	Monthly average of number of employees
	Effective employees	Monthly average number of effective employees/monthly average of employees
	Productivity of warehouse employees	Monthly average number of daily handling operations/monthly average number of warehouse employees
Storage	Material handling	Monthly average number of daily handling operations
	Pickup operations	Monthly average number of pickups/number of order lines monthly dispatched
	Savings	Monthly cumulated value of economic-financial savings deriving from cost-cutting initiative
	Inventory value	Overall average monthly value of inventory
Delivery	Deliveries per vehicle trip	Monthly average number of customers served by a vehicle trip
	Trip saturation	Monthly average amount of goods dispatched per vehicle/vehicle capacity
	Trip forecast	Trips planned in the month/effective trips in the month
	Deliveries dispatched within delivery time window	Number of lines dispatched in the month within delivery time window/total number of lines dispatched in the month
	Value of deliveries dispatched within delivery time window	Value of deliveries dispatched in the month within delivery time window/ total value of deliveries dispatched in the month
	Reliable deliveries	Monthly order lines delivered correctly on time/total monthly order lines
Costs	Budget	Average monthly total cost/monthly budgeted cost

The performance measures were computed in March and were normalized in the interval $[1, 10]$, using the *min–max* normalization procedure on the time series composed of the last 12 data entries available for each measure (from April of the previous year to March of the present year). The values obtained are shown in Table 1.10.

The logic of the normalization procedure is that for each measure, independently of its meaning, a normalized value equal to 1 corresponds to the worst possible outcome (e.g., the minimum number of orders or the maximum number of complaints per month), whereas 10 is the best one. Every performance measure within its own family was weighed in a suitable way (the sum of the weights equals 1), so as to find a single efficiency value for every family. Table 1.11 shows these values, together with the weights chosen for each measure in the month considered.

The logistics manager has determined that the minimum value to be achieved for each performance measure should be 6, and the objective should be 10. The control panel was constructed using a *radar chart* (see Figure 1.23) which has a great visual impact. The control panel allowed the logistics manager to identify the areas needing priority corrective action (those with a value lower than 6).

Table 1.10 Normalized performance measures for the Borg logistics system in the considered month.

Family	Performance measure	Value
Dispatch of orders	Number of orders	4.72
	Complaints	6.21
	Extent of completeness	5.77
	Errors in order lines	7.83
	Errors in orders	6.34
Staff	Warehouse employees	5.40
	Effective employees	7.23
	Productivity of warehouse employees	6.42
Storage	Material handling	6.15
	Pickup operations	5.05
	Savings	4.15
	Inventory value	6.24
Delivery	Deliveries per vehicle trip	7.28
	Trip saturation	6.34
	Trip forecast	7.22
	Deliveries dispatched within delivery time window	6.33
	Value of deliveries dispatched within delivery time window	4.21
	Reliable deliveries	4.87
Costs	Budget	4.88

Table 1.11 Performance measures for the Borg logistics system in the considered month.

Family	Performance measure	Value	Weight	Family performance
Dispatch of orders	Number of orders	4.72	0.20	6.13
	Complaints	6.21	0.25	
	Extent of completeness	5.77	0.18	
	Errors on order lines	7.83	0.17	
	Errors on orders	6.34	0.20	
Staff	Warehouse employees	5.40	0.35	6.31
	Effective employees	7.23	0.30	
	Productivity of warehouse employees	6.42	0.35	
Storage	Material handling	6.15	0.20	5.24
	Pickup operations	5.05	0.30	
	Savings	4.15	0.30	
	Warehouse value	6.24	0.20	
Delivery	Deliveries per vehicle trip	7.28	0.30	6.03
	Trip saturation	6.34	0.10	
	Trip forecast	7.22	0.10	
	Deliveries dispatched within delivery time window	6.33	0.15	
	Value of deliveries dispatched within delivery time window	4.21	0.25	
	Reliable deliveries	4.87	0.10	
Costs	Budget	4.88	1.00	4.88

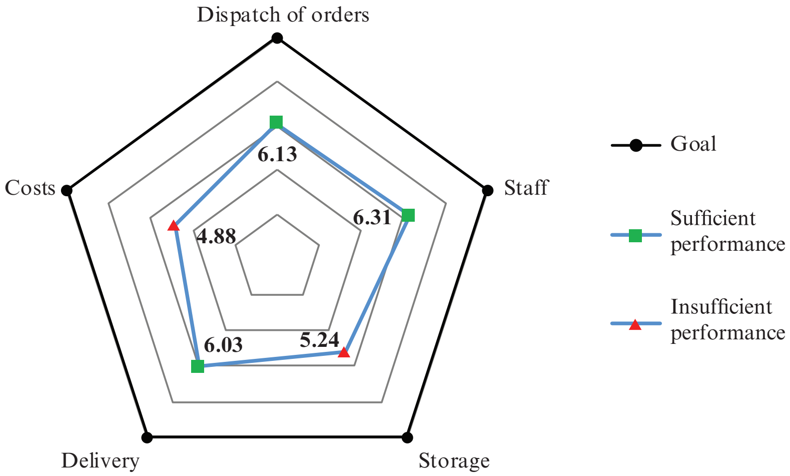

Figure 1.23 Control panel by a radar chart for the Borg logistics system in the considered month.

1.10 Data Analytics in Logistics

In the past, logistics managers made decisions based on pure judgement and experience, whereas today they rely more and more often on factual data. Indeed, the data flow generated every day by logistics operations is very large. *Logistics analytics* is the discipline that uses such data, along with information retrieval, statistical analysis, mathematical optimization, and simulation models, to help managers analyse and coordinate logistics systems in order to ensure the smooth running of operations in a timely and cost-effective manner. Analytics are customarily divided into *descriptive analytics*, *predictive analytics* and *analytics* (see Figure 1.24).

1.10.1 Descriptive Analytics

Descriptive analytics is the interpretation of historical data to better understand changes that have occurred in the logistics system. It takes raw data and makes use of information retrieval and descriptive statistics to allow logistics managers to make sense of them. The output is formatted as a set of charts representing the evolution of the logistics *outcomes* (KPIs or performance measures, see Section 1.8) over time. Nowadays, descriptive analytics are often associated with the term *big data*, an expression that indicates the technologies and algorithms that cope with data that are too large or complex to be dealt with by traditional approaches. In particular, big data applications require a parallel and distributed framework (e.g., MapReduce) that processes data across multiple servers. The peculiarities of big data applications are often referred to as the "three Vs": *volume* (the quantity of data), *variety* (the type and nature of the data; for example, structured data coming from relational databases and unstructured data in a natural language coming from social media like *Facebook* and *Twitter*), *velocity* (the speed at which the data are generated).

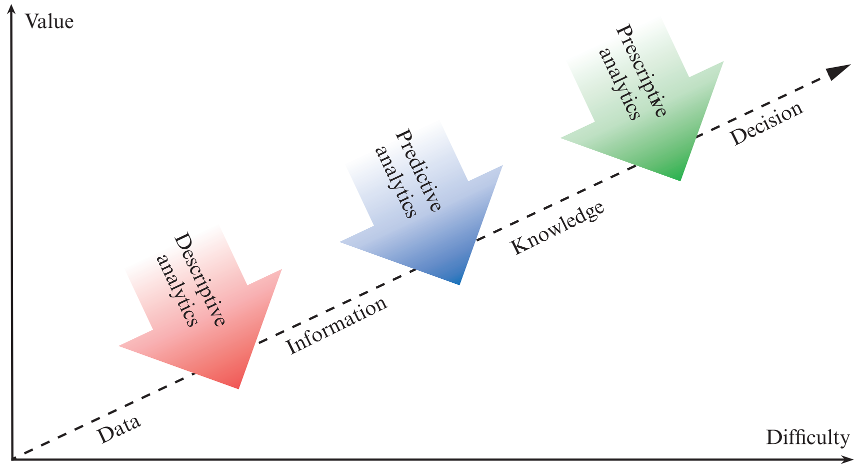

Figure 1.24 Taxonomy of analytics.

A remarkable example of big data application in logistics is Amazon (see Section 1.6.5), that handles millions of customer orders every day. This generates a multitude of shipment tracking updates coming from the sensors attached to AGVs in DCs, air terminals, airplanes and delivery vans. It also generates an enormous number of inventory updates and transactions with third-party sellers. Amazon relies on three Linux databases (with a total capacity of the order of several terabytes) running on a cluster of 28 servers with an Oracle database software.

1.10.2 Predictive Analytics

Predictive analytics aims to make forecasts about unknown future outcomes (e.g., sales trends and customer behaviour patterns). In logistics it is mainly used to predict the demand for finished products over time (as well as the associated material requirements).

Predictive analytics may be based on quantitative techniques such as *extrapolation methods* from *time series analysis*. Alternatively, it may be based on *explanatory methods*, such as *regression* or *supervised learning* methods that automatically capture the relationships between some explanatory variables and the outcome variable, and exploit them to make forecasts. See Chapter 2 for an in-depth discussion of these methods.

Amazon Forecast is a time series data forecasting service, operated by Amazon. It allows forecasting in supply chain planning, in particular, for product demands and travel demands, and, in addition, in financial planning. Amazon Forecasts exploits the potential of *machine learning* (ML) technology (and deep learning, in particular).

1.10.3 Prescriptive Analytics

Finally, prescriptive analytics suggests feasible actions (i.e., actions satisfying budget, logical, temporal and technological constraints) that optimize a given outcome z, based on available data. In the simplest case, there is a limited number n of feasible alternatives to choose from. If the outcome z_i of each alternative $i = 1, \dots, n$, is *deterministic*, that is, it depends on data known at decision time, then the optimal alternative i^* is trivially

$$i^* = \arg \min_{i = 1,\dots,n} \{z_i\},$$

assuming conventionally that the decision maker is interested in minimizing the outcome. The *weighted scoring method*, applied in Section 3.5 for locating facilities and in Section 4.4 for selecting suppliers, is based on this approach.

Timor is a grocery wholesaler that purchases, at the beginning of every week, a number of packs, typically between 1600 and 2000, of organically grown salad, which is a highly perishable product, at € 1.00 each. During the week, the company distributes the salad packs to some retailers, at € 1.50 each, on the basis of received orders. At the end of the week, the unsold packs are discarded since they have deteriorated. The problem faced by Timor is to determine how many salad packs to purchase in order to maximize its profit. There are five alternatives shown in Table 1.12. The profit (in €) for each choice is reported in the third column of the same table under the hypothesis that next week the retailers' orders will amount to 1780 packs. The best alternative is the third one with a purchase cost equal to € 1800, a revenue equal to 1780 × € 1.50 = € 2670 and hence a profit of € (2670 − 1800) = € 870.

Table 1.12 Profit (in €) corresponding to the five alternatives in the Timor problem.

Alternative (i)	Number of salad packs to purchase	Profit (z_i)
1	1600	800
2	1700	850
3	1800	870
4	1900	770
5	2000	670

The Bayes Criterion

On the other hand, if the outcome of alternative $i = 1, \dots, n$, depends on data that will only be disclosed in the future, but are not known at the moment of the decision, the outcome can be seen as a function f_i of one or more random variables, corresponding to unknown data (for the sake of simplicity, a single random variable Θ is assumed). Hence, the outcome is a random variable itself, denoted as Z_i:

$$Z_i = f_i(\Theta), i = 1, \dots, n.$$

If the probability distribution of each Z_i variable is known for $i = 1, \dots, n$, the decision maker may be interested in selecting the alternative i^* of least expected outcome (*Bayes criterion*), that is,

$$i^* = \arg \min_{i=1,\dots,n} \{E_\Theta[Z_i]\}.$$

If Θ is discrete with realizations $\theta_1, \dots, \theta_k$ and the mass probability function $Pr(\Theta = \theta_j) = p_j$ (where $\sum_{j=1}^{k} p_j = 1$), the expected outcome of alternative $i = 1, \dots, n$, is

$$E_\Theta[Z_i] = \sum_{j=1}^{k} p_j z_{ij},$$

where z_{ij} is the outcome of alternative i when $\Theta = \theta_j$.

If Θ is continuous with probability density function $p_\Theta(\theta)$, the expected outcome of alternative $i = 1, \dots, n$, is

$$E_\Theta[Z_i] = \int_{-\infty}^{\infty} p_\Theta(\theta) z_i(\theta)\, d\theta,$$

where $z_i(\theta)$ is the outcome of alternative i if Θ is equal to realization θ.

In the Timor problem, it is now assumed that the number of salad packs ordered by the retailers at the beginning of the week can be modelled as a discrete random variable Θ, whose realizations are 1600, 1700, 1800, 1900 and 2000, with estimated probabilities $Pr(\Theta = 1600) = 0.1$, $Pr(\Theta = 1700) = 0.2$, $Pr(\Theta = 1800) = 0.3$, $Pr(\Theta = 1900) = 0.2$ and $Pr(\Theta = 2000) = 0.2$. The associated outcome matrix is reported in Table 1.13. As shown in the rightmost column, the optimal solution is to purchase 1800 salad packs, with an expected profit equal to € 840 given by

$$0.1 \times € \, 600 + 0.2 \times € \, 750 + 0.3 \times € \, 900 + 0.2 \times € \, 900 + 0.2 \times € \, 900.$$

Table 1.13 Values of profit (in €) $z_{ij}, i = 1, \dots, 5, j = 1, \dots, 5$, by considering the alternatives i of salad packs purchase and the different realizations j of salad packs ordered by retailers in the Timor problem.

	Profit z_{ij}					
Alternative (i)	$j = 1$	$j = 2$	$j = 3$	$j = 4$	$j = 5$	$E_\Theta[Z_i]$
1	800	800	800	800	800	800
2	700	850	850	850	850	835
3	600	750	900	900	900	840
4	500	650	800	950	950	800
5	400	550	700	850	1000	730

The Expected Value of Perfect Information

It is now worth introducing the concept of *expected value of perfect information* (*EVPI*), which corresponds to the improvement, in terms of expected outcome, that might be achieved if the realization of the random variable Θ was known in advance, at decision time.

For the sake of simplicity, the discussion is limited to the discrete case of Θ. If the realization known in advance were $\theta_{\bar{j}}$, the optimal outcome would clearly be $\min_{i = 1,\dots,n} \{z_{i\bar{j}}\}$. Unfortunately, under perfect information, the decision maker knows in advance the realization of the uncertain parameters, but cannot choose their values. Hence, each realization $\theta_{\bar{j}}$ still occurs with a given probability $p_{\bar{j}}$. Consequently, in the long run, the decision maker should expect an outcome (*expected outcome under perfect information*) equal to

$$\sum_{j=1}^{k} p_j \min_{i\,=\,1,\dots,n} \{z_{ij}\}.$$

Therefore, the expected value of perfect information is

$$EVPI \;=\; \min_{i\,=\,1,\dots,n} \sum_{j=1}^{k} p_j z_{ij} - \sum_{j=1}^{k} p_j \min_{i\,=\,1,\dots,n} \{z_{ij}\},$$

where the right-hand side is always non-negative. *EVPI* represents the improvement in the expected outcome if the realization of the random variable Θ were known in advance, as compared to choosing the alternative before the realization of Θ becomes known. Since any forecasting method (see Chapter 2 for more details) to predict the value taken by the random variable Θ is based on imperfect information, then *EVPI* represents an upper bound on the outcome improvement which can be achieved when using any forecasting method.

In the Timor problem, the *EVPI* can be computed as follows. The expected profit under perfect information corresponds to € 910, given by

$$0.1 \times € \,800 + 0.2 \times € \,850 + 0.3 \times € \,900 + 0.2 \times € \,950 + 0.2 \times € \,1000.$$

The maximum expected profit, previously computed, is € 840 (recall that in the Timor problem the outcome is a profit to be maximized) and *EVPI* is equal to

$$EVPI \;=\; € \,910 - € \,840 \;=\; € \,70.$$

Hence, the additional expected profit that can be obtained by using any forecasting technique to predict the weekly demand of salad packs is no greater than € 70. Therefore, if Timor was offered a demand forecasting tool at a cost greater than *EVPI* (i.e., € 80 per week), it should refuse.

Indifference Zone Selection

If the mass probability function (or probability density function) of Θ is not known, the choice of the action having the best expected outcome is more complex since the expected outcomes $E_\Theta[Z_i]$ of alternatives $i \;=\; 1,\dots,n$, are not known and can only be estimated from a sample $z_{i1},\dots,z_{im_i}$ of finite size m_i. A point estimate of $E_\Theta[Z_i]$ is provided by the *sample mean*

$$\overline{Z}_i = \frac{1}{m_i} \sum_{j=1}^{m_i} z_{ij}.$$

In most cases, the decision maker also computes a *confidence interval* for the expected outcome, i.e., the interval in which $E_\Theta[Z_i]$ falls, with a prescribed *confidence level* $(1-\alpha)$, where α is the probability that $E_\Theta[Z_i]$ lies outside the confidence interval (e.g., $(1-\alpha) = 0.95$, hence $\alpha = 0.05$). This is because a point estimate does not necessarily coincide with the real expected value, while a confidence interval is more reliable.

The confidence interval at $(1-\alpha)$ level of $E_\Theta[Z_i]$, $i = 1, \dots, n$, is defined as

$$Pr\left(\overline{Z}_i - t_{\alpha/2,m_i-1}\frac{S_i}{\sqrt{m_i}} \le E_\Theta[Z_i] \le \overline{Z}_i + t_{\alpha/2,m_i-1}\frac{S_i}{\sqrt{m_i}}\right) = 1-\alpha,$$

where $t_{\alpha/2,m_i-1}$ is the quantile of order (1-$\alpha/2$) of the Student's t-distribution with m_i-1 degrees of freedom and S_i is the *sample standard deviation*

$$S_i = \sqrt{\frac{\sum_{j=1}^{m_i}(z_{ij}-\overline{Z}_i)^2}{m_i-1}}.$$

Therefore, the confidence interval $(1-\alpha)$ level of $E_\Theta[Z_i]$, $i = 1, \dots, n$, is

$$\left[\overline{Z}_i - t_{\alpha/2,m_i-1}\frac{S_i}{\sqrt{m_i}}, \overline{Z}_i + t_{\alpha/2,m_i-1}\frac{S_i}{\sqrt{m_i}}\right].$$

`[Lugan.xlsx, Lugan.py]` In the Lugan problem (see Section 1.8), recall that the number of observations of transportation times T_A and T_B is equal to $m_0 = 20$. Assuming $(1-\alpha) = 0.95$, hence, $\alpha/2 = 0.025$, $(1-\alpha/2) = 0.975$ and, consequently, $t_{0.025,19}$ = `T.INV(0.975;19)` = 2.0930, where `T.INV(0.975;19)` is the `Excel` function which returns the left-tailed inverse of the Student's t-distribution with probability equal to 0.975 (corresponding to $1-\alpha/2$) and degree of freedom equal to 19 (corresponding to $m_0 - 1$).

On the basis of the values of the sample mean $\overline{T}_A$ and the sample standard deviation S_{T_A} of the transportation time T_A computed by (1.1) and (1.2), respectively, the confidence interval at $(1-\alpha)$ level of T_A (in hours) is

$$\left[7.67 - 2.0930 \times 1.07/\sqrt{20}, 7.67 + 2.0930 \times 1.07/\sqrt{20}\right] = [7.17, 8.17].$$

Similarly, considering the values of the sample mean $\overline{T}_B$ and the sample standard deviation S_{T_B} of the transportation time T_B given by (1.3) and (1.4), respectively, the confidence interval at $(1-\alpha)$ level of T_B (in hours) is

$$\left[7.31 - 2.0930 \times 2.31/\sqrt{20}, 7.31 + 2.0930 \times 2.31/\sqrt{20}\right] = [6.23, 8.39].$$

The alternative to be selected among the n available alternatives would be i^*, which corresponds to the best sample mean $\overline{Z}_{i^*}$ of the outcome, with a confidence level equal to $(1-\alpha)$. However, it could happen that a second alternative $\hat{\imath}$ has a sample mean $\overline{Z}_{\hat{\imath}}$ very close to $\overline{Z}_{i^*}$, and therefore the difference between $\overline{Z}_{\hat{\imath}}$ and $\overline{Z}_{i^*}$ is so small that one would be indifferent between alternatives $\hat{\imath}$ and i^*. As a consequence, the confidence intervals corresponding to alternatives i^* and $\hat{\imath}$ overlap significantly (as happens, for example, in the Lugan problem for providers A and B). The correct selection of the best alternative (corresponding to the one with the best expected outcome which, as noted above, is not known), using the sample data could therefore fail; it could in fact happen that $\overline{Z}_{i^*} < \overline{Z}_{\hat{\imath}}$, while $E_\Theta[Z_{i^*}] \ge E_\Theta[Z_{\hat{\imath}}]$.

This motivates the introduction of *indifference zone methods*, such as the `RINOTT` procedure described below. In these methods, the decision maker must define an indifference parameter δ, which corresponds to the smallest difference between two

```
procedure RINOTT ($\alpha, n, m_0, \delta, \mathbf{m}, i^*$)
    # $\alpha$ is a value chosen in the $[0, 1]$ interval to define the confidence level $(1 - \alpha)$;
    # $n$ is the number of alternatives to evaluate;
    # $m_0$ is the number of samples initially available for each alternative $i = 1, \dots, n$;
    # $\delta$ is the indifference parameter;
    # $\mathbf{m}$ is the vector, returned by the procedure, of $n$ components, each of which corresponding to the number of samples used for each alternative;
    # $i^*$ is the best alternative returned by the procedure;
    Set the Rinott's constant $r$ corresponding to $\alpha$, $m_0$ and $n$ by using Rinott_constant.py;
    for $i = 1, \dots, n$ do
        # Compute the sample mean $\overline{Z}_i$ and the sample standard deviation $S_i$ based on the $m_0$ observations available for alternative $i$;
        $\overline{Z}_i = \frac{1}{m_0} \sum_{j=1}^{m_0} z_{ij}$;
        $S_i = \sqrt{\frac{\sum_{j=1}^{m_0} (z_{ij} - \overline{Z}_i)^2}{m_0 - 1}}$;
        # $\mu$ is the number of samples to draw a conclusion on the additional observations possibly required for alternative $i$;
        $\mu = \left\lceil \left(\frac{rS_i}{\delta}\right)^2 \right\rceil$;
        if $\mu > m_0$ then
            Take $\mu - m_0$ more observations for alternative $i$;
            $m_i = \mu$;
            $\overline{Z}_i = \frac{1}{m_i} \sum_{j=1}^{m_i} z_{ij}$;
            $S_i = \sqrt{\frac{\sum_{j=1}^{m_i} (z_{ij} - \overline{Z}_i)^2}{m_i - 1}}$;
        else
            # No additional samples are required for alternative $i$;
            $m_i = m_0$;
        end if
    end for
    Select the alternative $i^*$ to which corresponds the best value of $\overline{Z}_i$, $i = 1, \dots, n$;
    return $\mathbf{m}, i^*$;
end procedure
```

expected outcomes considered to be significant. In other words, the decision maker cannot discriminate between two alternatives whose expected outcomes differ by less than δ. Observe that the probability of selecting the best alternative increases when the sample size for each alternative increases. Based on this, the `RINOTT` procedure, depending on the parameter of indifference δ chosen, is based on determining, for each alternative $i = 1, \dots, n$, the number of additional observations eventually necessary, starting from the number m_0 of observations initially available for each of them. This number is such that, with probability not lower than $(1 - \alpha)$, the alternative corresponding to the best sample mean (i.e., the best expected outcome) is selected.

[`Lugan.xlsx`, `Rinott.py`] With reference to the Lugan problem, suppose that the company wants to establish which transportation provider between A and B is the fastest on average. As illustrated before, $m_0 = 20$. On the basis of the sample means and sample standard deviations of the transportation times T_A and T_B computed by using (1.1)–(1.4), the company estimates the number of observations needed to achieve a confidence level equal to $(1-\alpha) = 0.95$ with an indifference zone of 30 minutes (0.5 hour). In order to apply the `RINOTT` procedure, the proper Rinott's constant $r = 2.452$ is returned by the procedure implemented by `Rinott_constant.py` with $\alpha = 0.05$, $m_0 = 20$ and $n = 2$. For provider A, the value of $\delta = 0.5$ leads to

$$\mu = \left\lceil \left(\frac{2.452 \times 1.07}{0.5}\right)^2 \right\rceil = 28.$$

Since $\mu > m_0$, the company needs to collect $28-20 = 8$ more observations of the transportation time for provider A (i.e., $m_A = \mu = 28$). Similarly, for provider B,

$$\mu = \left\lceil \left(\frac{2.452 \times 2.31}{0.5}\right)^2 \right\rceil = 129,$$

hence, additional $129-20 = 109$ observations are required ($m_B = 129$). The sample means and sample standard deviations, computed by using again the `Excel` functions `AVERAGE` and `STDEV.S`, based on $m_A = 28$ and $m_B = 129$ observations are (see `Lugan.xlsx`):

$$\overline{T}_A = 7.67 \text{ hours}, S_{T_A} = 1.14 \text{ hours},$$
$$\overline{T}_B = 6.96 \text{ hours}, S_{T_B} = 1.91 \text{ hours}.$$

Since $\overline{T}_B < \overline{T}_A$, provider B is finally selected as the best.

The confidence interval at $(1-\alpha) = 0.95$ level of T_A (in hours) is updated as

$$\left[7.67 - 2.0518 \times 1.14/\sqrt{28}, 7.67 + 2.0518 \times 1.14/\sqrt{28}\right] = [7.23, 8.12],$$

since $t_{0.025,27}$ = `T.INV(0.975;27)` = 2.0518, and the updated confidence interval at $(1-\alpha) = 0.95$ level of T_B (in hours) is

$$\left[6.96 - 1.9787 \times 1.91/\sqrt{129}, 6.96 + 1.9787 \times 1.91/\sqrt{129}\right] = [6.62, 7.29],$$

since $t_{0.025,128}$ = `T.INV(0.975;128)` = 1.9787. The two updated confidence intervals are still slightly overlapping (but definitely not as much as in the previous case), but this does not influence the choice of the best provider.

Numerical Optimization

In most logistics applications, the planning alternatives are not known explicitly. Rather, the decision is represented by a vector $\mathbf{x}$ of n continuous or discrete *decision variables*. For example, $\mathbf{x}$ may describe the configuration of a logistics system (such as the allocation of retailers to RDCs) or the parameters of a policy (such as the reorder point in inventory management, see Section 5.12). The outcome z is expressed as a function $z = f(\mathbf{x}, \mathbf{c})$ of $\mathbf{x}$ and a vector $\mathbf{c}$ of deterministic input parameters. In the simplest case, $f(\mathbf{x}, \mathbf{c})$ is known in *closed form*, as, for example, in the following quadratic function $x_1^2 + 2x_2$ (with $\mathbf{x} = [x_1; x_2]^\mathrm{T}$ and $\mathbf{c} = [1; 2]^\mathrm{T}$). Then, the decision making process can be cast as an *optimization problem*

$$\underset{\mathbf{x}}{\text{Minimize}}\, z = f(\mathbf{x}, \mathbf{c}) \tag{1.5}$$

subject to

$$\mathbf{g}(\mathbf{x}, \mathbf{b}) \leq \mathbf{0}, \tag{1.6}$$

where the decision variables are constrained by (possibly non-linear) equalities and inequalities that can be always lead to the form $\mathbf{g}(\mathbf{x}, \mathbf{b}) \leq \mathbf{0}$, where $\mathbf{g}(\mathbf{x}, \mathbf{b})$ is a set of m functions $g_i(\mathbf{x}, \mathbf{b})$, $i = 1, \dots, m$, and $\mathbf{b}$ is a vector of known parameters. Depending on the problem structure and its size, as well as on the available computing time, a decision maker may use:

- an off-the-shelf general purpose solver (from the simpler `Solver` available in `Excel` to more sophisticated optimization software packages such as CPLEX, Gurobi, and Minos). Such solvers are typically based on exact iterative algorithms (simplex algorithm, branch-and-bound procedure, constraint programming, etc.) which for some specified classes of problems converge to an optimal solution, or on heuristics that may provide approximate solutions to some problems, although their iterates need not necessarily converge. Most programming languages offer a modelling interface that hooks up to solvers: this is the case of the `Pulp` library in `Python`;
- an ad hoc exact algorithm, in which an available algorithmic paradigm (dynamic programming, branch-and-bound, branch-and-cut, branch-and-price, Benders decomposition, constraint programming, etc.) is tailored to make the search more efficient for the problem at hand;
- an ad hoc heuristic, based on a constructive procedure (such as a greedy method) or metaheuristic framework (such as simulated annealing, tabu search, genetic algorithms, GRASP, etc.).

When a heuristic is used, the outcome $\overline{z}$ of the best feasible solution $\overline{\mathbf{x}}$ (if any) is no better than the optimal outcome z^*, that is, $\overline{z} \geq z^*$. Heuristic algorithms are generally faster and more efficient than exact algorithms. They are often employed when the computation of exact solutions is computationally too expensive and it is far better to try computing a suboptimal solution within a limited available time.

Coping with Uncertainty in Planning

When the input parameters $\mathbf{c}$ and $\mathbf{b}$ in (1.5)–(1.6) are unknown at the time of decision making, they can be formally replaced by vectors $\boldsymbol{\gamma}$ and $\boldsymbol{\beta}$ of random variables. In logistics planning, this is the case of market demand, cargo ship travel times, assembly time in a manufacturing site on a given day, etc. In this context, model (1.5)–(1.6) makes no sense any more. In some application settings, a sensible approach is to replace random vector variables $\boldsymbol{\gamma}$ and $\boldsymbol{\beta}$ with their expected values $E[\boldsymbol{\gamma}]$ and $E[\boldsymbol{\beta}]$, if they are known.

The resulting optimization model is

$$\underset{\mathbf{x}}{\text{Minimize}}\, z = f(\mathbf{x}, E[\boldsymbol{\gamma}]) \tag{1.7}$$

subject to

$$\mathbf{g}(\mathbf{x}, E[\boldsymbol{\beta}]) \leq \mathbf{0}. \tag{1.8}$$

Of course, if $E[\boldsymbol{\gamma}]$ and $E[\boldsymbol{\beta}]$ are not known, they can be substituted by their sample means. Anyway, when using this approach, a decision maker should be advised that a solution to (1.7)–(1.8) may violate some constraint for some realizations of the random vector $\boldsymbol{\beta}$. This may be acceptable in some applications (and indeed this approach is used almost always in the remainder of this book), but in others it is unacceptable. Then, two approaches can be used if the probability distribution of $\boldsymbol{\gamma}$ and $\boldsymbol{\beta}$ is known: *chance-constrained optimization* and *stochastic programming with recourse*.

Chance-constrained Optimization

In chance-constrained optimization, the decision maker optimizes the expected outcome while ensuring that the probability of satisfying constraints $\mathbf{g}(\mathbf{x}, \boldsymbol{\beta}) \leq \mathbf{0}$ is above a certain level $p \in [0, 1]$:

$$\underset{\mathbf{x}}{\text{Minimize}}\, z = E_{\gamma}[f(\mathbf{x}, \boldsymbol{\gamma})] \tag{1.9}$$

subject to

$$Pr\{\mathbf{g}(\mathbf{x}, \boldsymbol{\beta}) \leq \mathbf{0}\} \geq p. \tag{1.10}$$

Expression (1.10) ensures that *all* the constraints are satisfied with the prescribed minimum probability level p (this explain the reason why (1.10) is referred to as *joint* chance constraint). Since formulation (1.9)–(1.10) is very difficult to solve, even numerically, it is more common to impose that the probability of satisfying each constraint $j = 1, \dots, m$, is above p, that is,

$$Pr\{g_j(\mathbf{x}, \boldsymbol{\beta}) \leq 0\} \geq p, \quad j = 1, \dots, m. \tag{1.11}$$

The resulting formulation (1.9), (1.11) is usually much easier to solve than (1.9)–(1.10).

`[Moderan.xlsx, Moderan.py]` Moderan is a Croatian fashion apparel manufacturer serving the national market. In a few days, the logistician will define the production and transportation capacity for each of the main product groups for the next spring. For AlpinSkies backpacks, the company can use the production lines of three plants, located in Ljubljana, Zadar, and Sibenik, referred to as plants 1, 2, and 3, respectively, in the following. The market has been divided into three sales districts, Slavonia-Central Croatia, Istria-Kvarner, and Dalmatia (referred to in the following as districts 1, 2, and 3, respectively). The demand (in thousands of units) for AlpinSkies backpacks β_j, $j = 1, 2, 3$, in each of the three areas is assumed to be normally distributed with expected values μ_j and standard deviations σ_j reported in Table 1.14. The unit production and transportation costs (in €) from plant $i = 1, 2, 3$, to sales district $j = 1, 2, 3$, are random variables

γ_{ij} whose expected values are reported in Table 1.15. In each plant, the whole production capacity is shared among several product groups and the AlpinSkies backpacks may be assigned the capacity (in thousands of units) shown in the second column of Table 1.15.

A chance-constrained approach is used. The expected outcome to be minimized, corresponding to the overall production and transportation cost, is

$$z = E_{\gamma}\left[\sum_{i=1}^{3}\sum_{j=1}^{3}\gamma_{ij}x_{ij}\right] = \sum_{i=1}^{3}\sum_{j=1}^{3}E_{\gamma}[\gamma_{ij}]x_{ij},$$

where x_{ij} is the transportation capacity allocated, at the start of the season, to the replenishment of sales district $j = 1, 2, 3$, from plant $i = 1, 2, 3$.

Table 1.14 Expected value and standard deviation of the spring demand (in thousands of units) in the three districts of the Moderan problem.

Sales district (j)	**Expected spring demand (μ_j)**	**Standard deviation of spring demand (σ_j)**
1	90	5
2	120	15
3	110	10

Table 1.15 Production capacity, and overall expected unit production and transportation costs for each plant–district combination in the Moderan problem.

		Expected unit cost		
Production plant (i)	**Capacity [thousands of units]**	**$j = 1$ [€]**	**$j = 2$ [€]**	**$j = 3$ [€]**
1	140	20	30	10
2	120	50	40	80
3	130	50	60	80

The following inequalities impose that the demand of each sales district is satisfied with a minimum probability level p:

$$Pr\left(\sum_{i=1}^{3}x_{ij} \geq \beta_j\right) \geq p, \qquad j = 1, 2, 3,$$

which can be equivalently written as

$$Pr\left(\frac{\beta_j - \mu_j}{\sigma_j} \leq \frac{\sum_{i=1}^{3}x_{ij} - \mu_j}{\sigma_j}\right) \geq p, \qquad j = 1, 2, 3,$$

or

$$Pr\left(Z \leq \frac{\sum_{i=1}^{3} x_{ij} - \mu_j}{\sigma_j}\right) \geq p, \qquad j = 1, 2, 3, \tag{1.12}$$

where $\frac{\beta_j - \mu_j}{\sigma_j}$, $j = 1, 2, 3$, is the standard normal random variable Z.

Let z_α be the value such that $Pr(Z \geq z_\alpha) = \alpha$ ($\alpha \in [0, 1]$). Equivalently, z_α corresponds to $Pr(Z \leq z_\alpha) = 1 - \alpha$ (see Figure 1.25), i.e., the value under which a standard normal random variable falls with probability $(1 - \alpha)$ (the quantile of order $(1 - \alpha)$ of the normal standard distribution). For example, if $\alpha = 0.05$, $z_\alpha = 1.645$ and corresponds to the quantile of order 0.95 of the normal standard distribution. In `Excel` it can be obtained by using the `NORM.S.INV` function, i.e., $z_{0.05}$ = `NORM.S.INV(0.95)` = 1.645.

Hence, the satisfaction of the chance constraints (1.12) implies that

$$\frac{\sum_{i=1}^{3} x_{ij} - \mu_j}{\sigma_j} \geq z_{(1-p)}, \qquad j = 1, 2, 3,$$

or, equivalently

$$\sum_{i=1}^{3} x_{ij} \geq \mu_j + z_{(1-p)}\sigma_j, \qquad j = 1, 2, 3.$$

For $p = 0.95$ (and hence $z_{0.05} = 1.645$), the Moderan problem can be cast as follows:

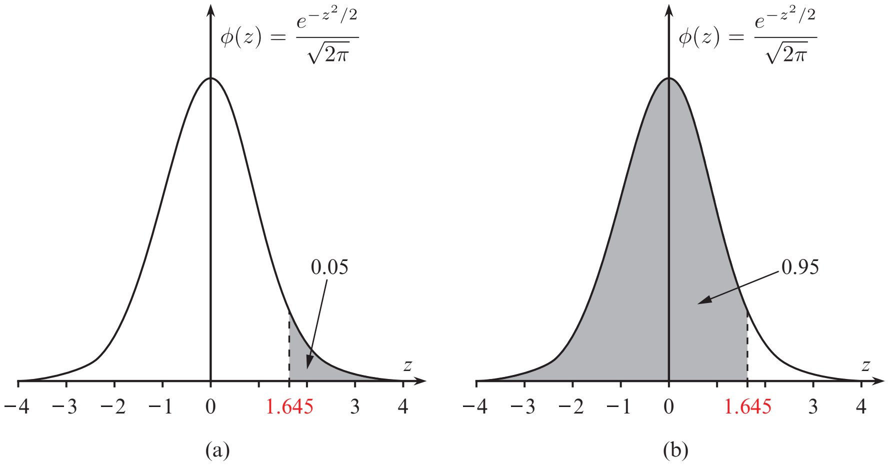

Figure 1.25 Graphical illustration of quantile $z_{0.05} = 1.645$: (a) $Pr(Z \geq z_{0.05}) = 0.05$; (b) $Pr(Z \leq z_{0.05}) = 0.95$.

$$\begin{aligned}
\text{Minimize } & 20x_{11} + 30x_{12} + 10x_{13}\\
& + \ 50x_{21} + 40x_{22} + 80x_{23}\\
& + \ 50x_{31} + 60x_{32} + 80x_{33}
\end{aligned}$$

subject to

$$\begin{aligned}
x_{11} + x_{21} + x_{31} &= 90 + 1.645 \times 5\\
x_{12} + x_{22} + x_{32} &= 120 + 1.645 \times 15\\
x_{13} + x_{23} + x_{33} &= 110 + 1.645 \times 10\\
x_{11} + x_{12} + x_{13} &\le 140\\
x_{21} + x_{22} + x_{23} &\le 120\\
x_{31} + x_{32} + x_{33} &\le 130\\
x_{11}, x_{12}, x_{13}.x_{21}, x_{22}, x_{23}, x_{31}, x_{32}, x_{33} &\ge 0.
\end{aligned}$$

The optimal solution, $x_{11}^* = 0.000$, $x_{12}^* = 13.551$, $x_{13}^* = 126.449$, $x_{21}^* = 0.000$, $x_{22}^* = 120.000$, $x_{23}^* = 0.000$, $x_{31}^* = 98.224$, $x_{32}^* = 11.121$ and $x_{33}^* = 0.000$, corresponds to an expected cost $z^* = €\ 12\,049.52$.

Stochastic Programming with Recourse

In stochastic programming with recourse, the decision maker may take corrective actions after a random event has taken place. In the simplest case (*two-stage recourse*),

- a first-stage decision is made (represented by a vector $\mathbf{x}$ of decision variables), producing some outcome;
- some random events happen; realizations of $\boldsymbol{\gamma}$ and $\boldsymbol{\beta}$, indicated collectively as a *scenario* s, become known;
- some recourse actions (represented by a second-stage vector $\mathbf{y}^{(s)}$ of decision variables, one for each scenario s), are made to correct what may have been wrong in each scenario s.

The objective is to minimize the first-stage outcome plus the expected outcome of the second-stage recourse actions.

`[HealthyLife.xlsx, HealthyLife.py]` HealthyLife imports dry grain, cereals, vegetables, and fruit juice to Europe. For a particular product, the buying price at the start of the winter season is a known value $c_0 = 100$ €/tonne. On the other hand, the demand $\boldsymbol{\beta}$ (in tonnes) and the buying price $\boldsymbol{\gamma}$ (in €/tonne) during the winter show a strong uncertainty. In Table 1.16 a joint probability p_s characterizes the realizations β_s and γ_s of $\boldsymbol{\beta}$ and $\boldsymbol{\gamma}$ for each scenario $s = 1, 2, 3$. The company has to decide how much inventory x to buy at the beginning of the season (holding costs are neglected for the sake of simplicity) and how much inventory $y^{(s)}$ to buy, as a recourse action, in each scenario $s = 1, 2, 3$. The selling price can be assumed to be constant and unsold goods have no value. The model is formulated as follows:

$$\text{Minimize } z = 100x + 0.5 \times 80y^{(1)} + 0.4 \times 160y^{(2)} + 0.1 \times 180y^{(3)}$$

subject to

$$x + y^{(1)} \geq 100$$
$$x + y^{(2)} \geq 120$$
$$x + y^{(3)} \geq 150$$
$$x, y^{(1)}, y^{(2)}, y^{(3)} \geq 0,$$

where the expected recourse cost is $p_1\gamma_1 y^{(1)} + p_2\gamma_2 y^{(2)} + p_3\gamma_3 y^{(3)}$. The optimal solution is found in `Excel` by using the `Solver` tool. The total expected cost is equal to € 12 180 with $x^* = 100$, $y^{*(1)} = 0$, $y^{*(2)} = 20$, $y^{*(3)} = 50$. Therefore, if scenario 1 occurs, no additional amount of product should be purchased during the season. If scenario 2 occurs, the company needs 20 further tonnes of product, whereas, in case of occurrence of scenario 3, the amount of product to be purchased during the winter is 50 tonnes.

Table 1.16 Demand, buying price, and probability values for each scenario $s = 1, 2, 3$, of the HealthyLife problem.

Scenario (s)	**Demand [tonnes]** (β_s)	**Buying price [€/tonne]** (γ_s)	**Probability** (p_s)
1 (low demand)	100	80	0.5
2 (medium demand)	120	160	0.4
3 (high demand)	150	180	0.1

Simulation

In some complex logistics systems, the outcome z of a decision is represented by a function of variables $\mathbf{x}$ that is not known in *closed form*. In this case, the computation (or estimation) of z can be done by *simulation* for any given $\mathbf{x}$. Simulation means formalizing and reproducing cause–effect relations within a system, under given conditions, by using a *simulator*. In *computer simulation*, each part of the system is represented by a subroutine which reproduces its input–output behaviour. In this way, the logistician can obtain the relevant information about the outcome of the decision.

The Coca-Cola company, world leader in the production and distribution of soft drinks and syrup concentrates, has recently decided to reorganize the logistics activities carried out at the DC in Taguatinga (Brazil). A simulation model has been specifically developed by a consulting firm to reproduce how the different DC zones (see Section 5.1.2) and all the processes within them work, in order to identify operational limits in the current configuration and to suggest the best improvements to layout, storage, and flow within the DC (for further details in the warehouse design see Chapter 5). After several simulation experiments, the consulting firm has identified the greatest inefficiency in the picking and staging zones, and, hence, a new warehouse configuration has been proposed. In particular, the new DC layout configuration has been based on the introduction of a larger staging zone for palletized unit loads, a reduction of the total loading bays (from 16 to 8) and the complete redesign of the picking zone. Simulation has led to several improvements in the warehouse performance:

- with the new shipping zone, all the trucks can be loaded before 6:00 while in the current configuration around 46% of the trucks are late;
- with the new product allocation strategy, the productivity of the picking zone increases, with a reduction of 1.5 minutes on average for preparing a complete pallet;
- the vehicle loading time is reduced by 26% and the storage capacity is increased by 20%.

Simulation can be *deterministic* or *stochastic*. If the system does not show any degree of uncertainty, its simulation depends only on known (deterministic) input parameters.

`[LogMe.py]` LogMe is a French company operating a logistics platform near Nantes. The platform is an area where different activities of warehousing and transshipment are carried out by various operators, both for national and international transit. The current packing zone includes one packaging station.
On a given day, at time $t_0 = $ 10:05, a packaging station is expected to process a list of 10 parcels. Each parcel $i = 1, \dots, 10$, is characterized by an arrival time a_i and has to be loaded onto a pallet $p_i \in \{A, B\}$ (see Table 1.17). The station needs $c = 2$ minutes to process any parcel. The truck on which pallet A has to be shipped must leave at time $t_f = $ 10:20. The platform queue is managed according to a *first-in, first-out* (FIFO) policy. The objective is the minimization of the total completion time z for loading and packaging the parcels onto pallets A and B. Since no closed-form expression is known for the completion times of both A and B pallets, the logistics manager makes use of a simulation model (see `PACKING_STATION_SIMULATION` procedure), in order to both check the feasibility of the solution (that is, $g \leq t_f$, where g is the completion time for loading pallet A) and assess the outcome z. It turns out that the completion time for pallet

A is 10:20 (hence satisfying the company's operational requirement) and the total completion time *z* for loading the 10 parcels was 10:28.

Table 1.17 List of 10 parcels in the LogMe problem.

Parcel (i)	**Arrival time** (a_i)	**Pallet** (p_i)
1	10:05	*A*
2	10:07	*B*
3	10:08	*A*
4	10:09	*A*
5	10:10	*B*
6	10:11	*A*
7	10:18	*A*
8	10:19	*B*
9	10:20	*B*
10	10:26	*B*

If the system is stochastic, its behaviour is affected by uncertain parameters that can be treated as random variables or stochastic processes. The most common approach to analyse the influence of uncertain inputs on output variables relies on *Monte Carlo methods*. These are a broad class of computational algorithms in which repeated random sampling (from *pseudo-random number generators*, RNGs) is used to make numerical estimations of the unknown input parameters. In Monte Carlo methods, multiple simulation runs may be needed in order to draw a conclusion about the value of the outcome to be estimated.

`[LogMe2.py]` In LogMe problem, assume that packaging time c is a discrete random variable with probability distribution

$$Pr(c = 1) = 0.3, Pr(c = 2) = 0.4 \text{ and } Pr(c = 3) = 0.3. \tag{1.13}$$

A Monte Carlo method is used by the logistics manager to estimate the expected overall completion time, the expected completion time for loading pallet *A* and the probability that the company's operational constraint is violated. A single simulation run of the packaging station can be obtained from `PACKING_STATION_SIMULATION` procedure by substituting c with a call to a RNG, reproducing probability distribution (1.13). For $N = 1000$ simulation runs, the sample means and sample standard deviations of z and g are:

$\bar{z} = 28.12$ minutes;

$$S_z = 0.93 \text{ minutes};$$

$$\overline{g} = 20.38 \text{ minutes};$$

$$S_g = 1.14 \text{ minutes},$$

where $\overline{z}$ and $\overline{g}$ are expressed in minutes (in decimal notation) past 10:00 and, consequently, corresponding to times of 10:28:07 and of 10:20:23, respectively. Moreover, in $N' = 239$ simulation runs (out of $N = 1000$) the loading time g of pallet A exceeds $t_f = 10{:}20$. The confidence interval at $(1 - \alpha) = 0.95$ level of the expected outcome is (recall that $z_{0.05} = 1.645$)

$$\left[28.12 - 1.645 \times 0.93/\sqrt{1000}, 28.12 + 1.645 \times 0.93/\sqrt{1000}\right],$$

that is, a time interval given by [10:28:04, 10:28:10]. Similarly, the confidence interval of the expected completion time of loading pallet A is

$$\left[20.38 - 1.645 \times 1.14/\sqrt{1000}, 20.38 + 1.645 \times 1.14/\sqrt{1000}\right],$$

that is, a time interval corresponding to [10:20:19, 10:20:26]. Finally, the probability of violating the company's operational constraint is $N'/N = 0.24$.

```
procedure PACKING_STATION_SIMULATION ($n, L, \mathbf{a}, t_0, c, z, g$)
    # $n$ is the number of parcels;
    # $L$ is the list of $n$ parcels;
    # $\mathbf{a}$ is the vector of the arrival times of the parcels;
    # $t_0$ is the starting time of the packing station;
    # $c$ is the time required by the packing station to load a parcel;
    # $z$ is the total completion time returned by the procedure;
    # $g$ is the completion time for pallet $A$, returned by the procedure;
    $t_{now} = t_0$;
    while $L \neq \emptyset$ do
        Extract the parcel $i$ of least arrival time $a_i$ from $L$;
        if $t_{now} < a_i$ then
            $t_{now} = a_i + c$;
        else
            $t_{now} = t_{now} + c$;
        end if
        if $p_i = A$ then
            $g = t_{now}$;
        end if
    end while
    Set $z = t_{now}$;
    return $z, g$;
end procedure
```

While in the LogMe problem the simulator was written in a general-purpose programming language (`Python`), it is sometimes easier to make use of special-purpose simulation languages and visual interactive modelling systems (VIMSs), such as Arena and Simio, to ease this task.

What-if Analysis

What-if analysis is a predictive technique whose objective is to evaluate how a change in the problem data (or the deletion of a constraint, and so on) affects the KPIs and performance measures (cost, profit, losses, efficiency, etc.) with respect to a baseline solution (current configuration of the logistics system, current policy, etc.). Each combination of such variations is called a *scenario* and may require the solution of a new optimization problem. *What-if* analysis is a very popular tool to support managers in making strategic and tactical decisions.

[`FCT.xlsx`] FCT, a German company specializes in the production and distribution of automotive spare parts at competitive prices, actually manages a logistics system composed of two production plants (nodes 1 and 2 in Figure 1.26), a CDC (node 3) and three RDCs (nodes 4, 5, and 6). Groups of retailers geographically close to each other are referred to as nodes 7 and 8 (for simplicity, a single node is considered for each group of retailers). The current monthly volumes of spare parts moved along the arcs and the unit transportation costs are reported in Table 1.18. The DCs 3, 4, 5, and 6 have a limited handling capacity per month equal to 600, 200, 200, and 200 pallets, respectively, and monthly running costs (including storage costs) equal to € 14 000, € 9500, € 7400 and € 8600, respectively. In the current configuration (see `FCT.xlsx` for details), the monthly total

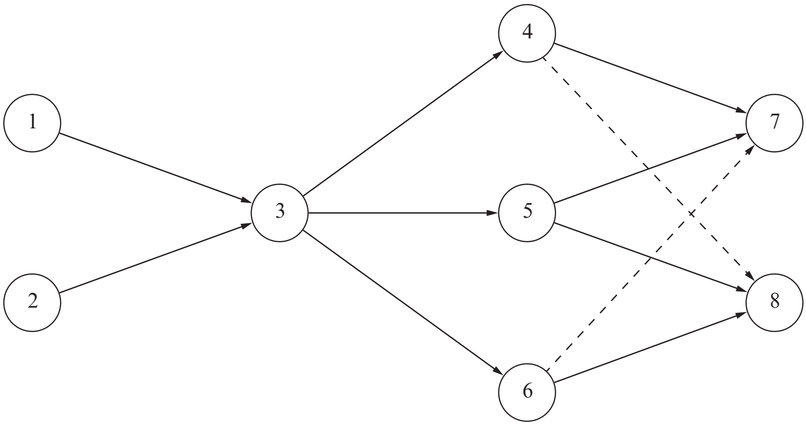

Figure 1.26 Representation of the FCT logistics system. Dashed arcs correspond to transportation links not activated in the current configuration.

Table 1.18 Monthly volume and unit transportation cost in the FCT problem.

Arc	Volume [pallets]	Unit cost [€/pallet]	Arc	Volume [pallets]	Unit cost [€/pallet]
(1,3)	200	30.0	(4,7)	150	13.0
(2,3)	200	30.0	(4,8)	0	16.5
(3,4)	150	14.0	(5,7)	100	14.0
(3,5)	200	16.0	(5,8)	100	14.5
(3,6)	150	15.0	(6,7)	0	15.0
			(6,8)	150	10.5

cost is equal to € 68 425, derived from the sum of € 39 500 (running costs of the DCs) and of € 28 925 (transportation costs along overall the arcs used). Considering an expected increase in sales of 20% for each retailer, the FCT director of the logistics function has proposed to review the current organization within the logistics system, making the distribution phase more efficient, if possible. To this end, the manager decides to perform a what-if analysis to evaluate three different possible scenarios: A, B, and C. The idea is to investigate how the divestment of one or two RDCs within the logistics system (scenarios B and C, respectively) will influence the total costs, compared with the alternative of maintaining the actual configuration (scenario A). The analysis has to simultaneously guarantee the satisfaction of the demand constraint. The three possible scenarios are described in the following.

A. Reorganization of the freight flows within the current logistics system for reducing the overall cost as much as possible. In this configuration, we allow an increase of 20% of the capacity of each RDC and, consequently, of the running costs.

B. Closure of one of the three RDCs, increasing the capacity of those remaining by 50%, against an increase of the operating costs by up to 50%. Consider that for the RDC candidate for closure it is necessary to pay a monthly quote of the total disposal cost equal to € 1200 for node 4, € 1300 for node 5 and € 1100 for node 6.

C. Use of only one of the three RDCs available, providing an appropriate increase of its capacity. In this configuration, the RDC monthly running costs are assumed equal to three times the current value. In addition, the monthly quote of the disposal cost is the same of that reported in the previous alternative.

It is assumed that there are no vehicle capacity constraints and the increase in sales is equally distributed for both groups of retailers. As far as the three alternatives are concerned, the hypothesis of the sales increase equally distributed among retailers leads to a monthly demand of 300 pallets for each of the nodes 7 and 8.

In the case of scenario A, the capacity of each RDC is increased to 240 pallets (20% more than 200 pallets). With the aim of optimizing the transportation costs, a least-cost path for moving 300 pallets from CDC (node 3) to the destination node 7 is determined. There exist three different feasible solutions: path $(3, 4, 7)$, with a unit cost of € $(14.0 + 13.0) =$ € 27.0; path $(3, 5, 7)$, with a unit cost of € $(16.0 + 14.0) =$ € 30.0; path $(3, 6, 7)$, with a unit cost of € $(15.0 + 15.0) =$ € 30.0. This implies that the maximum fraction allowed of the demand (240 pallets) is moved through the least-cost path $(3, 4, 7)$, saturating the capacity of node 4, and the remaining part (60 pallets) is transported through the second least-cost path $(3, 5, 7)$. Similarly, for moving freight from node 3 to node 8 there are only two feasible solutions: path $(3, 5, 8)$, with a unit cost of € $(16.0 + 14.5) =$ € 30.5 and path $(3, 6, 8)$, with a unit cost of € $(15.0 + 10.5) =$ € 25.5. Note that path (3, 4, 8) is not considered since node 4 has no residual capacity. In this case, 240 pallets are moved through the least-cost path $(3, 6, 8)$ and 60 pallets along the path $(3, 5, 8)$. The monthly total cost of the logistics system corresponding to scenario A is of € 78 830, as reported in the third column of Table 1.19, generated in `Excel` by using the `What-If Analysis` → `Scenarios` tool, under `Data` tab (see `FCT.xlsx` for more details).

Scenario B corresponds to three different subscenarios: closure of node 4 (scenario B1), closure of node 5 (scenario B2) and closure of node 6 (scenario B3). Note that when a node is closed, the capacity of the remaining others increases up to 300 pallets each. A similar approach to that used in scenario A to optimize the transportation costs is considered. The results, in terms of monthly cost of the logistics system, obtained by using the `What-If Analysis` tool in `Excel` for the three subscenarios are reported in columns 5, 7 and 9 of Table 1.19.

Also scenario C leads to three different subscenarios: the use of only RDC 4, 5, and 6, respectively (corresponding to scenarios C1, C2, and C3, respectively). Note that when only one RDC is used, its capacity increases to 600 pallets. The monthly total cost of the logistics system corresponding to scenarios C1, C2, and C3 are summarized in columns 11, 13, and 15 of Table 1.19.

The conclusion driven from the what-if analysis is that the closure of the first RDC (node 4), corresponding to scenario B1, leads to the minimum monthly total cost of the FCT logistics system.

Table 1.19 Monthly costs of different scenarios in the FCT problem.

Arc/Node	Scenario A		Scenario B1		Scenario B2		Scenario B3		Scenario C1		Scenario C2		Scenario C3	
	Volume [pallets]	Cost [k€]	Volume [pallets]	Cost [k€]	Volume [pallets]	Cost [k€]	Volume [pallets]	Cost [k€]	Volume [pallets]	Cost [k€]	Volume [pallets]	Cost [k€]	Volume [pallets]	Cost [k€]
(1,3)	300	9.00	300	9.00	300	9.00	300	9.00	300	9.00	300	9.00	300	9.00
(2,3)	300	9.00	300	9.00	300	9.00	300	9.00	300	9.00	300	9.00	300	9.00
(3,4)	240	3.36	0	0.00	300	4.20	300	4.20	600	8.40	0	0.00	0	0.00
(3,5)	120	1.92	300	4.80	0	0.00	300	4.80	0	0.00	600	9.60	0	0.00
(3,6)	240	3.60	300	4.50	300	4.50	0	0.00	0	0.00	0	0.00	600	9.00
(4,7)	240	3.12	0	0.00	300	3.90	300	3.90	300	3.90	0	0.00	0	0.00
(4,8)	0	0.00	0	0.00	0	0.00	0	0.00	300	4.95	0	0.00	0	0.00
(5,7)	60	0.84	300	4.20	0	0.00	0	0.00	0	0.00	300	4.20	0	0.00
(5,8)	60	0.87	0	0.00	0	0.00	300	4.35	0	0.00	300	4.35	0	0.00
(6,7)	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	300	4.50
(6,8)	240	2.52	300	3.15	300	3.15	0	0.00	0	0.00	0	0.00	300	3.15
3	-	14.00	-	14.00	-	14.00	-	14.00	-	14.00	-	14.00	-	14.00
4	-	11.40	-	1.20	-	14.25	-	14.25	-	28.50	-	1.20	-	1.20
5	-	8.88	-	11.10	-	1.30	-	11.10	-	1.30	-	22.20	-	1.30
6	-	10.32	-	12.90	-	12.90	-	1.10	-	1.10	-	1.10	-	25.80
Total cost		78.83		73.85		76.20		75.70		80.15		74.65		76.95

1.11 Segmentation Analysis

Segmentation analysis is a methodology that allows partitioning products and market in different parts (*segments*) that share common features. The ultimate goal is to manage each individual segment with specific procedures. In particular, as far as SCM is concerned, segmentation amounts to identifying which combinations of products and markets have to be serviced by the same supply chain (or with the same policy) in order to best pursue the logistics objectives (see Section 1.8). In other words, supply chain segmentation allows managers to recognize the logistics services required by each segment, to define the supply chain capabilities and implement solutions to improve performance. The most common segmentation techniques used in logistics are *customer* and *product* segmentations.

1.11.1 Customer Segmentation

In SCM, customer segmentation is aimed at partitioning customers into groups of individuals (or companies) expecting the same level of logistics service. Customer segmentation can be based on the following four criteria.

1. *Demographic*. In B2C markets, demographic customer segmentation relies on the customers' gender, age, level of education, profession, income, and marital situation. In B2B markets, it is based on the companies' annual turnover, number of employees, corporate sector, etc.
2. *Geographic*. In geographic market segmentation, users are subdivided with respect to their geolocation; this is the simplest criterion to create groups of customers with similar culture, climatic conditions, and habits.
3. *Psychographic*. In psychographic customer segmentation, customers are grouped with respect to their lifestyle, hobbies, values, etc.
4. *Behavioural*. In behavioural market segmentation, segments are generated by considering the past buying behaviour exhibited by customers towards the company's products and services.

Procter and Gamble is an American multinational consumer goods corporation, producing and marketing a wide range of cleaning and personal care products in over 180 countries. The main market segmentation operated by the company is realized by considering a geographical criterion, based on six different *selling and market areas* (SMAs): Europe, Asia–Pacific area, Greater China, Middle East, Africa and India, Latin America and North America. Inside each segment, the distribution channels, different for size and typology, are represented by a large variety of retailers: grocery stores, drug stores, hyper and super markets, distributors, baby stores, e-commerce, high-frequency stores, pharmacies, and nanostores. For this reason, in each SMA a local market access plan is specifically developed, through which dedicated retail customers, sales channels, and country-specific teams are clearly identified, focusing on efficiency and effectiveness in terms of SCM.

1.11.2 Product Segmentation

Product segmentation is a technique to deal with multiple products in supply chains.

ABC Classification

ABC classification is the most popular product segmentation technique and allows products to be subdivided into three classes, called A, B, and C, on the basis of their "value" (typically, the revenue they generate in a reference period, for example, a year). Class A is defined as the set of products achieving a given high percentage of the overall annual revenue (e.g., 80%). Class B is made up of the articles that constitute an additional 15% of the revenue, whereas class C is made up of the remaining articles. The classification is achieved by ordering the list of products in non-increasing fashion, and successively selecting the articles in that order, up to a predetermined cumulated value.

It is empirically observed that class A will most likely account for a modest fraction of the products. This property is often referred to as the *80–20 principle*, or *Pareto principle*, based on the observation made by the scholar V. Pareto who observed that, in the nineteenth century, 20% of the Italian population owned 80% of the national wealth. In contrast, class C, which accounts for a small percentage of total value, is usually made up of a large number of products. This observation suggests different logistics policies for the three product segments. For example, it is worth using several CDCs and RDCs, with high inventory levels, for class A products. On the other hand, the distribution of class C products can be done by using a single CDC and reducing the stocked quantity of products to a minimum.

`[Blucker.xlsx]` Blucker is the owner of an Irish plant manufacturing building materials. The Cork warehouse is used to store and distribute products in the water-based dispersion adhesives category to wholesalers. There is a total of 15 products. The annual revenue, sales volume, and average annual inventory value of the Blucker products are provided in Table 1.20. The *ABC* (80−15−5) classification of the products by annual revenue can be derived from Table 1.21, in which the products are sorted in non-increasing order with respect to revenue. Class *A* products make up 79.95% of the annual revenue, whereas they represent only 40.66% of the overall amount sold in the year. Class *B* products represent 14.45% of the annual revenue and generate 32.22% of the annual sales volume, whereas class *C* products make up only 5.60% of the annual revenue; the weight of these products is equal to 27.12% of the overall amount sold in the year. The cumulative percentages of the annual amounts sold and of the annual revenue for each of the 15 products are plotted in Figure 1.27. The same figure exhibits the 80−20 curve of equation $y = [(1 + \alpha)x]\,/(\alpha + x)$ which best fits the plotted values (y is the cumulative percentage of the annual revenue, x is the cumulative percentage of the amounts sold, $\alpha = 0.238$ is obtained by using the least-squares method, which involves in `Excel` the use of the `Solver` tool under the `Data` tab, see `Blucker.xlsx` for more details).

Table 1.20 Annual revenue, average annual inventory value and amounts sold of the Blucker products.

ID	Article	Revenue [€]	Amounts sold [kg]	Average inventory [€]
1	FIL12	424 764	38 614	109 000
2	BG1	126 000	33 452	26 000
3	BG2	959 800	24 522	401 400
4	BG3	84 540	25 545	53 000
5	P	441 280	24 767	23 800
6	TX	356 984	19 768	30 260
7	K0	762 250	32 234	157 000
8	K1	128 150	17 669	41 000
9	K2	51 206	22 600	9 900
10	K3	80 596	32 574	18 500
11	P-L1	144 625	30 578	33 900
12	P-L2	653 600	31 400	109 200
13	P-L3	35 608	33 560	127 000
14	P-L4	133 720	18 768	42 300
15	P-L5	118 300	35 287	27 000

Table 1.21 *ABC* classification of the Blucker products.

ID	Article	Annual revenue [€]	Annual amounts sold [kg]	Cumulated annual amounts sold [%]	Cumulated annual revenue [%]	Class
3	BG2	959 800	24 522	5.82	21.32	*A*
7	K0	762 250	32 234	13.47	38.26	*A*
12	P-L2	653 600	31 400	20.92	52.78	*A*
5	P	441 280	24 767	26.80	62.58	*A*
1	FIL12	424 764	38 614	35.97	72.01	*A*
6	TX	356 984	19 768	40.66	79.95	*A*
11	P-L1	144 625	30 578	47.91	83.16	*B*
14	P-L4	133 720	18 768	52.37	86.13	*B*
8	K1	128 150	17 669	56.56	88.98	*B*
2	BG1	126 000	33 452	64.50	91.77	*B*
15	P-L5	118 300	35 287	72.88	94.40	*B*
4	BG3	86 540	25 545	78.94	96.28	*C*
10	K3	80 596	32 574	86.67	98.07	*C*
9	K2	51 206	22 600	92.03	99.21	*C*
13	P-L3	35 608	33 560	100.00	100.00	*C*
	Total	4 501 423	421 338			

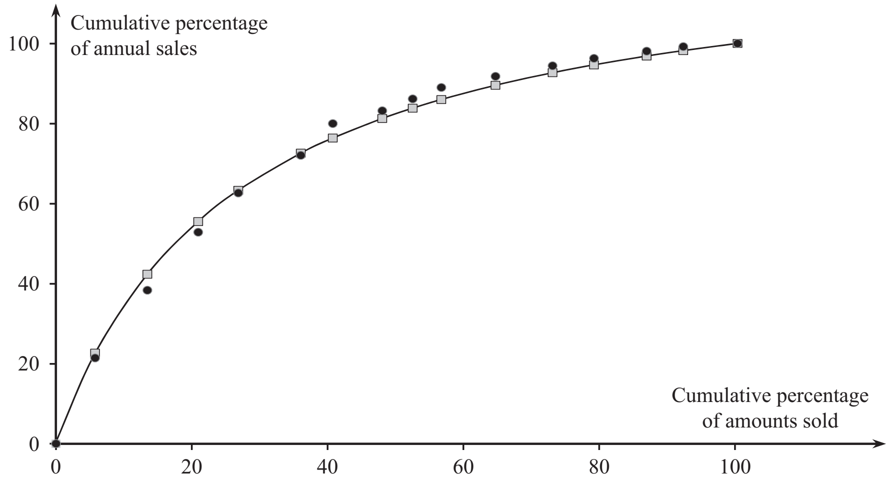

Figure 1.27 80–20 curve for the Blucker products. In black, the Blucker data. In grey, the corresponding values on the 80–20 curve.

ABC Cross Analysis

ABC cross analysis consists of performing simultaneously two independent *ABC* classifications with respect to two product values, for example, the revenue generated and the average inventory value in a reference period. This procedure allows identification of nine subclasses (*AA*, *AB*, *AC*, *BA*, *BB*, *BC*, *CA*, *CB* , and *CC*) that are reported in a double entry table (see Table 1.22). The nine classes give an in-depth representation of the current products' performance, allowing companies to evaluate possible corrective actions. On the main diagonal are the most virtuous product classes (*AA*, *BB*, and *CC*), characterized by a balanced and homogeneous logistics management. In particular, these classes are made up of products for which the high (medium or low) level of revenues corresponds to high (medium or low) value of stocks, respectively. The class *AA* is the most lucrative but also the most expensive in terms of inventory costs. A large number of products within this class could lead to a too conservative inventory management policy to avoid stockout; in this case, the company has to evaluate a stock reduction. Classes that are placed above the main diagonal (*AB*, *AC*, and *BC*) contain products with low inventory turnover (see Section 1.8), high stock level and low revenue. From a logistics viewpoint, these products are managed worse than the

Table 1.22 *ABC* cross analysis.

Average inventory	Revenue		
	Class *A*	**Class *B***	**Class *C***
Class *A*	*AA*	*AB*	*AC*
Class *B*	*BA*	*BB*	*BC*
Class *C*	*CA*	*CB*	*CC*

average. In particular, class *AC* usually contains obsolete products. In this case the company should reduce the stock level and revise its purchase policies. Classes that are placed under the main diagonal (*BA*, *CA*, and *CB*) are characterized by a high inventory turnover, a low inventory level, and a high revenue. This means that the products belonging to these classes are generally managed better than the average. However, they could be at risk of stockout because an unforeseen increase of the demand level may not be covered by inventories, especially for class *CA*.

`[Blucker.xlsx]` Blucker decided to perform an *ABC* cross analysis (with thresholds 80–15–5) with respect to the revenue generated and average inventory. The annual revenue, sales volume and average inventory of the Blucker products are provided in Table 1.20. Considering the average inventory criterion, class *A* is made up of the BG2, K0, PL-3, PL-2, FIL12, and BG3 products; class *B* contains the P-L4, K1, P-L1, TX, PL-5, and BG1 products; class *C* is composed of the P, K2, and K3 products. The resulting cross classification is summarized in Table 1.23. The analysis shows that the majority of the products fall along or under the main diagonal. Hence, they are correctly managed from a logistics point of view. Nevertheless, there are two obsolete products (PL-3 and BG3 in class *AC*) for which the company has to evaluate the opportunity of discontinuation. Finally, a product (P in class *CA*) is at high risk of stockout, which suggests increasing its stock level with the aim of moving the product to class *BA*.

Table 1.23 *ABC* cross analysis of the Blucker products.

Average inventory	**Revenue**		
	Class *A*	**Class *B***	**Class *C***
Class *A*	BG2, K0, P-L2, FIL12	–	P-L3, BG3
Class *B*	TX	P-L4, K1, P-L1, BG1, PL-5	–
Class *C*	P	–	K2, K3

1.12 Information Systems

Nowadays, the administrative processes and the managerial tasks of many organizations are supported by a variety of software applications. No unique classification of such systems exists, the functional separation between applications is blurred and even on the terminology there is no consensus in the scientific and business communities.

A *management information system* (MIS) is a software application which, in its basic form, collects, stores, and processes information from various sources, mainly for the purpose of reporting.

An *enterprise resource planning* (ERP) software is a category of MIS which uses data across various departments (manufacturing, distribution, procurement, sales, accounting, etc.) to monitor business resources (personnel, cash, inventories, production capacity, etc.) and the status of business commitments (orders from customers, purchase orders, payments, etc.), as well as interpret data, make forecasts, support organizational tasks (creating and keeping deadlines, assigning operational tasks, making schedules, etc.).

The modern versions of ERP are provided as a *cloud service*, so they can be accessed from anywhere using different devices (a Web browser and a basic internet connection are needed). In addition, they incorporate real-time analytics tools enabling discovery of hidden information that can be used to make critical decisions (see Section 1.10).

An ERP is composed of several modules which can be seen as a unique integrated software system or composed of independent parts that can interact each other through various *electronic data interchange* (EDI) mechanisms (see Problem 1.3). Figure 1.28 shows a schematic representation of the interaction of ERP modules with two specific logistics applications, namely the *warehouse management system* (WMS) and the *transportation management system* (TMS), briefly described in the subsequent chapters (in particular, WMS in Section 5.9 and TMS in Section 6.5).

The fourth generation of SAP Business Suite is called S/4HANA. S/4HANA is an ERP for large companies, also deployable as a cloud solution, whose strengths are, above all, its usability and flexibility. S/4HANA offers:

- a unified global SCM platform involving multiple countries, currencies, languages and subsidiaries;
- an e-commerce suite for Web stores;
- a retail software solution for supporting multichannel shoppers.

S/4HANA includes, among others, the following modules: finance and controlling, sales, sourcing and procurement, inventory management, production planning, quality management, plant maintenance, project management, and product life cycle management.

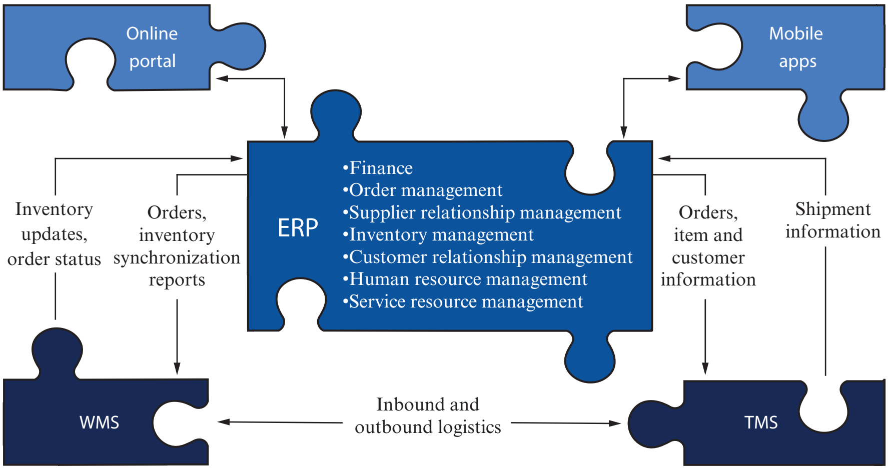

Figure 1.28 Interaction of ERP modules with WMS and TMS.

1.13 Questions and Problems

1.1 Adama is a French manufacturer of photovoltaic panels. The company has a production plant in Rennes, which supplies four warehouses located in Angers, Bourges, Clermont-Ferrand, and Montauban. The warehouses directly supply the installers, grouped, for this purpose, into 10 districts. The installers belonging to the same district are served from a single warehouse. Each installer returns defective photovoltaic panels to the corresponding warehouse; these panels are then sent to a repair centre located in Poitiers. Represent the logistics system of Adama as a directed graph. (Hint: assume that the installers of a district are concentrated in a single point.)

1.2 In 2010, Nokia and Yahoo! announced a partnership to let both companies broaden their global reach by offering messaging and navigation services on mobile devices and PCs. By making available the integration of its Ovi Maps, Nokia has become a global supplier for the navigation service and maps of Yahoo!. On the other hand, Yahoo! made its own messaging technology available to Nokia, becoming the official supplier of Ovi Mail and Ovi Chat. Which type of integration is implemented within the partnership described?

1.3 Barilla is an Italian multinational food company which “has believed in B2B e-commerce and, in particular, in EDI, especially in terms of Web-EDI, which supports the order–delivery–invoice cycle as well as in collaborative approaches, such as the *continuous replenishment program* (CRP) and the *collaborative forecasting and replenishment program* (CPFR)” [Mauro Viacava, CEO of Barilla]. What is presumably the role played by EDI, CRP, and CPFR in Barilla’s integrated logistics system?

1.4 Search the website of a company operating in the beverage sector and sketch a representation of its logistics system.

1.5 Discuss logistics operations in a bank (including secure cash replenishment in *automated teller machines*, ATMs) compared with logistics in a manufacturing company such as a chemical producer.

1.6 Consider the case of a manufacturing company with a logistics network made up of two suppliers, a production plant, a CDC, two RDCs, and several retailers. Describe the structure of the information flow assuming that the supply chain is (a) MTS; (b) MTO; (c) ATO; (d) ETO.

1.7 Perform a Web search to look for examples of 1PL, 2PL, 3PL, 4PL, and 5PL providers and write a short report on their logistics operations.

1.8 A pneumatic refuse collection (PRC) system transports waste at high speed through underground tubes to a collection station where it is shredded and sealed in containers. Illustrate the difference in logistics activities of a PRC system and a traditional vehicle-operated door-to-door collection system in a densely populated urban area.

1.9 What are the key issues in relief supply management just after the occurrence of a environmental disaster? What are the information flows? What are the main challenges in logistics operations?

1.10 What is the job description for a position in a department of defence logistics?

1.11 Mercitalia Rail is the main rail cargo company in Italy and one of the most important in Europe. Find out about its logistics system and, in particular, about

Mercitalia Fast, the company's high speed service specialized in the transportation of roll containers.

1.12 Sustainable logistics aims at implementing a *closed-loop supply chain*. Perform a Web search to look for examples of such systems. Describe challenges and opportunities.

1.13 Deliveroo is one of the most popular online food delivery companies in Europe. Illustrate its service structure and identify the peculiar aspects of its crowdsourcing delivery approach.

1.14 Cargo bikes are becoming more and more popular in city logistics. Browse the Web to identify case studies where this freight transportation system is currently used. Moreover, explain how cargo bike hubs are designed and operated.

1.15 Belton is a US company producing wooden panels. Recently, its managers discovered some inefficiencies in the order information flow for both customers and suppliers. For this reason, the company invested in a new order processing software that allowed it to improve order registering, order processing, order preparation and receiving, shipping, billing collection, and payments. Furthermore, the company provided a unique contact person to coordinate the order approval process and manage exceptions. The result was a reduction in cost and a speed up of the entire ordering process. Which KPIs did the investment have an impact on?

1.16 Assume that, for a certain company, the estimated annual sales *versus* service level curve is $r(l) = 950\,000\,(l/100) - 328\,000\,(l/100)^2$, where l denotes the percentage of customers served within 24 hours and $r(l)$ is expressed in \$. The annual logistics costs (in \$) are estimated as 280 000, 320 000, 380 000, 410 000, 460 000, 510 000, with respect to the following service levels: 50%, 60%, 70%, 80%, 90% and 100%, respectively. Determine the service level at which the maximum estimated annual profit is achieved.

1.17 Five alternative configurations have been identified for a logistics system. Their costs and service levels are plotted in Figure 1.29. Determine which

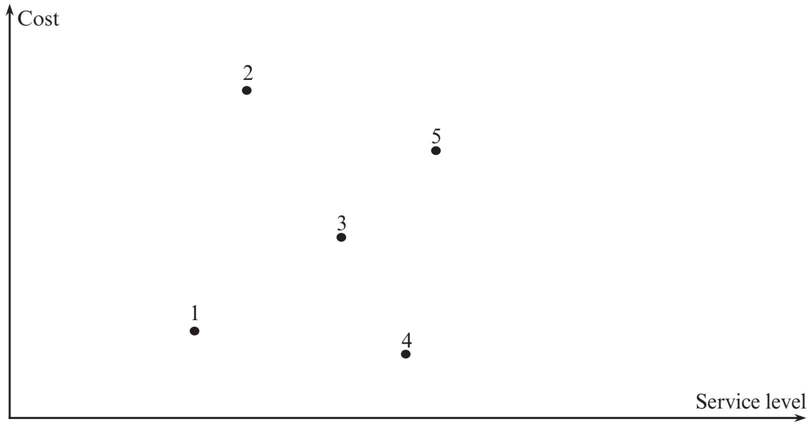

Figure 1.29 Costs and service levels of five alternatives for the design of the logistics system of Problem 1.17.

configurations should be taken into account as a possible solution and which ones should be discarded.

1.18 `[Tranexpress.xlsx]` Tranexpress is an international freight forwarder. Its OCT consists of two components: (a) shipment preparation, customs paperwork, customs inspections, warehousing, consolidation and container loading, dubbed additional services; (b) transportation. Some past observations are reported in Table 1.24. Characterize the OCT by computing the sample mean and the sample standard deviation of the corresponding random variable. Express service variability as a quantitative index.

1.19 Norsk is a Danish company which specializes in the production of food products for daily consumption. It has five associated subsidiaries in the European Union and a network of distributors in North America. Recently, the company decided to redesign its distribution network in Scandinavia where 140 DCs have been transformed into simple warehouses without administrative functions. The administrative functions have been concentrated in 14 regional logistics centres. Moreover, forecasting activities based on data analysis have been centralized in the company's headquarters. List and classify the decisions taken at a business management level during the reorganization phase of the logistics system.

1.20 Describe the functional structure of a petrochemical company and highlight the position of the logistics activities in the organizational chart. Compare the advantages and disadvantages of adopting a divisional organization.

1.21 `[AjtSolar.xlsx]` Ajt Solar is an Indian producer of solar-powered products. To control the supply chain, some critical logistics activities are monitored monthly. Three families of performance measures, related to order processing,

Table 1.24 Observed data related to additional services and transportation times (in days) of Tranexpress.

Additional services		Transportation	
Number of recorded data	Time	Number of recorded data	Time
1	25	20	159
3	26	29	160
4	27	56	161
9	28	66	162
18	29	52	163
35	30	26	164
42	31	16	165
22	32		
13	33		
2	34		
1	35		

Table 1.25 Performance measures used by Ajt Solar.

Family	Performance measure	Computing method
Order processing	Orders	Number of orders in a month/ number of weekdays in a month
	Complaints	Number of complaints in a month
Inventory	Stock value	Average inventory value on a monthly basis
Transportation	Deliveries	Average number of customers served in a vehicle trip
	Vehicle trips	Monthly number of trips carried out/ monthly number of planned trips

Table 1.26 Performance measure values for Ajt Solar in the last 15 months.

Month	Orders	Complaints	Stock value [$]	Deliveries	Vehicle trips
1	154.26	21	470 800	15.48	1.07
2	151.04	12	500 800	36.76	0.97
3	161.23	16	533 000	18.94	1.13
4	145.33	24	565 900	33.07	1.14
5	158.66	14	567 700	31.15	1.13
6	171.25	16	471 900	40.37	1.10
7	98.66	31	522 200	23.35	0.83
8	102.45	8	531 000	14.33	1.00
9	134.74	12	509 800	39.80	0.93
10	147.24	16	579 700	18.37	1.20
11	133.54	21	548 300	26.04	1.15
12	154.81	18	458 700	30.10	1.00
13	148.82	20	542 100	36.60	0.95
14	124.31	13	524 500	26.52	1.11
15	164.03	11	567 400	33.46	1.00

inventory management, and transportation are considered (see Table 1.25). The performance measures for the past 15 months are reported in Table 1.26. In the current month (with 23 working days), the company has recorded the following data: 3568 orders, 15 complaints, an inventory value of $ 560 400, 24.25 customers served on average in a trip, 4 950 planned vehicle trips and 4702 trips made. Build a control panel to monitor the three identified families of performance measures, according to the methodology illustrated in Section 1.9.3.

1.22 `[Arka.xlsx]` Arka is a Serbian manufacturer of diesel engines. The logistics manager in charge of designing the supply chain for product named WMF has identified four configurations (denoted as $i = 1, 2, 3, 4$ in the following). Based on the judgement of a panel of experts (see Section 2.2 for more details), the

Table 1.27 Profit (in k€) for each configuration-demand scenario pair in the Arka problem.

	Demand in the next five years		
Configuration (i)	**low**	**medium**	**high**
1	800	400	−400
2	500	250	100
3	400	650	100
4	−200	700	1200

demand in the next five years is expected to be high, medium, or low, with probabilities 0.5, 0.3, and 0.2, respectively. An in-depth analysis of the company's cost structure has allowed the manager to determine the profit of the four configurations for every demand scenario (see Table 1.27). Determine the optimal configuration with respect to the Bayes criterion. Also compute the expected value under perfect information.

1.23 `[Lugan.xlsx]` In the Lugan problem, assume that no additional travel time observations can be collected and a decision has been made on the basis of the initial 20 samples. Under this hypothesis, determine the *minimum* indifference zone width δ that allows the company to choose between providers A and B with a confidence level $(1-\alpha) = 0.95$. Then identify the provider to be selected.

1.24 `[Moderan.xlsx]` In the Moderan problem, assume that $p = 0.99$ and determine the optimal solution of the corresponding chance-constrained model. Hence compare the solutions obtained for $p = 0.95$ and $p = 0.99$. Which is more robust? Which is more expensive?

1.25 `[HealthyLife.xlsx]` In the HealthyLife problem assume that the inventory $y^{(s)}$ to be bought, as a recourse action, in each scenario $s = 1, 2, 3$, cannot be greater than 20. Determine the optimal solution of the new version of the stochastic programming model with recourse. What is the company's new strategy?

1.26 A *supply chain digital twin* is a virtual supply chain replica that consists of simulated suppliers, plants, warehouses, etc. Perform a Web search and learn more about this paradigm. Which are the main differences between a digital twin and a traditional simulation model?

1.27 Garbi is a waste collection municipal agency operating in a small district near Bilbao (Spain). Every morning seven trucks arrive at the waste processing facility located at Ibaiondo at 8:42, 8:53, 8:55, 9:00, 9:10, 9:15, 9:25 to drop their content. Determine the average waiting time of a truck if vehicle unloading takes 10 minutes.

1.28 In the Garbi problem, assume that the time needed to unload a vehicle is normally distributed with an expected value of 10 minutes and a standard deviation of 2 minutes. Develop a `Python` code to simulate vehicle queueing at the waste processing facility. Execute 20 simulation runs and determine the confidence interval at 0.95 level for the expected vehicle waiting time.

1.29 In the second version of the Garbi problem, determine how many simulation runs are needed to obtain a confidence interval whose semi-width is 1% of the sample mean.

1.30 Eurlux is a Dutch company that has recently decided to start production and sale of a new energy-efficient light bulb. During the phase of the logistics system design, three alternatives are considered.

- Use the foreign manufacturing plant located in Tartu (Estonia), where the unit production cost is € 0.97 (the cost of raw materials purchase is included). The transportation cost to the CDC of Groningen is € 5 per box, where a box contains 100 units of the product. For simplicity, it is assumed that this cost includes also inventory costs at the CDC. The CDC of Groningen supplies two RDCs, situated in Delft and Eindhoven; their annual demands are 28 000 and 35 000 boxes, and the transportation costs per box are € 9 and € 10, respectively.
- Use the national manufacturing plant of Dordrecht, where the unit production cost is € 1.38. This facility supplies the RDC of Delft and Eindhoven and the unit transportation costs are, in this case, € 8.5 and € 7.0 per box, respectively.
- Use the national manufacturing plant of Dordrecht to satisfy the demand of the RDC of Delft; while the demand of RDC of Eindhoven is covered by a foreign manufacturing plant located in Antwerp (Belgium) with a unit production cost of € 1.18 and a transportation cost of € 5.6 per box.

Determine which alternative to select through the `Excel What-If Analysis` tool, considering the minimization of production and transportation costs as the logistics objective to pursue.

1.31 [`Florim.xlsx`] Florim is an Albanian company specializing in the manufacturing of ceramics. The company manufactures six products, whose sales are reported in Table 1.28. Let $y = [(1 + \alpha_1)x]/(\alpha_1 + x)$ be the equation of the 80–20 curve C_1 defined such that the first 21% of products sold corresponds to 68% of the annual sales; similarly, let $y = [(1 + \alpha_2)x]/(\alpha_2 + x)$ be the 80–20 curve C_2, obtained by assuming that the first 21% of products corresponds to 62% of the annual sales. Check which of the curves C_1 and C_2 is a better approximation of the actual cumulative percentage of the annual revenue with respect to the cumulative percentage of the annual quantity sold.

1.32 [`Zuick.xlsx`] Zuick is a German import–export company of household appliances. The company, whose headquarters are located in Hannover, distributes 15 products whose weekly sales volumes and revenues are reported in Table 1.29. The company is investing additional financial resources in two products, K-505 and K-506, for which the logistics manager proposes an aggressive distribution strategy, involving more CDCs and higher inventory levels. By using an *ABC* classification (20–30–50) with respect to weekly sales, verify whether the distribution strategy proposed by the logistics manager is correct and, if not, modify it accordingly.

Table 1.28 Annual revenue (in €) and quantity sold of the six Florim products.

Product	Revenue [€]	Quantity [quintals]
1	350 000	2700
2	160 000	2200
3	920 000	2500
4	125 000	1500
5	360 000	4200
6	160 000	1900

Table 1.29 Weekly quantity sold and corresponding revenue (in €) in the Zuick problem.

Product	Quantity [quintals]	Revenue [€]
K-501	155	119 806
K-502	64	31 448
K-503	70	25 607
K-504	66	24 406
K-505	61	15 196
K-506	58	13 112
K-507	60	10 106
K-508	197	11 395
K-509	154	9 489
K-510	56	8 664
K-511	74	13 955
K-512	208	16 283
K-513	164	14 085
K-514	71	12 984
K-515	163	123 935

1.33 [`ElMa.xlsx`] El.Ma is an American distributor of electrical equipment. The warehouse in Columbus (Ohio) has 18 products in stock. Monthly sales and average monthly stock values are reported in Table 1.30. Make an *ABC* classification (80–10–10) of the products with respect to monthly sales and monthly average stock values, respectively. Which inventory policy should El.Ma adopt for product "locking release 24V"?

Table 1.30 Monthly sales and average monthly stock values (in €) of the El.Ma products.

ID product	Description	Sales	Stock value
1	Digital starter	25 356	980
2	Differential block 4P	147 800	3667
3	Land trolley	10 450	1174
4	HCS cable	65 980	2030
5	Engine control unit 380V CA	17 654	652
6	Contacter 24-60V CC	27 580	1721
7	Control builder	19 768	558
8	Universal dimmer	46 225	1015
9	BRI interface	8 766	775
10	Circuit breaker 10KA	80 350	3159
11	Motoadaptor	13 746	1100
12	OPC server	57 558	3111
13	Spring relay	7 852	733
14	Electronic delayer	9 785	724
15	Sectioner	32 400	894
16	Locking release 24V	12 328	1020
17	TMA360	15 980	1058
18	Control unit for release	11 900	1062