Chapter 14
Outbound Logistics and Distribution Management

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Abstract Distribution and outbound processes are important for many companies because they directly connect them with the customers in a value chain. Market and customer demands relative to quality, speed as well as information and service orientation of logistics processes matter in terms of overall evaluation and satisfaction. At the same time, there are significant cost advantages or disadvantages. In the trade and retail sector, this operational field is especially of high strategic importance and closely connected to e-commerce or multi-channel strategies. It can be said that all the excellence as well as product and service quality built up throughout the value chain can be delivered or destroyed within these last miles of distribution, point of sale, and customer contact. This chapter outlines the core definitions and objectives for outbound logistics and distribution management (Sect. 14.1) before providing an extensive case study for this specific topic (Sect. 14.2). It then provides the operational concepts for distribution in Sect. 14.3 (basic level). In Sect. 14.4 (advanced level), it describes differentiations in terms of multi-echelon inventory models and multi-objective concepts (service levels, cost optimization, batch and emergency deliveries etc.). Current trends and developments such as sharing economy and customer integration concepts as well as cooperation and new technologies are elaborated in Sect. 14.5 (state-of-the-art). Future topics for distribution management research are discussed briefly and further reading materials are listed in Sect. 14.6.

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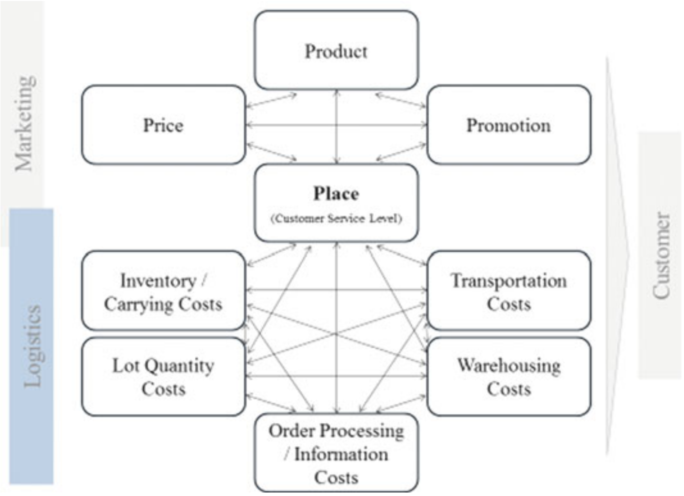

Fig. 14.1 Connectivity of marketing and logistics in distribution

14.1 Definition and Objectives in Outbound Logistics and Distribution Management

Distribution entails providing the customer of a value chain with the desired quantity, quality, and type of products specified in a customer order. Therefore, this function in the operations, logistics, and supply chain domain is of high importance as customer satisfaction, quality, service appeal, and brand quality are finally determined here.

The definition of outbound logistics and distribution management is connected to the "place" function in the strategic marketing concept ("4 P": Product, Price, Promotion, Place). Figure 14.1 outlines the interconnection of various fields in-between marketing and logistics, especially distribution.

Therefore, distribution is per se customer-centered and relates to the requirements and satisfaction of customers. Customers themselves can be different entities, from internal corporate customers to external corporate customers ("Business-to-Business—B2B") or external private customers ("Business-to-Consumer—B2C"). One exemplary *definition for distribution management* is[1]:

- *The planning, implementation, evaluation, and control of the physical movement of goods from a supplier or manufacturer to the point of sale and the customer, the connected information and financial flows as well as return flows of goods.* This includes the management of resources and processes used to deliver a product from a production location to the point-of-sale, including storage at warehousing locations, delivery to retail distribution points or customer sites or homes.

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[1] Compiled by the authors based on different descriptions, see for alternative explanations for example: Blanchard (2007), pp. 121ff); Hugos and Thomas (2006, pp. 34ff).

Distribution management also includes the determination of optimal quantities of a product for delivery to specified warehouses or points-of-sale in order to achieve the most efficient, sustainable, transparent, and satisfactory delivery to customers.

Distribution management is therefore an overarching, strategic concept that refers to a series of activities and processes such as packaging, inventory, warehousing, and transportation. Usually it involves establishing the following systems and processes among others:

- A *packaging* process with the connected packaging system to ensure secure shipping (avoiding damages to the goods as well as the environment). The reader is encouraged to read Chap. 13, which discusses packaging logistics.
- A set of distribution channels to distribute the goods directly from the manufacturer, or a manufacturer's warehouse, a third-party warehouse, or a third party who matches customer demand with manufacturing supply. Some of the questions that need to be addressed include: How many manufacturing plants and warehouses to locate? Where to locate them? How large should each be? What items should be produced or stocked at each location? What are the levels of production or inventory at each location? Models and algorithms are usually employed for addressing these problems.
- A *transport* system to move the goods to multiple geographical areas.
- A *tracking* system that ensures the right goods reach the right place at the right time in the right quantity.
- A system to *return* goods from retail partners and customers (reverse logistics). The reader is also encouraged to read Chap. 16 on closed loop supply chains.
- A continuous *evaluation* and tracking of places and retail channels where the product can be placed such that there is a maximum opportunity to distribute it to the customer (B2C).

Effectively managing the entire distribution process is critical to financial success and corporate survival. The larger a corporation or the greater the number of supply points a company has, the more it will need to rely on elaborate concepts and automation to effectively manage the distribution process. Furthermore, typical *objectives* within the field of outbound logistics and distribution management are:

- *Quality*: Quality from the customer perspective is an important objective as total customer satisfaction may largely depend on distribution quality ("place"). It may, for example, include the product being free from damages and according to the customer specifications. Quality preservation may also require strong consolidation (e.g., for fresh products) but also speed (e.g., the cut flowers distributed by Flora Holland (largest flower auction in the world lose some 10% of their value every day).
- *On Time and In Full ("OTIF")*: This key performance indicator (KPI) is measured by many companies in their inbound/supply section. It requires the ordered product to be delivered at the specified time according to the order requirements (quantity, packaging, and other requirements). In addition, private customers ("B2C") are

increasingly aware of this key service element. For example, a customer can select his or her parcel in e-commerce with specified delivery windows.[2]

- *Customer Satisfaction and Transparency*: Tracking and Tracing are important service features as well as a friendly and helpful support (phone/mail/chat hotline or other channels). Transparency in transportation cannot be rated high enough for its influence on total customer satisfaction.
- *Flexibility/Stability/Scalability/Resilience*: The implemented processes as well as systems within the distribution function have to be flexible (be able to accommodate changes in volume, destination, and product requirements) and stable given possible external shocks from weather incidents, strikes or other impacts. Furthermore, scalability, i.e., the ability to significantly increase or decrease processed and transported cargo volumes is required, especially in e-commerce environments where online orders of a product can skyrocket within minutes or hours (e.g., with a new book release, a new film or any social media news for example on fashion items). Finally, resilience as a further requirement also falls into this category, to ensure that the distribution system is able to withstand long-term as well as short-term changes. Examples include road toll introduction, emission legislation on vehicles, severe customer and market shifts or the impact of political events like embargos or even civil wars.
- *Cost-Efficiency*: The entire outbound and distribution system, including the other corporate and supply chain processes, must be cost-efficient. This implies the use of state-of-the-art technologies and automation, economies of scale, effective personnel and human resource (HR) management[3] as well as rigorous selection and cooperation processes for cost management amongst all distribution partners and suppliers as well as logistics service providers.
- *Sustainability and CSR*: Finally, societies and customers today also rightfully expect sustainable distribution solutions with a low carbon emission impact and reduction in noise, congestion, and smog. Thus, minimizing the ecological footprint and adhering to corporate citizenship as well as social responsibility principles are important considerations in outbound and distribution systems.

It must be recognized that the *deliver* "function" of distribution is repeated several times throughout the supply chain as depicted (see the two alternative versions of the SCOR model in Fig. 14.2). Thus, although we discuss the distribution field primarily from the point of view of the end customer in a supply chain, most concepts can be used also at other places and processes throughout the network of supply chain operations as depicted in Fig. 14.2. For example, the deliver function occurs several times throughout typical supply chain networks and therefore has multiple places throughout the supply chain operation.

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[2] See for example the DHL (http://www.dhl.de/en/paket/pakete-empfangen/paketankuendigung-wunschtag.html) or UPS solutions for private B2C customers https://www.ups.com/content/us/en/bussol/browse/personal/delivery_options/my_choice.html.

[3] See Chap. 10 on Human Resource and Knowledge Management.

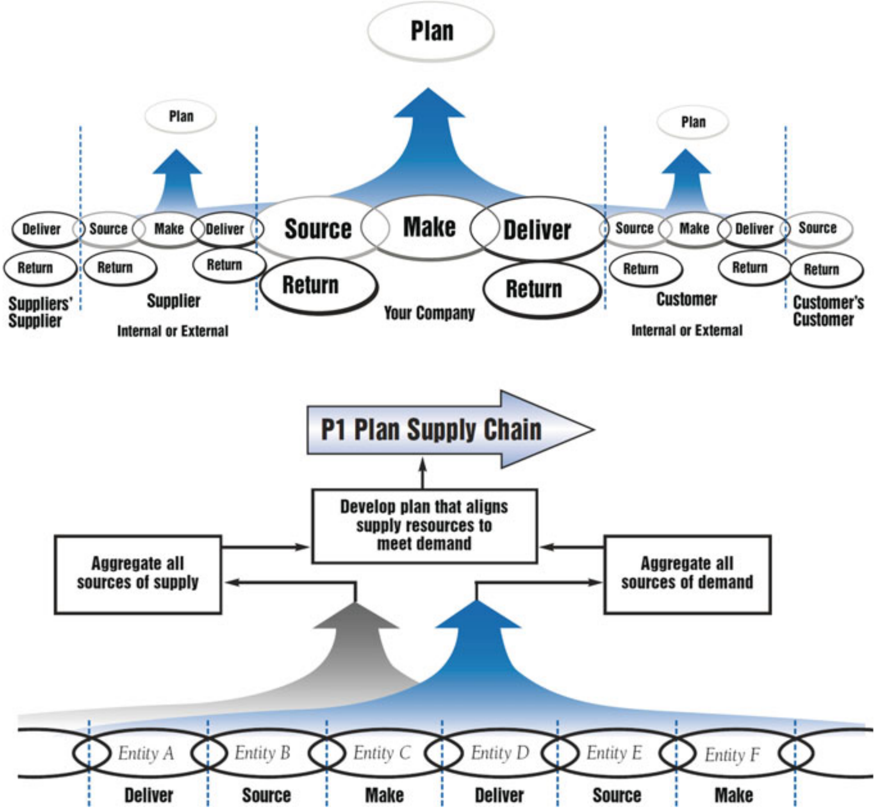

Fig. 14.2 SCOR model of supply chains (Supply Chain Council 2006, p. 3/22)

14.2 Case Study: Ann Inc.

Ann Inc., was founded in 1954 as Ann Taylor. It offers two brands—Ann Taylor and Loft, and is a retailer specializing in women's apparel, shoes and accessories. It operates over 1,000 retail stores in most states in the US and Canada. To stock and restock its retail stores, Ann Inc., has one warehouse located in Louisville, Kentucky (USA). The 256,000 square feet Distribution Center (DC) receives supplies from all over the world. More than 60% of the inventory is cross-docked. In other words, these items come into the DC from a factory in the Far East via container ships, rail and road, already packaged and labeled to be dispatched to one of the 1,000 retail stores. They are unloaded from the inbound truck, go through a sortation system and are loaded to a shipping truck without the item spending any time on a shelf in the DC. Some items such as a carton of T-shirts do, but wedding gowns come in from the factory already in a clothes hanger, go through a sortation system and are transported through the supply chain all the way to a retail store on a hanger. Some basic design and operational questions that arise in outbound distribution and logistics relative to a DC include:

- What percentage of the goods handled should be cross-docked?
- What material handling systems should be installed for sorting and moving the goods from inbound trucks to outbound trucks?
- How many part-time workers to assign in each month of the year?

Ann Inc., decided to locate its warehouse in Louisville, KY so that it could utilize UPS' extensive distribution network (with its only air-hub located in Louisville) and be able to ship packages to stores overnight. Because the retail stores are located in fashionable shopping districts where the cost to rent or lease retail space is relatively high, these stores wish to use more of their available space for item display than to maintain store inventory. As a result, these stores require replenishment of their inventory two or three times a week. It is the primary function of the DC to ensure the required items are delivered to each of the 1,000 stores as requested on time even though the factories may be located in multiple countries all over the world.

Because of the air-hub location, Ann Inc., can ship as late as 10 pm on a given day and be able to deliver to any of its US stores the very next day. Because storing items in a warehouse is a non-value added activity, Ann Inc., also prefers to minimize the time cartons containing high-value items spend time on storage racks and thus opts to cross-dock most—more than 60%—of its items even though they may be coming from as far away as China. Like most retailers, Ann Inc., faces significant demand fluctuation. Its DC activity tends to peak in the October–December time period. Thus, to keep labor costs down, it relies on seasonal employees to fulfill the orders. In order to ensure the availability of seasonal employees, Ann Inc., offers competitive wages as well as annual healthcare and retirement benefits. Of course, if an employee wants full-time employment, Ann Inc., will provide that to that employee, but he or she must be willing to work in all areas of the DC, not just in order picking in order to provide a reasonable level of flexibility.

As can be seen from the above example, distribution logistics covers a myriad of design and operational problems and each must be solved efficiently for the organization to succeed as a whole.

14.3 Core Concepts of Distribution (*Basic*)

14.3.1 Conceptual Definitions and Levels of Distribution Management

On a *strategic* ("macro") level—directly derived from the definition of distribution management and outbound logistics—a balance between four interlinked areas of distribution decisions must be taken. As depicted in Fig. 14.3, the *geographical reach and the markets* where products must be distributed have to be declared (in line with marketing strategies and concepts, e.g., if products shall be available and be delivered to South Africa). Next, the level and details of *delivery service* in the distribution domain must be determined. Some examples are listed below:

- delivery time(s)/standard, express and exceptional defined as the proposed time,
- customer communication and services, e.g., order acknowledgement, track and trace services of the delivery,
- standard packaging definitions to avoid damaged goods as well as exceptional packaging options,
- request and feedback services and times.

Third, elements of *differentiation* must be elaborated, e.g., how to differentiate in distribution from competitors. Finally, an efficiency and *rationalization* component needs to be outlined in order to keep the distribution cost levels in balance (e.g., where to use automated communication and transport applications).

On a *tactical* ("meso") level, additional decisions must be taken regarding the warehousing structure and points of distribution (see Fig. 14.4). In this case, interconnected determinations of the *vertical structure* ("How many levels of warehouses and distribution points?") as well as the *horizontal structure* ("How many warehouses per level, at what locations, with what specific functionalities, e.g., return processes?") of distribution must be determined.

Fourth, *cooperation and distribution partners* are selected and managed and fifth, *transport modes and vehicles* must be defined (e.g., selection of modes of transportation based on cost, time, and other considerations). Again, it must be stressed that all decision areas are interlinked, meaning that decision in one field will have an impact on other decision areas.

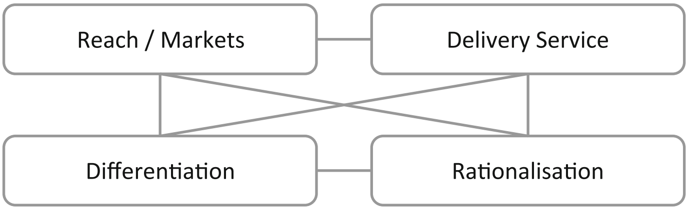

Fig. 14.3 Strategic ("Macro") decision fields in distribution

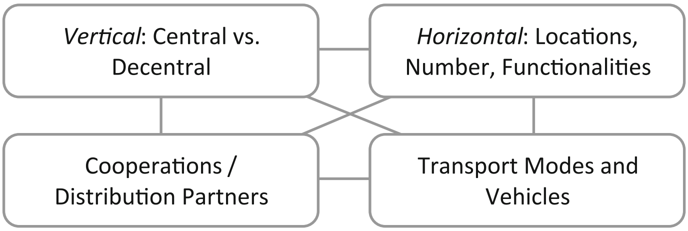

Fig. 14.4 Tactical ("Meso") decision fields in distribution

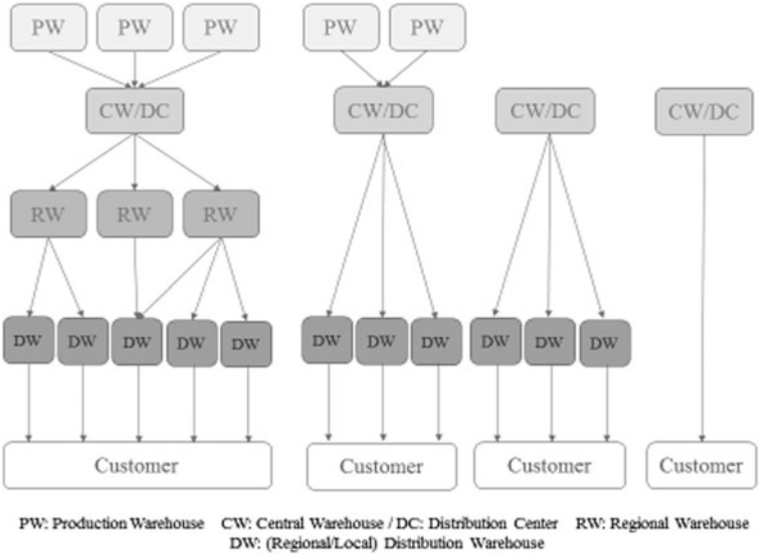

Fig. 14.5 Operational ("Micro") decisions and setup in distribution

On an *operational* ("micro") level, additional decisions must be taken regarding the specific setup and capacities of distribution points and warehouses. As depicted in Fig. 14.5, the structure of such distribution systems may be very complex when the product portfolios are large. Note that a typical retailer offers more than 10.000 stock keeping units (SKUs).

As the number of warehouses increases, the operating, inventory, and transportation costs curve changes as shown in Fig. 14.6. The planner thus needs to trade-off the various costs involved and determine the optimal number of warehouses to operate.

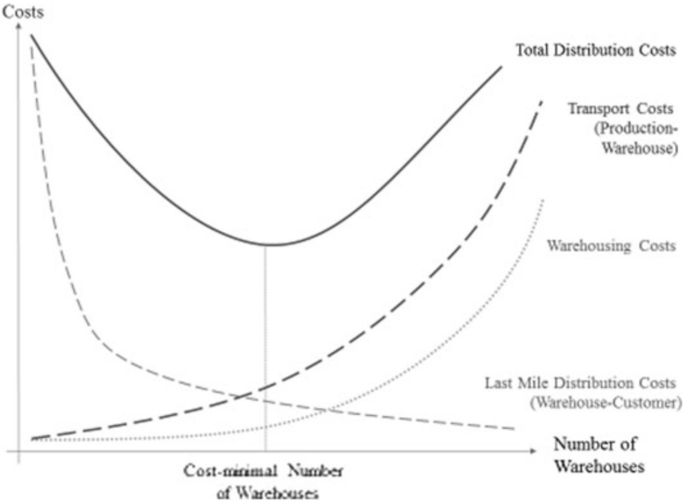

Fig. 14.6 Cost optimization problem in distribution

14.3.2 Additional Concepts in Outbound and Distribution

An important characteristic of a supply chain in general and especially "downstream" in the distribution phase, is the ***bullwhip effect*** (see Lee et al. 1997; Carranza Torres and Villegas Morán 2006). This recognizes *excess increases of order volumes* "upstream" due to information and transparency gaps between the supply chain actors. So, as depicted in Fig. 14.7, if the customer (or a group of customers) orders an increased level of product volumes at the retail *point of sale* (say in London, UK), usually without further information any (human) actor is prone to adding a security level for good measure in her/his own order volume with her/his supplier. This occurs several times throughout the chain, so that finally order volumes become disproportionately high at the most upstream producer and supplier entities (e.g., in Poland in the example in Fig. 14.7). This empirical recognition of excess logistics costs throughout the supply chain based on limited information and human behavior is utilized in a simulation and education game.[4]

An elaborate concept for cooperative distribution stemming from the retail sector is the ***Efficient Consumer Response (ECR)*** concept. This concept implies the *strategic cooperation* of producer and retailer in a consumer product area such as food, cosmetics or other fast-selling items; this is enabled by the *increase of transparency* by data sharing among supply chain partners (including the producer, suppliers and the retailer as well as logistics service providers). The key elements for this retail

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[4] Compare for example http://supplychain.mit.edu/supply-chain-games/beer-game or alternative simulations with other universities, e.g.: http://www.beergame.org or http://www.beergame.lim.ethz.ch.

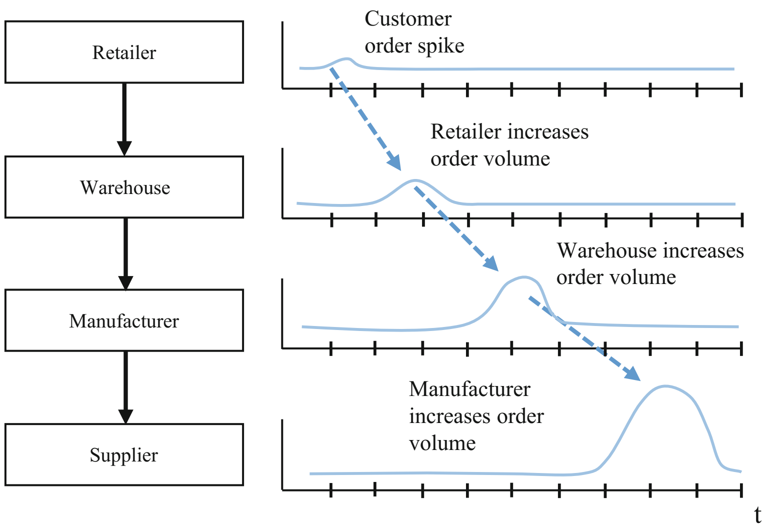

Fig. 14.7 Bullwhip effect

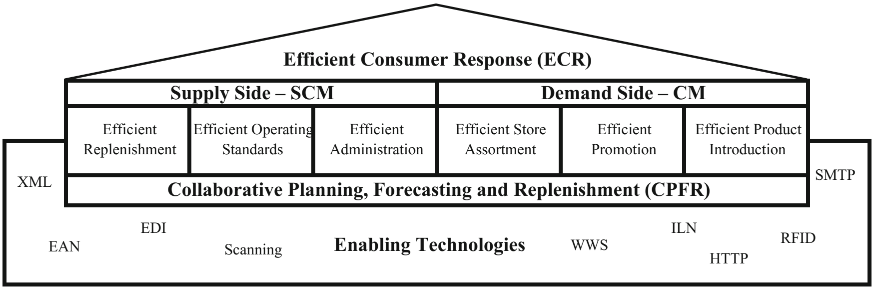

Fig. 14.8 Efficient consumer response concept

logistics concept—implemented and successfully adapted throughout many industries today—are depicted in Fig. 14.8.

On the Supply Side/Supply Chain Management (SCM) part of the ECR concept, there are three specific instruments to be used:

- *Efficient Replenishment* aims at furthering the quality and efficiency of all replenishment processes by using cross-dock concepts, the Continuous Replenishment Program (CRP) or Roll Cage Sequencing. CRP has the basic idea that long- and mid-term forecasts are shared among all the partners in a supply chain, enabling adaptation and alignment along the way. This could lead to a significant reduction of frictions and distorted or antagonistic forecast and replenishment decisions between supplier, retailer, logistics service provider or other entities in a supply chain.

- Furthermore, *Efficient Operating Standards* provide the option to use standardized sizes in order to optimize vehicle and storage use. For example in Europe, the cargo heights within trucks and warehouses are standardized for the EUL 1 (1.20 m) and EUL 2 (2.40 m) categories. This allows more efficient transport and storage of cargo, especially when all the partners in a supply chain adhere to these standards. Similarly, a product "base footprint" of 40 by 60 cm is defined in accordance with the European pallet size (120 cm × 80 cm), indicating that four base units can efficiently be put on one pallet.
- Finally, *Efficient Administration* provides the guidelines for further improvements in the management of the supply processes in the (retail) supply chain, e.g., by using *resource pooling systems* where different partners within the supply chain jointly use resources such as warehouses or transport vehicles.

On the Demand Side/Category Management (CM) part of the ECR concept, there are at least four specific instruments to be applied:

- The method of *Category Management* is structured within the realm of marketing addressing the question of how to organize the large portfolio of items offered to customers. To manage this, specific product categories are defined (e.g., the health and cosmetics section, the food category or the clothes category). This allows for a further use in structuring demand and supply and presenting items to customers.
- The *Efficient Assortment* concept elaborates on the preceding categories. The optimal mix of products and quantities offered in the retail system and stores are decided jointly by supplier, retailer, and logistics service partner, taking into consideration customer preferences, production, and transportation constraints as well as other factors.
- Within product development and *Efficient Product Introduction*, again the core value and principle of cooperation and coordination are assumed to be the basis for an efficient introduction process ("ramp-up") for new products on the retail shelves.
- In a similar manner, *Efficient Promotions* are guided by the principle that specific sales activities should be planned and executed jointly by all the supply chain partners. For example, production and delivery of special promotion products and advertising material within retail stores must be aligned with marketing and PR activities within the retail system.

There exist several specific instruments pertaining to the basic enabling technologies for ECR. Examples include:

- *Electronic Data Interchange* (EDI) systems and standards allow the supply chain partners to automatically share and distribute information on sales, stock and production volumes for an efficient alignment of downstream activities such as replenishment orders or production lot decisions.
- Additional instruments may include, systems and hardware standards, joint value evaluation and customer research or joint e-commerce initiatives of all supply chain partners.

These instruments within ECR are feasible and require the unrestricted cooperation of supply chain partners, especially on information exchange and transparency.

Finally, there are many ***quantitative outbound distribution problems*** in practice that involve *transporting goods from a warehouse to a customer* or from a manufacturing plant to a warehouse. In these problems, the objective is to *minimize* the cost of transporting the goods from their source(s) to their destinations, while satisfying demand and supply constraints (Fig. 14.9). A transportation model is typically applied in order to model such problems—an example is shown below.

Consider the following notation:

Parameters:

m	number of plants
n	number of warehouses
c_{ij}	cost of transporting a unit from plant i to warehouse j
S_i	supply capacity of plant i (in units)
D_j	demand at warehouse j (in units)

Decision Variable:

x_{ij}	number of units transported from plant i to warehouse j

The transportation model is:

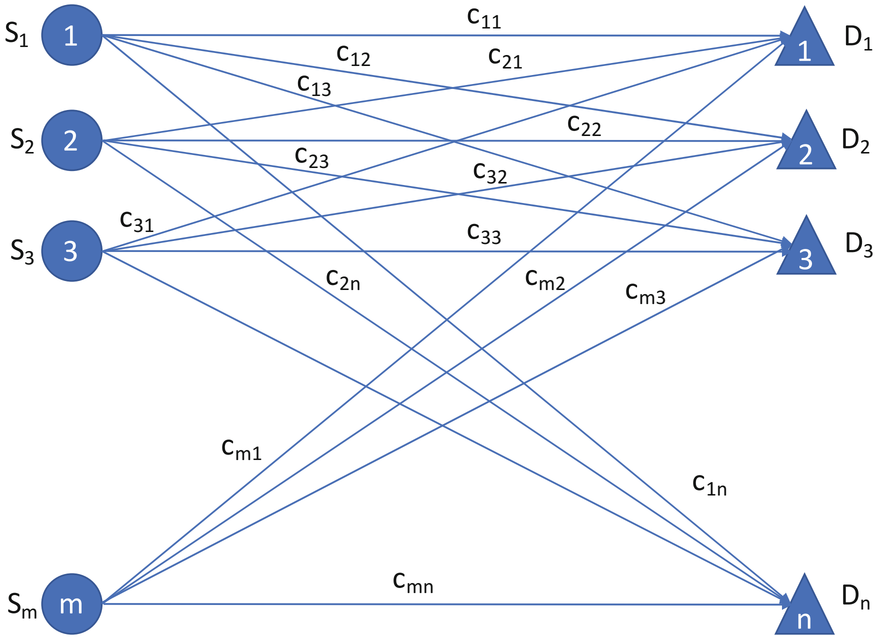

Fig. 14.9 Graphical representation of a transportation problem

$$\text{Model} \quad \sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij}x_{ij} \tag{14.1}$$

$$\text{Subject to} \quad \sum_{j=1}^{n} x_{ij} \le S_i \quad i = 1, 2, \ldots, m \tag{14.2}$$

$$\sum_{i=1}^{m} x_{ij} \ge D_j \quad j = 1, 2, \ldots, n \tag{14.3}$$

$$x_{ij} \ge 0 \quad i = 1, 2, \ldots, m; \; j = 1, 2, \ldots, n \tag{14.4}$$

The objective function (14.1) minimizes the total cost of transporting the goods from the plants to the warehouses. Constraint (14.2) ensures that the total number of units leaving each plant does not exceed its capacity. Constraint (14.3) ensures that the total number of units received at each warehouse is greater than or equal to the demand at that location. If the total demand equals the total supply, we have a balanced transportation problem. If the total demand exceeds the total supply (or the total supply exceeds the total demand), we can add a dummy plant (warehouse) that produces (absorbs) the excess demand (capacity) to convert the unbalanced problem to a balanced transportation problem. In the balanced transportation problem, all the inequality signs [$\le$ in constraint (14.2) and $\ge$ in constraint (14.3)] can be replaced by equality signs. Constraint (14.4) ensures that the number of units transported from each plant to each warehouse are nonnegative. Although integer restrictions are not imposed on the x_{ij} variables, it should be noted that these are automatically satisfied in the optimal solution provided the S_i and D_j values are all integers.

14.4 Multi-perspective Outbound Management (*Advanced*)

14.4.1 Location Analysis for Distribution

Embedded in outbound and distribution questions and concepts are usually a series of operational questions demanding a multi-perspective analysis and decision process. For example location decisions must be made. As seen in the case study in Sect. 14.2, these decisions involve estimating a series of cost and quality outcomes. Thus, location decisions must be made carefully. In the German mail distribution system example depicted in Fig. 14.10, a series of *warehouse and distribution locations* for the delivery of parcels and letters is necessary so that the customers are served with speed and flexibility, while keeping costs low, and operating in a sustainable manner by minimizing the pollution from transportation. Such locations are re-evaluated regularly, see for example Fig. 14.10.

For the mathematical analysis of transportation and location problems, the "Steiner-Weber-Problem" is formulated as follows—minimizing the transportation

Fig. 14.10 Location map for Germany/Mail System (DPDHL)

costs depending on the location decisions (*x* and *y* coordinates in a geographical setting. Note the similarity to the basic transportation model introduced in the previous section):

Model:

$$\min \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij} \omega_{ij} \sqrt{\left(x_i - u_j\right)^2 + \left(y_i - v_j\right)^2}$$

with the restrictions:

$$\sum_{i=1}^{m} \omega_{ij} \geq D_j \quad j = 1, \ldots, n$$

$$\sum_{j=1}^{n} \omega_{ij} \leq S_i \quad i = 1, \ldots, m$$

$$\omega_{ij} \geq 0 \quad i = 1, \ldots, m; \; j = 1, \ldots, n$$

Parameters:

m	number of originating locations
n	number of destination locations
x/y	coordinates of origin locations
u/v	coordinates of destination locations
c_{ij}	cost of transporting a cargo unit per distance unit
D_j	demand at destination j (in units)
S_i	supply capacity of origin i (in units)

Decision Variable:

ω_{ij}	number of units transported from origin i to destination j

14.4.2 Comprehensive Location-Allocation Model

In this section, we present a comprehensive production-distribution model that considers a real-world problem (see Geoffrion and Graves 1974). Multiple product types are produced at several plants with known production capacities. The demand for each product type at each of several customer areas is also known. The products are shipped from plants to customer areas via intermediate warehouses with additional restrictions, e.g., each customer area is serviced by only one warehouse to improve customer service. Upper and lower bounds on the capacity of each warehouse, potential locations for these, inbound and outbound transportation costs at each of these warehouses (i.e., from each plant and to each customer area), and the fixed cost of opening and operating a warehouse at each potential location are known.

The problem is to find the optimal locations for the warehouses, the corresponding capacities, the customers served by each warehouse, and how products are to be shipped from each plant, in order to minimize the fixed and variable costs of opening and operating warehouses as well as the distribution costs. Consider the following notation:

S_{ij}	production capacity of product i at plant j
D_{il}	demand for product i at customer zone l
F_k	fixed cost of operating warehouse k

V_{ik}	unit variable cost of handling product i at warehouse k
c_{ijkl}	average unit cost of producing and transporting product i from plant j via warehouse k to customer area l
UC_k	Upper bound on the capacity of warehouse k
LC_k	Lower bound on the capacity of warehouse k
x_{ijkl}	number of units of product i transported from plant j via warehouse k to customer area l

$$y_{kl} = \begin{cases} 1 \text{ if warehouse } k \text{ serves customer area } l \\ \text{otherwise} \end{cases}$$

$$z_k = \begin{cases} 1 \text{ if warehouse is opened at location } k \\ \text{otherwise} \end{cases}$$

$$\text{Minimize} \sum_{i=1}^{p}\sum_{j=1}^{q}\sum_{k=1}^{r}\sum_{l=1}^{s} c_{ijkl}x_{ijkl} + \sum_{i=1}^{p}\sum_{l=1}^{s} D_{il}\sum_{k=1}^{r} V_{ik}y_{kl} + \sum_{k=1}^{r} F_k z_k \tag{14.5}$$

$$\text{Subject to} \sum_{k=1}^{r}\sum_{l=1}^{s} x_{ijkl} \le S_{ij} \quad i = 1, 2, \ldots, p; j = 1, 2, \ldots, q \tag{14.6}$$

$$\sum_{j=1}^{q} x_{ijkl} \ge D_{il}y_{kl} \quad i = 1, 2, \ldots, p; k = 1, 2, \ldots, r; l = 1, 2, \ldots, s \tag{14.7}$$

$$\sum_{k=1}^{r} y_{kl} = 1 \quad l = 1, 2, \ldots, s \tag{14.8}$$

$$\sum_{i=1}^{p}\sum_{l=1}^{s} D_{il}y_{kl} \ge LC_k z_k \quad k = 1, 2, \ldots, r \tag{14.9}$$

$$\sum_{i=1}^{p}\sum_{l=1}^{s} D_{il}y_{kl} \le UC_k z_k \quad k = 1, 2, \ldots, r \tag{14.10}$$

$$x_{ijkl} \ge 0 \quad i = 1, 2, \ldots, p; j = 1, 2, \ldots, q; k = 1, 2, \ldots, r; l = 1, 2, \ldots, s \tag{14.11}$$

$$y_{kl}, z_k = 0 \text{ or } 1 \quad k = 1, 2, \ldots, r; l = 1, 2, \ldots, s \tag{14.12}$$

The objective function (14.5) minimizes the total cost of producing goods at the plants and transporting them to customers via warehouses. It also minimizes the fixed and variable costs of opening and operating the required number of warehouses. Constraint (14.6) ensures that the capacity constraints for making each product at each plant are not violated. Constraint (14.7) ensures that the demand of each product at each customer zone is met. Constraint (14.8) requires that each customer area is serviced by a single warehouse. Constraints (14.9) and (14.10) have a dual purpose.

Not only do they enforce the upper and lower bound on the warehouse capacity, they also “connect” the y_{kl} and z_k variables. Because a warehouse can serve a customer area only if it is opened, we must have $y_{kl} = 0$ for $l = 1, 2, \ldots, s$ if $z_k = 0$. If on the other hand a particular $z_k = 1$ for some k, then $y_{kl} = 1$ for the same k and at least one $l \in \{1, 2, \ldots, \mathrm{s}\}$. Constraints (14.11) and (14.12) are the usual nonnegativity and integer value constraints.

We can add more linear constraints not involving x_{ijkl} variables to the above model to:

- Impose upper and lower limit on the number of warehouses that can be opened;
- Enforce precedence relations among warehouses (e.g., open warehouse at location 1 only if another is opened at location 3); and
- Enforce service constraints (e.g., if it is decided to open a certain warehouse, then a specific customer area must be served by it).

Other constraints that can be added are discussed further in Geoffrion and Graves (1974). Such constraints reduce the solution space, and for this model, they allow a faster solution while giving the modeler much flexibility.

Real-world problems such as the Hunt-Wesson Foods, Inc. location-allocation problem considered in Geoffrion and Graves (1974), which had more than 11,000 constraints, 23,000 x_{ijkl} variables as well as 700 y_{kl} and x_k binary variables, have been rather easily solved using a modified version of Benders’ decomposition algorithm.

14.4.3 Transport Mode Analysis and Selection

A further complex decision within distribution systems usually is the question of transport mode as well as vehicle selection and fleet management. For many transportation tasks within distribution, the road is the premier mode of choice due to its flexibility. In fact, road travel is typically the only choice for the last mile delivery. However, when transporting via long distances or transportation, speed is important. Thus, other modes of transportation such as rail, ship, or air are utilized. Besides speed and cost, other considerations such as sustainability, transparency concerns, service supplier market power or domination, and other must be incorporated. For example, several companies such as Volkswagen or Mercedes are taking over distribution tasks from logistics companies due to the lack of quality or trust. Similar patterns occur in the other direction as well where logistics service providers operate distribution warehouses for their customers (e.g., logistics providers for Aldi and Samsung in Germany also manage their inventory).

Typically, transport mode analysis and decisions are derived from a set of *distinction categories* such as cost, distance, sustainability (carbon emission comparison by mode), speed or other specifics such as transport density as with the following example of a transport mode analysis for personnel transportation in an urban area (Fig. 14.11).

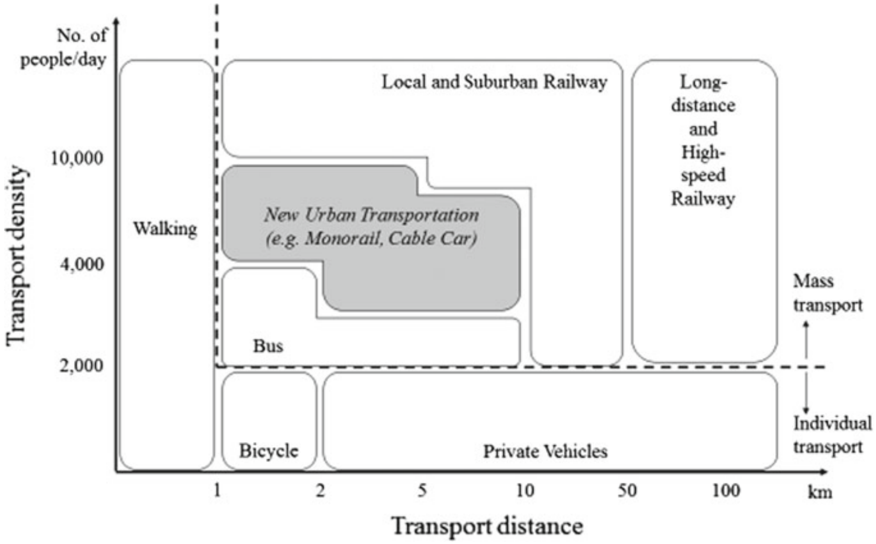

Fig. 14.11 Transport mode comparison (example passenger transport)

14.4.4 Vehicle Routing in Distribution

In this section, we present a model that is often used for outbound distribution management. It is used for last-mile delivery. Consider the problem faced by a parcel delivery company in its hub location. It wants to determine the number of vehicles required to: (1) serve its customers (pick-up or deliver parcels) so that each customer is visited once and only once per day, (2) the vehicle capacity is not exceeded, and (3) the total travel time is minimized. Using the notation provided next, we present the model in Chandran and Raghavan (2008) for the capacitated vehicle routing problem (VRP).

Parameters:

S_i	shortest time to travel from customer i to the depot, $i = 1,2,\ldots, n$
T_{ij}	shortest time to travel from customer i to customer j, $i, j = 1,2,\ldots, n$
D_i	demand at customer i, $i = 1,2,\ldots, n$
C	capacity of each vehicle

Decision Variables:

$$x_{ij} = \begin{cases} 1 & \text{if customer } j \text{ is immediately visited after customer } i \text{ in a tour} \\ 0 & \text{otherwise} \end{cases}$$

$$y_{ij} = \begin{cases} 1 & \text{if customers } i \text{ and } j \text{ are visited by the same vehicle} \\ 0 & \text{otherwise} \end{cases}$$

$$p_i = \begin{cases} 1 \text{ if node } i \text{ is the first customer visited in a tour} \\ 0 \text{ otherwise} \end{cases}$$

$$q_i = \begin{cases} 1 \text{ if node } i \text{ is the last customer visited in a tour} \\ 0 \text{ otherwise} \end{cases}$$

The VRP model is:

$$Minimize \sum_{i=1}^{n} S_i(p_i + q_i) + \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} T_{ij}x_{ij} \tag{14.13}$$

$$Subject\ to\ D_i + \sum_{j=i+1}^{n} D_j y_{ij} \leq C, \quad i = 1, 2, \ldots, n \tag{14.14}$$

$$y_{ij} + y_{jk} - y_{ik} \leq 1, \quad i, j, k = 1, 2, \ldots, n : i < j < k \tag{14.15}$$

$$x_{ij} - y_{ij} \leq 0, \quad i, j = 1, 2, \ldots, n \tag{14.16}$$

$$p_j + \sum_{i=1}^{j-1} x_{ij} = 1, \quad j = 1, 2, \ldots, n \tag{14.17}$$

$$q_i + \sum_{j=i+1}^{n} x_{ij} = 1, \quad i = 1, 2, \ldots, n \tag{14.18}$$

$$p_i, q_i, x_{ij}, y_{ij} = 0\, or\, 1, i, j = 1, 2, \ldots, n : i < j \tag{14.19}$$

The objective function (14.13) minimizes the total travel time to and from the depot as well as between the customers. Constraint (14.14) ensures that the sum of the demands at customers served by a vehicle does not exceed its available capacity. Constraint (14.15) ensures that if customers *i* and *j* as well as customers *j* and *k* are served by a truck, then, customers *i* and *k* must also be served by the same truck. Constraint (14.16) ensures that customer *j* can be visited immediately after visiting customer *i*, only if both customers are served by the same vehicle. Constraints (14.17) and (14.18) ensure that each customer is served by exactly one truck. Constraint (14.19) imposes (binary) integer restrictions on the decision variables.

Numerous heuristics are available to solve the VRP. See Bodin et al. (1983) for a survey of the various algorithms and models for this problem. Alfa et al. (1991) have proposed a combined 3-opt and simulated annealing algorithm for this problem. We will not provide any algorithm here, but recommend the reader to consult the above two sources for ways of solving the VRP.

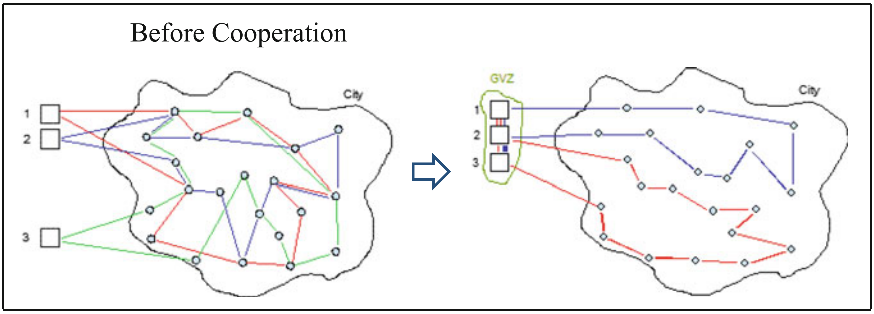

Fig. 14.12 Cooperative distribution for Urban areas

14.4.5 Last Mile and Urban Distribution

The last leg in distribution is usually known as the "last mile" delivery. This is critical for many highly populated urban areas, because congestion, availability as well as transport speed and flexibility and other factors must be considered. Cooperation among competitors (sharing transportation services or warehouse space among competitors) is one way to cope with these problems. Instead of travelling independently into urban areas as depicted in Fig. 14.12, cooperation among partners, consolidating shipments outside the city area and implementing an optimized tour plan within the city with fewer vehicles allows competitors to share resources and minimize environmental impact while meeting their own delivery requirements efficiently.

14.5 New Developments in Distribution (*State-of-the-Art*)

There are many developments taking place in logistics and distribution. Some of the innovative concepts are outlined in this section.

Third-party logistics is an increasingly important and successful business model for many companies. Consider United Parcel Services (UPS). Not only is UPS a distributor of goods, but it also manages inventory and provides value-added services for its customers. A few years ago, UPS was not only responsible for transporting Toshiba notebooks, but it also served as a repair facility. A customer who had to have his or her laptop repaired simply had to go to Toshiba's website, print out an address label, and drop it off for pick-up by UPS. UPS employees would then transport the laptop to their Louisville air-transportation hub, where a set of trained technicians (also UPS employees) would then repair the laptop and by the end of the day put the laptop back into the distribution network for delivery to the customer the next day. The same is true for many other modern-day logistics service providers such as FedEx, DHL, Schenker, Excel and others.

The Unilever warehouse in Beauvais, France, for example, has a fully automated warehouse in which DHL drivers load and unload pallets into an automated high rise warehouse. Autonomous vehicles (see Cai et al. 2014) then pick up these pallets, travel along guided rails and elevators to deposit pallets into their designated locations (see the red vehicles visible in the background in Fig. 14.13 and more clearly in Fig. 14.14). Once stored, the pallets are called as needed for order-picking in another part of the warehouse where robots put together customer orders also in a fully automated manner. Many forms of automation have been employed in the industry. Some technologies (e.g., the Kiva or Grey Orange robots) bring pods of items to the operator for picking, whereas others, e.g., the Savoye logistics system described in Chap. 15 as well as the Symbotic and the Swisslog mobile robots bring totes to the order picker. See https://www.therobotreport.com/news/goods-to-man-robotic-systems for additional details.

Amazon, for example, is experimenting with the delivery of individual orders directly to the customer using drones or unmanned aerial vehicles. While there are operational and regulatory hurdles that need to be cleared, this appears to be an important technology that can help with the last-mile delivery. Distributors find that they can manage long-haul distributions effectively using air, rail, road, and river systems, but the *last-mile delivery* is highly inefficient for a variety of factors including traffic, congestion of road networks, and involvement of humans in the last-mile delivery—not only truck drivers, but also customers who receive the package. For that reason, last-mile distribution is often considered the most expensive part of a distribution system. As a result, companies such as DHL are now experimenting using driverless vehicles or even robots for the last-mile delivery.

Fig. 14.13 An automated warehouse system (Savoye Logistics)

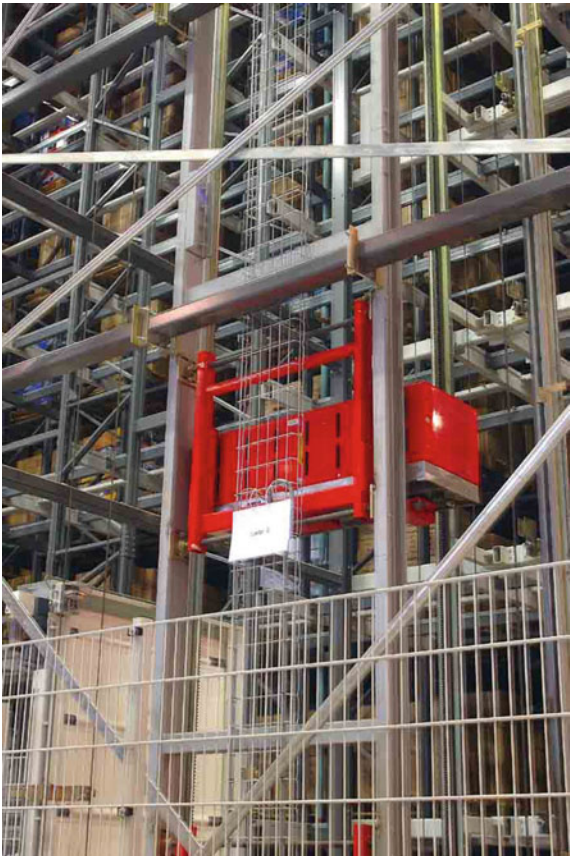

Fig. 14.14 Automated warehouse system using autonomous vehicles and lifts (Savoye Logistics)

A few of the many emerging topics in logistics and transportation are briefly mentioned below:

- New collaboration forms and sharing economy (buddy transport systems): Many trailers and containers travel fully or partially loaded one way and empty or almost empty in the reverse direction. By sharing information, it is possible to reduce empty or partially loaded travel.
- New functions and roles of 3PL/4PL are expected, e.g., in the essential areas of logistics cooperation and pooling of resources (warehousing) as well as optimization (see Wu et al. 2016). In this field, AI applications are also expected to have a major impact (also see Chaps. 24 and 28).
- Peer to peer-concepts are predicted to emerge and affect many transportation segments, for example by customer integration in delivery processes within the CEP sector (e.g., Uber).
- For distribution purposes on a global scale, we also expect significant regional changes in demand and volume patterns, e.g., the continuing rise of Intra-Asian transportation (e.g. from/to India), increasing importance of Africa and the Mid-

dle East for transportation as well as the impact of future trade agreements on transportation volumes (CETA/TTIP).

- Automated transportation will play a role especially in specific niche segments (delivery robots, drones); in Germany, for example Deutsche Post DHL is testing delivery robots (“PostBOT”) supporting mail delivery in urban areas.[5]
- Finally, there will be a prominent role for predictive analytics applications, especially for outbound distribution.

14.6 Outlook and Further Reading

In 2014, MHI convened a set of brainstorming sessions in four cities in the US (Atlanta, Chicago, Los Angeles, and Washington, D.C.) with more than 100 thought leaders from academia, industry, and government.[6] The charge to this group was to *predict logistics and distribution challenges* faced by the materials handling and supply chain industry in the year 2025 and to identify the technologies that would need to be developed in order to overcome these challenges. The deliberations of these groups led to the development of a roadmap. The societal, economic, and technological trends identified in the roadmap that will affect the state of the logistics and distribution in 2025 are:

- E-commerce growth,
- Competition,
- Mass personalization,
- Urbanization,
- Mobile and wearable computing,
- Robotics and automation,
- Sensors and the Internet of Things,
- Big data and predictive analytics,
- The changing workforce,
- Sustainability.

A number of the above topics have been briefly discussed in this chapter. We encourage the reader to consult the MHI roadmap for additional discussions on these topics. One of the topics that is mentioned as an addendum is 3D printing. Along with driverless vehicles (ground-based or aerial) and virtual reality, this technology will have significant impact on the logistics and distribution industry. There will be reduced need for transportation of small products and replacement parts, because these can now be made on a 3D printer. 3D printing also makes mass customization a reality. Chapter 23 discusses 3D printing and its impact on the supply chain and the reader is encouraged to review that chapter. Although many companies claim they

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[5] See: http://www.dpdhl.com/en/media_relations/press_releases/2017/new_delivery_robot_supports_mailmen.html.

[6] Compare: http://www.mhlroadmap.org.

Fig. 14.15 Logistics trend radar (DHL 2016)

are able to provide customized products to individual consumers, they only allow the consumer to select from a list of options, which when combined makes the product somewhat unique. On the other hand, 3D printing truly allows the customer to customize products to suit their physical attributes, taste, style, aesthetical requirements, and others. This will further revolutionize business, markets and value chains throughout all industries (Fig. 14.15).

Similar studies have been implemented for logistics in general, e.g., in Europe by DHL such as the “Delivering Tomorrow” scenario study (DHL 2012) or the “Logistics Trend Radar” (several editions, latest 2016, DHL 2016). The above figure outlines such a trend radar picture with an overview of relevant technology and society chances for logistics developments.

For further reading we also refer the reader to the following sources:

For more information on distribution in urban areas, see Antun (2016), Kant et al. (2016), Sakai et al. (2016) or Klumpp et al. (2014);
To address automation developments in distribution, see for example, Arendt et al. (2016) or Klumpp et al. (2013b);
For elaborate concepts in routing, we refer to Simchi-Levi et al. (2015);
For advances in distribution center management, see Cipres et al. (2014);
To explore supply chain and distribution risks in detail, see Klumpp and Abidi (2013) or Waters (2007);

Finally, for general trends and developments, refer to Speranza (2016), Novaes et al. (2014) or Klumpp et al. (2013a).

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