Chapter 21
Transportation Management

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Abstract This chapter provides an introduction to transportation management. In Sect. 21.1 we describe the ***basic*** elements of transportation network design, comprising the selection of modes, transportation units, loading units, and the timing of transportation. A brief introduction to intermodal transportation is used to illustrate the relevance of transportation management in modern logistics. With Sect. 21.2 we move to the ***advanced*** topic of orchestrating transportation via intermodal networks by introducing the concept of synchromodal transportation. Furthermore, it highlights several issues specific to contemporary long-haul transportation and last-mile transportation. Section 21.3 presents various ***state-of-the-art*** research trends related to the management of transportation in integrated networks. We discuss applications of multi-criteria analysis, multi-agent simulation, and conclude with research directions for the construction of the Physical Internet.

21.1 Transportation Network Design (Basic)

Demand for the transportation of goods arises from the fact that goods are typically not produced and consumed at the same location. Although the essence of transporting goods from one location to another appears to be trivial, identifying the best way to do so out of many possible options is not. This section aims to provide insights into the considerations that play a role in transportation management.

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The responsibility for arranging transportation does not always reside with the same actor. In addition, a single actor may have multiple roles within a supply chain. Typically, the transportation process starts with a *receiver* that places an order at a *shipper* resulting from a demand for goods. Based on the received orders, the shipper seeks to transport the goods to one or more receivers. The shipper may retain control of the process itself, transporting goods with its own resources, or hire one or more *carriers* to transport the goods. However, as shippers may lack the volume or logistics expertise to arrange transportation efficiently, they may also decide to outsource the shipment to a *Logistics Service Provider* (LSP). An LSP might be a carrier itself (known as a 3rd Party LSP or 3PL), but may also be an intermediate party without any (or with limited) physical transportation resources (known as a 4th Party LSP or 4PL). In general, higher volumes result in relatively lower costs due to economies of scale, allowing to identify better consolidation opportunities (bundling of goods) and to utilize transportation resources more efficiently. Although various parties may be responsible for the organization of transportation, they all share the common objective to reduce the transportation costs while complying with regulations and satisfying the required service levels. In the remainder of this chapter, we therefore refer to a *decision maker* who tries to optimize the transportation processes. We exemplify the complexity of transportation management with the following running example.

Example Case: Intermodal Transportation by a Dutch LSP

This case is based on the operations of a leading Dutch 4PL service provider active in the European transportation market. This company provides logistics services (i.e., transportation and warehousing) to its customers and has contracts with multiple carriers that have one or more modalities (e.g., truck, train, and barge) available to transport the goods. In this example, we consider several customers (receivers) located in Italy that ordered certain products from a number of producers located in the Netherlands. These producers (the shippers) all hire the Dutch 4PL to orchestrate their transportation activities. The transportation process starts in the Netherlands with a truck picking up the goods at these shippers, thereby consolidating the goods into a single shipment. However, instead of driving directly to Italy, the truck unloads at a nearby inland port to make use of so-called intermodal transportation (see Sect. 21.1.6). Subsequently, the goods are placed in a container and transported to Germany by a river barge, where the container is transferred to a freight train to Italy. After arrival at the train terminal in Italy, the individual shipments are delivered to the final customers using courier services. See Fig. 21.1 for an illustration. For details on the transportation planning decisions faced by this Dutch 4PL and how to support these decisions, we refer to Mes and Iacob (2016).

During the entire process, transportation must comply with legislation (cf. Chap. 7), anticipate possible disruptions, and meet the expected delivery dates of the customers, while preferably also yielding a profit in a highly competitive transportation sector. Achieving these objectives requires an advanced level of transportation management.

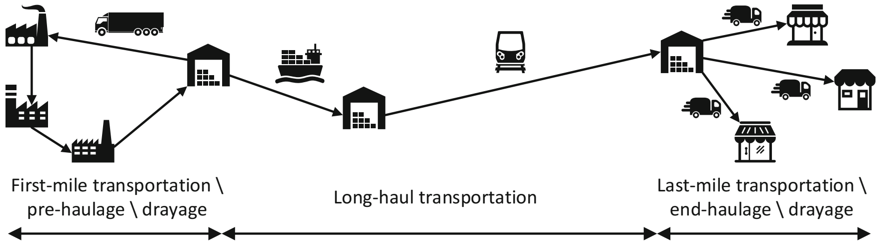

Fig. 21.1 Intermodal transportation example. Icons made by Freepik from www.flaticon.com

The scope of this chapter comprises the construction of physical routes and the selection and timing of transportation modes (e.g., truck, train, barge), thereby aiming to utilize the transportation capacity of the network as efficiently as possible by exploiting consolidation opportunities. By adopting this scope, we focus primarily on the tactical level of decision-making.

The outline of the remainder of this section is as follows. Section 21.1.1 introduces the basis structure of a transportation network. Section 21.1.2 provides some basic terminology for transportation networks. Section 21.1.3 discusses the selection of transportation modes, whereas Sect. 21.1.4 discusses the selection of transportation units (e.g., containers, trailers) and loading units (e.g., pallets, roll containers). In Sect. 21.1.5 we describe the role of timing in transportation management. Section 21.1.6 concludes this section with an assessment of intermodal transportation.

21.1.1 Basic Structure of a Transportation Network

A transportation network may be described as a set of available logistics services—including both transportation services and bundling services—that may be used to transport goods from origin to destination. In mathematical form, a transportation network is typically expressed as a graph $\mathcal{G} = \{\mathcal{V}, \mathcal{A}\}$, with the set of vertices $\mathcal{V}$ representing physical locations and the set of arcs $\mathcal{A}$ signifying transportation services. The vertices $\mathcal{V}$ may be divided into subsets of origins, transfer hubs, and destinations. Here, origins are the pickup points of goods (e.g., factories or warehouses), transfer hubs are points at which goods may be transferred from one transportation mode to another (e.g., ports or railway depots), and destinations are points at which the goods must be delivered (e.g., retailers or households). The role of transfer hubs is twofold; they may allow to switch transportation units from one mode to another (e.g., lifting a container from a ship onto a train), but also to split and bundle goods within individual containers or trailers. Transportation management may relate to direct transportation, i.e., transportation from origin to destination without transfers, typically using trucks, as well as to transportation that utilizes transfer hubs, typically to combine truck with barge and train. The focus of this chapter is primarily on the latter.

The network vertices are connected by arcs that represent transportation services. Without any design efforts, a transportation network might be modelled as a complete graph in which all vertices are directly connected to each other, corresponding to a network in which goods can be transported following the shortest path between any two locations (typically using trucks). However, transportation over longer distances often requires the use of transfer hubs. Direct transportation between individual customer locations is often a financially unattractive option that may safely be omitted from the graph without sacrificing the solution quality. Therefore, realistic transportation networks are typically represented by incomplete graphs; the decision maker must choose a suitable route that connects origin and destination by selecting a connected path of arcs in such a graph.

We can represent certain characteristics of a mode by defining them as arc properties. Such properties may include, e.g., departure times, travel speeds, costs, emissions, and idle load capacity. Similarly, we may allocate additional properties to vertices, such as handling times and storage capacity. An important modelling decision is whether to represent the transportation network by a *time-expanded* graph or a *time-dependent* graph. Time-expanded graphs represent time properties by separate arcs or vertices, e.g., each train departure on a given line is represented by a unique arc. Time-dependent graphs are defined only in space and use functions to incorporate time properties, e.g., train departures are then reflected by adding a timetable property to the arc. Transportation management requires graphs to be sufficiently detailed to make informed decisions with respect to allocation and timing, but typically omits high-level details that are required on the operational and real-time levels of decision making, such as congestion information.

21.1.2 Terminology of Transportation Networks

Transportation networks can often be divided into various segments or network subsets, often with vastly distinct characteristics. For example, intercontinental shipping services and delivery tours in the city are subject to significantly different planning considerations. Such segments are often characterized by their own terminology and research branch. In this section, we introduce some basic terminology of transportation networks.

Long-haul transportation is freight transportation that takes place over a long distance. What exactly is considered ‘long’ depends on the context of the transportation. In our example case, we may consider the non-truck segment from the Netherlands to Italy as the long haul. However, also the transportation between two cities located only a few hundreds of kilometres apart might qualify as long-haul transportation. Typically, when we refer to the long haul, we consider a distance that is sufficiently long to consider transportation modes other than truck; transportation management on the long haul often includes transportation by trains and vessels.

Short-haul transportation or *drayage* is transportation taking place over a short distance, often referring to a segment of a longer transportation move. Again, what exactly qualifies as 'short' depends on the context. In intercontinental transportation, the last part of the transportation route might comprise the drayage segment between the port and the customers and producers in the so-called *hinterland* (the area served by this port, which may still be of a considerable size). In parcel transportation between two cities, it might relate to the final delivery tour within the city center. Drayage operations from the origin to the first transfer hub is referred to as *first-mile transportation* or *pre-haulage*. Similarly, drayage operations on the route segments from the last transfer hub in the route to the destination is known as *last-mile transportation* or *end-haulage*.

When planning routes, it is often not necessary to consider all available transportation services. In our running example, the decision maker would not consider to ship goods from the Netherlands to Italy via, e.g., Norway. Instead, the planning focus would be on a subset of the transportation network that is generally oriented from the Netherlands to Italy. Such subnetworks are known as *corridors*, which may be defined as sets of (contracted) transportation services that connect two areas with a high volume of transportation flows between them.

21.1.3 Selection of Transportation Modes

In the selection of transportation modes, decision makers must take into account various metrics. Aside from the costs of each option, factors such as the service level required by the receiver, environmental goals, and reasons of competitiveness may play roles in determining the most suitable modes. We describe five of the most common forms of transportation (Davidsson et al. 2005).

• *Pipelines* are used to transport continuous physical flows of liquids or gases. Although high capital costs are required to construct a pipeline, the variable costs of pipeline transportation are low. They are therefore suitable for transporting high volumes between fixed locations during longer periods	
• *Waterway transportation* is the transportation of goods by a ship via sea or inland waters. It is typically the cheapest transportation option for goods that cannot be transported by pipeline, but suffers from low travel speeds and the inaccessibility of many destinations. The sizes of ships vary greatly, with the largest sea vessels being able to carry well over 10,000 containers	

• *Railway transportation* is executed by train over the railway network. Most cargo trains are able to carry over 200 containers, typically against lower costs than road transportation. In addition, it is significantly faster than waterway transportation. However, trains offer low flexibility, as they can only unload at stations located in the railway network. In addition, as trains share a dedicated infrastructure, railroad transportation is limited by the availability of time slots	
• *Road transportation* is conducted via the road network. A variety of road vehicles may be used for this, varying from trailer trucks to cargo bikes. Virtually every location can be visited via the road network. However, the costs of road transportation are relatively high. As many locations are inaccessible by train or ship, road transportation typically comprises at least a part of the route. The high flexibility of road transportation still makes it the most common form of transportation	
• *Air transportation* is typically conducted by airplanes (an exception are the helicopters used, e.g., for oil rigs and wind turbines). The high speed of this mode is its chief benefit, yet the costs associated with this mode are high as well. Thus, this mode is typically used only when high service levels (e.g., rapid intercontinental delivery) are required. Cargo transportation by air requires the use of airports, the number of locations that may be reached directly by plane is therefore limited	

21.1.4 Selection of Transportation Units and Loading Units

Aside from the selection of arcs and modes, the decision maker must also determine which transportation units and loading units to use, taking into account the handling requirements during the transportation (Bektaş 2017).

Transportation units are the devices used to contain and transport goods, most commonly containers or trailers. *Containers* are standardized transportation units that can be transported by trains, ships, and trucks; their size is often expressed in TEU (Twenty Feet Equivalent Units, leading to a volume of 38.5 m^3). Most regular containers measure 2 TEU. Due to the standardization of containers, handling, storage, and transportation can be organized in an efficient manner. By using cranes, full truckloads can be loaded or unloaded with a single lifting- or lowering operation. In addition, containers can be transported efficiently by ships, since they can be stacked. *Trailers* are transportation units on wheels that can be connected to trucks and can be rolled on and off ships and trains, allowing for a seamless integration. However, unlike containers, they cannot be stacked. Besides these two basic transportation units, it might be necessary to take into account other units or specific enhancements to transportation units. For example, liquids such as gasoline are often transported by dedicated tank units. Food often needs to be cooled during transportation, requiring special containers or trailers with cooling systems. In addition, the (un)loading capacities at hubs and receivers must be taken into account. For example, a small retailer may not have a ramp or forklift at its disposal, in which case the trailer might need to be equipped with a tailboard to unload the goods.

On a smaller scale, we distinguish between various *loading units*. Goods may be transported in many different forms, e.g., in the form of boxes, crates, reels, barrels, or bags. Individual items are often combined in loading units such that they become easier to handle. The most commonly used loading units are *pallets*. Pallets allow bundling a variety of individual items and, due to their standardized form, can be handled easily by forklift trucks or pallet jacks. Other common loading units are *roll containers*. Unlike pallets, roll containers can be handled without dedicated equipment, allowing more convenient handling for some users. However, in terms of spatial utilization they are typically less efficient. The choice of loading unit may change during the execution of transportation. For example, a batch of parcels may be shipped on pallets, but broken down into individual parcels before the final delivery to end-consumers takes place.

A relevant distinction exists between *Full-Truck Load* (FTL) and *Less-than-Truck Load* (LTL) transportation. For FTL transportation, consolidation may take place on the level of the mode, e.g., by placing as many containers on a freight train as possible. On the LTL level, consolidation might take place within transportation units, e.g., by combining two half truckloads into a single trailer at a transfer hub.

21.1.5 Timing of Transportation

In addition to the selection of the physical route properties and resources, another important aspect of transportation management is the dispatch timing. The time to dispatch certain goods should be determined for each vertex in the route. Returning to our case, any new order received from Italy may directly be dispatched, resulting in the quickest delivery. However, the decision maker might want to wait with dispatching until, e.g., a container is completely filled with goods destined for Italy, thereby optimally utilizing the transportation units. On a larger scale, the barge sailing from the Netherlands to Italy might want to wait until all its container slots are filled. However, one must also take into account the reliability of the transportation service and the timeliness of deliveries. Therefore, dispatch timing is essentially a trade-off between timeliness, reliability, and efficiency.

With respect to dispatch timing, a key distinction is made between static planning and dynamic planning. In static planning, all shipments are known in advance, allowing to optimally allocate them to resources over time. In dynamic planning, shipments are gradually revealed during the execution of the transportation processes (or alternatively, other time-varying circumstances, such as travel times, forced re-planning over time). Practical settings are typically characterized by dynamic characteristics, although the planning itself may still be performed statically over a given time horizon (e.g., periodically). In a dynamic setting, dispatch decisions must be made without fully knowing how they affect future decisions. Thus, one may decide to ship a container that is only half filled, not knowing that another large shipment request that could fill up the container will arrive the next day. To improve the dispatch timing decisions, decision makers might anticipate future requests, e.g., based on historical data.

Another relevant aspect of dispatch timing is the uncertainty embedded in the transportation network, e.g., variable travel times or the possibility of disruptions. Although delaying dispatch as long as possible might aid in identifying new consolidation opportunities, it eliminates the flexibility to anticipate disruptions, which may lead to due date violations. In case of transportation with transfers, delaying shipments upstream might reduce consolidation opportunities at the downstream transfer points.

21.1.6 Intermodal Transportation

In the previous sections, we have discussed the selection of modes, transportation units and loading units, as well as the dispatch timing. In transportation management, these decisions are often integrally made, attempting to maximize efficiency while meeting targets for timeliness and reliability, and complying with other constraints (e.g., legislation and environmental goals) that may play a role. Such decisions are particularly complex when considering flexibility in modes, dispatch times, and transfer options.

Various definitions exist on the concept of *intermodal transportation* and the closely related terms *multi-modal transportation and co-modal transportation*, see, e.g., Crainic and Laporte (1997), Janic (2007), and SteadieSeifi et al. (2014). In this chapter, we rather broadly define intermodal transportation as the practice of using one or more transportation modes—with modes that may be of the same type or different—to transport containerized goods from origin to destination, using transfer hubs to connect the modes and facilitate consolidation of goods. Examples of transportation forms falling under this definition are (i) goods transported by two distinct trucks, swapping the container at a transfer hub where additional goods are loaded in the container, (ii) a container transported partially by train and partially by ship, and (iii) goods delivered by a single truck while having other realistic transportation options available as well.

By considering multiple modes, one may take advantage of the benefits of a specific transportation mode. For example, a large barge can hold hundreds of containers; clearly sending a single barge from the Netherlands to Italy is more efficient than hundreds of trucks. From the last transfer hub onwards, we can benefit from the flexibility of trucks to reach all customer locations. Another benefit of using multiple modes is that it may facilitate the bundling of goods for only a part of the route, e.g., goods from the Netherlands destined for Germany may be combined with goods destined for Italy on a part of the route, as they are transported in the same direction.

Although intermodal transportation has distinct benefits, it also introduces several challenges. Switching modes requires physical transfers of transportation units or loading units (e.g., at a port or consolidation centre), introducing additional costs to the transportation process. To achieve a financial benefit, these costs should be compensated by a higher transportation efficiency. The shorter the distance between origin and destination, the more challenging it is to compete financially with direct transportation (Janic 2007).

Intermodal transportation also introduces various planning challenges. The first is the mode selection. As discussed before, each mode has its own benefits and drawbacks, with the primary trade-off being between costs and service level. Furthermore, transportation units and loading units should be chosen such that they allow for efficient handling between modes. Finally, at each vertex in a route multiple dispatch timing decisions might be made. The combination of all these options may result in a high number of possible schedules. In such complex environments, high-quality transportation management is essential to meet the high financial, environmental, and service standards that are commonplace in contemporary logistics.

In practice, the complexity of intermodal transportation is partially mitigated by fixing various options in transportation contracts. For example, a shipper may agree a fixed price to ship a given number of containers per train every month, or agree to use a specific transportation mode. As a result, traditional intermodal transportation is mainly concerned with decisions on the strategic and tactical levels. Although contracting reduces uncertainty in the network and simplifies planning, it also results in sub-optimal use of transportation networks and ignores operational circumstances that might prompt alternative decisions. In Sect. 21.2, we define synchromodal transportation, which focuses on the flexible use of intermodal networks and therefore prompts a shift towards operational and real-time decision-making.

21.2 Design of Integrated Transportation Networks (Advanced)

As discussed in Sect. 21.1, intermodal networks embed the potential to manage transportation more efficiently than direct transportation allows. Although intermodal transportation is far from a new phenomenon, optimizing the use of intermodal networks might well become a necessity due to recent trends in logistics. Developments such as e-commerce and lean storage management result in smaller, more fragmented, and more frequent shipments, which—especially when coupled with higher service standards—make it more difficult to efficiently utilize transportation resources. Many individual decision makers have reached the limits of what is achievable by optimizing their internal processes; to make improving steps, cooperation with other actors is of vital importance. By sharing resources, information, and shipments, higher efficiency gains might be attained than achievable by individual actors. To facilitate such gains, the establishment of transfer hubs and efficient operations for (un)bundling goods are essential. The increasing shift from direct transportation towards intermodal transportation also has a notable impact on the scope of transportation management.

Aside from the financial motivations to improve transportation efficiency, the negative effects that freight transportation has on the environment and the society are becoming increasingly relevant. The fragmentation of freight flows, growth of the overall population, and higher living standards are key drivers behind the growing number of transportation movements, amplifying the negative side effects of transportation. From an environmental perspective, emissions are the chief hazard of freight transportation. Greenhouse gases are known to contribute to climate change, whereas other emissions have polluting effects on the environment. Important societal effects are the negative contribution of transportation to congestion, the effects of emissions on health, noise hindrance, and reduced traffic safety. New legislation is continuously being developed to encourage or enforce decisions that take into account environmental aspects; also, companies themselves become more concerned with an environmentally sustainable business and corresponding image. Thus, transportation decisions are no longer made from a purely financial perspective. A decision maker might for example prefer barge transportation to road transportation due to the lower emissions per container.

Section 21.2.1 discusses how the concept of synchromodal transportation is used to utilize intermodal networks more efficiently. Section 21.2.2 focuses explicitly on long-haul transportation in modern logistics, whereas Sect. 21.2.3 focuses on last-mile transportation.

21.2.1 Synchromodal Transportation

The term 'synchromodality' is relatively new in the world of transportation. *Synchromodal transportation* might be viewed as an extension of intermodal transportation in which the aim is to select the best combination of modes for each individual shipment. Unlike traditional intermodal transportation, synchromodal transportation is also not restricted to containerized transportation only. Synchromodal transportation focuses explicitly on seamless connections between modes and a high degree of flexibility based on the prevailing circumstances in the network (Tavasszy et al. 2015). As noted before, traditional intermodal transportation typically involves contractually fixed transportation flows. Although this reduces the uncertainty in the network and simplifies planning, it also results in sub-optimal use of the transportation network and ignores operational circumstances that might prompt alternative decisions.

As synchromodality implies a large degree of freedom in selecting the best solution for each individual shipment, this concept is challenging from a transportation management perspective. We divide our assessment of managing synchromodal networks into three categories: physical management, information management, and financial management.

With respect to physical management, we may distinguish between offline planning and online planning. *Offline planning* is concerned with the construction of a transportation network with sufficient flexibility to facilitate synchromodal transportation. Typically, a single party does not own a transportation network of the required magnitude, such that a suitable network usually consists of own transportation modes and transfer hubs as well as subcontracted transportation resources (Van Riessen et al. 2015). From a transportation management perspective, the key challenge is to construct a network that is dense both geographically and with respect to timing, such that the decision maker can truly take advantage of planning flexibility. However, the complexity of managing the network also increases with its temporal-spatial density. The construction of transportation networks over space and time is known as *Service Network Design*; we refer to Crainic (2000) for a detailed description. *Online planning* focuses on the actual routing of individual orders transported via the synchromodal network. As each order is individually planned based on the prevailing state of the network, traditional manual planning is often too time-consuming for synchromodal planning. Efficient algorithms are indispensable to quickly identify good routes and respond to disturbances. To this end, Bock (2010) presents a method based on local search principles, explicitly focusing on planning in a real-time environment. The ability to respond to disruptions during the execution of routes clearly contrasts with traditional intermodal transportation. Another synchromodal planning algorithm is presented by Mes and Iacob (2016). They describe a constructive algorithm that efficiently plans synchromodal transportation, proposing a solution method based on the k-shortest path problem. This approach may be used to present multiple high-quality solutions to a human planner, allowing the planner to address possible considerations not reflected in the mathematical model, without having to deal with large numbers of solutions manually.

The second category to be discussed is information management. To offer the desired flexibility of synchromodal transportation, decision makers must be able to respond rapidly to changes in the network. Therefore, the real-time exchange of timely and accurate information is essential. Examples of information relevant for transportation management are the idle capacity of modes, order properties, delays in travel time, and disruptions at transfer hubs. Singh (2014) describes an outline for an IT platform facilitating synchromodal transportation, stating that much work still needs to be done to achieve such a generic platform.

The third and final category that we address here is the financial perspective. Traditionally, transportation is paid per utilized transportation mode. In synchromodal transportation, modes are not selected in advance, yet it is eminent that potential additional costs for the sake of system-wide efficiency (e.g., a detour to warrant higher container utilization) should not be charged to individual shippers. In addition, many shippers are cautious or reluctant to hand over control of the transportation process, preferring to have a high degree of autonomy in arranging their transportation (Van Riessen et al. 2015). To overcome these barriers, shippers must be provided with the proper incentives to consider synchromodal transportation. Revenue management based on desired service levels is already common in sectors such as the airline industry. In freight transportation, comparable pricing mechanisms are less widespread.

21.2.2 Long-Haul Transportation

In Sect. 21.1, we pointed out that there is no fixed definition of the distance that constitutes long-haul transportation. In the context of intermodal transportation, we might argue that the distance should be sufficiently long to consider reasonable alternatives to direct transportation. The minimum distance for intermodal transportation to be financially competitive with direct transportation is believed to be a distance somewhere between 300 and 500 km (Wagener 2014). Developments in automated handling and information exchange might cut costs in the future and thereby reduce the minimum required distance.

When viewed from a holistic perspective, managing long-haul transportation is not only concerned with routing decisions. Aspects that also must be managed are, e.g., the positioning and distribution of empty containers, the assignment of crews to modes, fuel management, and the frequency of long-haul services (Crainic 2003). Such decisions should be made integrally to create a balanced long-haul transportation network that is aligned with the expected transportation flows. While fleet management is already challenging for individual carriers, the challenges become even more pronounced when considering cooperation with subcontractors. Coordination, pricing, and risk control are essential factors in integrated fleet management.

An aspect of long-haul transportation that we highlight here is the influence of regulation on transportation management. On the one hand, liberation of markets, globalization, and alignment of national regulations have made it easier to arrange cross-border transportation. On the other hand, regulations with respect to safety and the environment have become more stringent. Examples of regulations affecting transportation management are break schedules and rest periods of drivers, the availability of track capacity for railroad transportation, and the restrictions of maritime law on vessel operations. These topics exemplify the complicating effects that regulation has on transportation management.

We conclude this section with an example of transportation management in long-haul transportation. Van Heeswijk et al. (2016) study the dynamic selection of long-haul services in intermodal networks (trucks, barges, and trains) for LTL goods, and present a methodology to support this decision. For each incoming transportation request, the proposed methodology picks the k best paths out of a large number of potential solutions and subsequently checks for possible consolidation opportunities within containers. Routes may be replanned (if not already started) to allow the consolidation of goods and to cut the overall transportation costs, taking advantage of the bundling capacity of transfer hubs. Aside from financial concerns, mode speeds and emissions per route may play a role in the decision. This example illustrates how the variety of transportation modes and the presence of transfer hubs can be utilized for more cost-efficient and environment-friendly long-haul transportation.

21.2.3 Last-Mile Transportation

In this section, we discuss transportation management considerations in last-mile transportation, with a focus on last-mile transportation in urban environments. Although we only discuss last-mile transportation here, similar considerations play a role in first-mile transportation.

Last-mile transportation covers only a small part of a transportation route, yet it accounts for a disproportionally large part of the total transportation costs (Gevaers et al. 2011) and poses significant challenges. Due to slow and congested traffic, as well as many pickup and delivery stops that require handling operations, last-mile transportation is time-consuming and fuel-inefficient (e.g., due to bridges with weight limits and access time constraints). In addition, environmental and societal concerns weigh heavier on the last mile. Various emissions—such as SO_X, NO_X, and particulate matter—have strong local effects on health and the environment that become more pronounced in densely populated urban areas. Societal concerns include safety, noise hindrance, and congestion. Therefore, there is increased pressure to arrange last-mile transportation in a way that is both efficient and environment-friendly.

Heavy trucks are efficient modes for transportation over longer distances, but in urban environments, where last-mile transportation typically takes place, their drawbacks become severe (Dablanc 2007). Therefore, we might prefer to deploy smaller, more environment-friendly vehicles, such as electric vans for deliveries within the city. Sometimes, such a change of transportation mode might even be enforced, e.g., due to a ban on certain trucks within the city center (e.g., trucks that do not meet certain engine requirements). Thus, we might want to decouple the freight flows stemming from the long haul at a transfer hub, which has the additional advantage that goods from different inbound trucks may be bundled, allowing for more efficient last-mile delivery routes.

A common solution to reduce the number of heavy trucks in urban areas is the concept of *urban consolidation centers*. These transfer hubs are typically located at the edge of urban areas, where inbound trucks may unload the goods destined for the city. At the hub, goods are subsequently bundled and delivered with smaller vehicles such as delivery vans or electric cargo bikes. The planning problem faced by the transfer hub is twofold, as it must (i) plan routes in a complex environment with congestion, delivery windows, and possible access constraints and (ii) decide on the dispatch timing, anticipating future consolidation opportunities. An algorithm for the congestion routing problem with delivery windows is presented by Kok et al. (2012). This model takes into account the variation in travel speeds as a function of the time of the day, allowing to create congestion-avoiding routes. As a result, service levels may be increased and costs may be decreased. The dispatch timing problem is addressed in Van Heeswijk et al. (2017b). In this study, goods arrive at the transfer hub from the long haul. The hub operator seeks to bundle and deliver these goods as efficiently as possible, but does not know in advance, which goods arrive or when exactly they arrive. Thus, in the timing of dispatch, the operator has to consider the potential customer locations, delivery windows, and the volume of goods. Based on the expected arrival process, the operator is able to construct dispatching policies that take into account future consolidation opportunities. Dellaert et al. (2016) argue that for larger cities, a single consolidation center does not suffice to arrange last-mile transportation effectively, instead opting for multi-echelon systems that typically contain one layer of consolidation centers and one layer of smaller satellite facilities. Mega-cities may even require more than two layers of transfer hubs. Such structures are challenging to handle from a transportation management perspective, as they require highly integrated decision-making with respect to facility selection, dispatch timing, and mode selection.

Besides last-mile transportation in an urban setting, we also briefly describe its use within an intermodal transportation context. Last-mile transportation in the context of intermodal transportation, which we denote by drayage, entails decisions comparable to urban transportation, but may focus on different aspects. An important aspect is the time it takes to load or unload a container at a customer. Decoupling the transportation unit makes it possible for trucks to move on while such operations take place (Pérez Rivera and Mes 2017). For example, a truck might leave an empty trailer at a customer and pick up a full trailer at the same customer, leaving the empty trailer to be filled and to be picked up later on by another truck. Also the distinction between containers and trailers is important; trucks should be equipped with the proper chassis to pick up a container, whereas trailers have their own chassis. Additional considerations arise when considering rigid trucks (having a transportation unit fixed to the frame) pulling a trailer, or trucks transporting two containers; in those cases decoupling decisions must be made for multiple transportation units per vehicle.

21.3 Current Research Trends in Integrated Transportation Networks (State-of-the-Art)

Throughout this chapter, we have touched upon various developments that are relevant to the future of transportation management. We briefly reiterate these developments before linking them to various research trends in transportation management.

We have asserted that cooperation and coordination between actors in logistics is becoming increasingly important, due to globalization, higher service level standards, and fragmentation of freight flows. Furthermore, environmental and societal concerns are gaining prominence in both legislation and decision-making. These developments limit the efficiency that may be achieved by individual actors. Instead of direct transportation of goods from origin to destination, transportation moves are increasingly characterized by the use of multiple modes and transfer hubs, which are often controlled by various actors. Thus, transportation management is no longer concerned only with managing the set of resources controlled by the decision maker, but also the integration with network segments of other actors.

Although we have mentioned several challenges that complicate the planning of intermodal transportation, there are also trends that provide opportunities. Important developments in recent years have occurred in the tracking of vehicles, transportation units, and individual shipments, as well as the real-time exchange of information. Many vehicles nowadays are equipped with GPS and a board computer, transferring information about the whereabouts of the vehicle and the progress of its route. RFID chips and barcodes are used to read the properties of goods with no or minimal handling involved. Developments in information systems and the speed of data transfers allow to quickly share this information, enabling for instance the identification of idle space in a container. Furthermore, today's computing power enables the processing of large amounts of real-time data or to evaluate millions of routes within limited time. Combined with increasingly sophisticated algorithms, planners are able to find high-quality solutions even for large and complex networks. Finally, innovations in automation lower the costs of certain transportation and handling operations, paving the road to more integrated transportation networks. A recent example of automation is the deployment of automated guided vehicles in ports, which collect containers at quayside cranes and transport them to the container stacks without human intervention.

Although many trends may be identified in transportation management research, the focus of this section is on topics that explicitly take into account the importance of collaboration, non-financial objectives, and the integration of transportation networks. In Sect. 21.3.1, we describe the concept of multi-criteria analysis. Section 21.3.2 briefly discusses multi-agent systems that may be used to model processes in transportation management. Section 21.3.3 concludes the chapter with an introduction to the Physical Internet, giving an outlook to the expected developments in transportation management in the next decades.

21.3.1 Multi-Criteria Analysis

Transportation management is no longer driven purely by financial incentives, but also takes into account aspects such as safety, emissions, and service levels. Deploying decision making tools that focus solely on a single performance indicator therefore no longer suffices for many decisions in contemporary transportation management. Instead, multiple criteria often need to be taken into account to reach satisfactory solutions.

Velasquez and Hester (2013) provide an overview of multi-criteria decision methods, pointing out various methods that are particularly suitable in transportation settings. Assigning weights to criteria, ranking alternative solutions, and handling uncertainty in input data are important properties of good multi-criteria decision methods. Multi-criteria analysis provides a structured approach to make transportation management decisions, taking into account the complexity of the sector and the increasing availability of data. Macharis et al. (2009) extend the notion of multi-criteria analysis by also adopting a multi-actor perspective, which may be used for, e.g., evaluating transportation policies and the selection of transportation technologies. From a transportation management perspective, the main benefit of considering multiple actors is that the objectives of stakeholders, such as shippers and residents, are explicitly taken into account, increasing the chances of identifying solutions that receive system-wide support. It also illuminates gaps in the perspectives of different actors. As transportation management is becoming increasingly dependent on cooperation with external parties and satisfying non-financial criteria, it is of paramount importance that all involved actors deem the proposed solution acceptable and are willing to commit time and resources to aid in achieving system-wide objectives.

There are multiple uses for the application of multi-criteria analysis in transportation management. For example, in the selection of supply chain partners, non-financial criteria, such as reliability, capacity, and connectivity (supported by appropriate information systems) are important aspects to consider, yet these are often difficult to translate in financial terms. Other common non-financial criteria in transportation management are, e.g., emissions and route durations. Also when setting up collaboration structures between various actors (e.g., constructing an integrated transportation network), multi-criteria analysis may be applied to assess how the structure affects each of the involved actors and whether the requirements of each actor are satisfied.

Nowadays, large amounts of data are available to aid decision-making in transportation. As modern computers are well-equipped to handle large data sets, multi-criteria analysis has become a powerful tool to aid decision making in complex environments. Research efforts are increasingly directed towards algorithmic approaches that handle many criteria and their corresponding data sets. With the ongoing integration of transportation networks and the abundant availability of both data and computing power, multi-criteria analysis is expected to remain a relevant research topic for transportation management in the foreseeable future.

21.3.2 Agent-Based Systems

We have emphasized the importance of integrating transportation networks in modern logistics, indicating that multiple actors must cooperate or at least coordinate their activities to benefit from bundling resources, information, and shipments. Often these networks lack a clear power structure between actors, therefore transportation management essentially has to deal with various autonomous decision makers whose support is required to successfully implement solutions. A suitable method for evaluating and optimizing decisions in such an environment is an *agent-based system*, in the form of a *multi-agent system* or *agent-based simulation*. Chapter 27 is dedicated to agent-based systems in logistics; we therefore restrict ourselves to a very basic introduction here.

Agent-based systems model the behaviour of real-life actors by pieces of software called *agents*. The system embeds multiple agents that autonomously make decisions and might be able to communicate and interact with each other. This decentralized structure mimics a real-life setting in which each agent attempts to make decisions that optimize its own objective function, disregarding whether this also contributes to the desired system-wide solution. Depending on the purpose for which the system is developed, the intelligence of agents might range from very basic decision rules to sophisticated planning algorithms.

Although the body of transportation research literature contains vast numbers of highly advanced decision methods, most studies focus on optimizing from the perspective of individual or centralized decision makers. As the focus of transportation management increasingly shifts towards integrated transportation networks, additional attention for the application of agent-based systems is required to tackle the problems faced in modern logistics.

In transportation taking place over longer distances, the focus of agent-based analysis is often on either horizontal or vertical collaboration in supply chains. Horizontal collaboration is often concerned with the coordination between transportation services offered by different agents and achieving a workload distribution that is both efficient and agreeable to the agents. Vertical collaboration often focuses on information exchange that facilitates flexible planning of freight flows.

In first- and last-mile transportation, agent-based simulation is used to evaluate solutions that affect multiple actors within this transport segment. We illustrate the application of agent-based simulation in last-mile transportation using a case study on urban freight transport in the city of Copenhagen.

Case Study: Agent-Based Simulation to Evaluate Urban Logistics Schemes

This case is based on a study on urban freight transport in the city of Copenhagen. In this study, the stakeholders in urban logistics, i.e., carriers, receivers, an urban consolidation centre, and the municipality, are modelled as autonomous agents. Carriers arrive from the long-haul with goods destined for the city. They may enter the city themselves or outsource the last-mile transportation to the consolidation centre. The receivers—located in the low-emission zone of the city—place transportation orders. Subsequently, they must spend time on receiving each shipment. In addition, they need to fulfil value-adding services such as storage, labelling clothes, or collecting waste. They might outsource the last-mile delivery as well as the value-adding services to the consolidation centre. Both the carriers and the receivers aim to minimize their costs and must decide whether to outsource to the consolidation centre. The centre aims to maximize its profit. Efficient routing and handling help to achieve this goal, which in turn requires the collaboration with as many users as possible. Finally, the municipality attempts to reduce the environmental and societal impact of freight transportation by imposing access restrictions and subsidy measures. Figure 21.2 illustrates the test setting.

To study the interaction between the decision makers, an agent-based simulation framework has been designed. This framework splits decision-making into three levels. On the strategic level, the administrator sets policies such as subsidy measures and access restrictions for trucks; these decisions are fixed for multiple years. Tactical decisions are made for two-month periods. First, the consolidation centre adjusts its price levels based on the handled volume. Subsequently, carriers and receivers decide whether to outsource to the consolidation centre. On the operational level daily routing decisions are made by both carriers and the consolidation centre.

By applying agent-based simulation, the interaction between the agents, their choices over time, and the eventual impact on both financial and environmental performance indicators can be monitored. In particular, the most effective combinations of administrative policies to support the use of the consolidation centre can be evaluated. As individual measures typically have insufficient impact, simultaneous implementation of multiple measures is often necessary. For example, combining temporary subsidies to carriers for using the UCC, with access time restrictions for heavy trucks, might be efficient when applied in conjunction, whereas the measures have limited impact when applied in isolation. The simulation framework enables to test many of such combinations within a short amount of time.

This case illustrates that transportation management in an urban context often cannot be regarded as an optimization process by a single actor, but should instead be viewed in the light of interaction with other actors that strive to accomplish certain objectives (both financial and non-financial) for themselves. For further details on this study, we refer to Van Heeswijk et al. (2017a).

Due to the applicability of agent-based simulation for evaluating solutions involving multiple autonomous decision makers, this research branch is becoming increasingly relevant in transportation management.

21.3.3 Physical Internet

In this chapter, we have discussed the shift of transportation management towards managing integrated networks, stressing the importance of collaboration and sharing

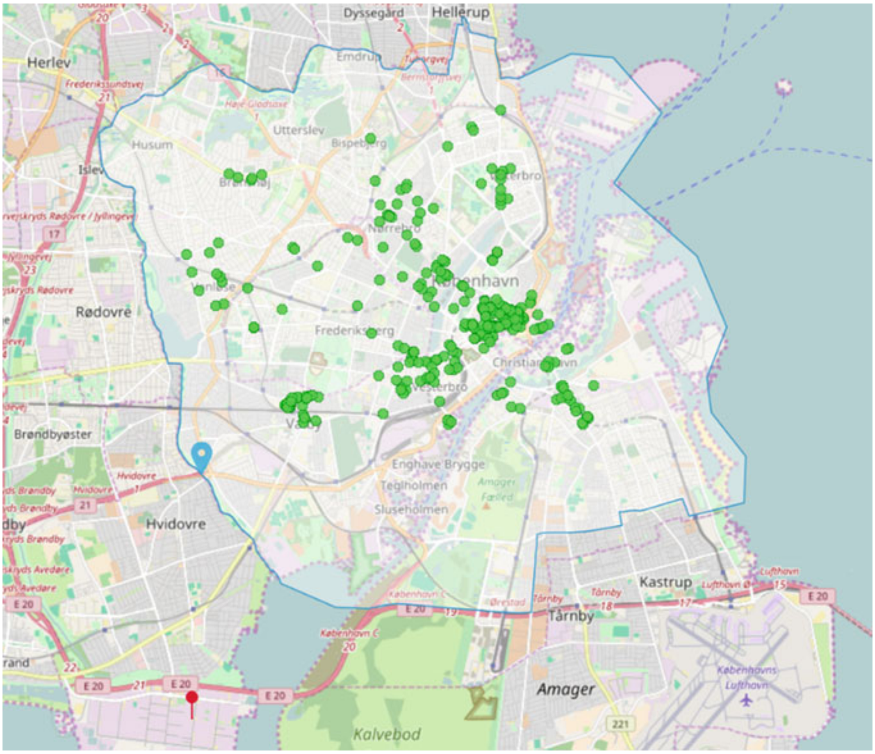

Fig. 21.2 Map of the Copenhagen test setting, showing the receiver locations (green) in the shaded low-emission zone, the UCC location (blue marker), and the long-haul exit point for carriers (red marker) (OpenStreetMap.org)

transportation resources to deal with future challenges. The *Physical Internet* is a logistics concept that stretches this notion to the extent of a completely integrated global logistics system (Montreuil 2011). It essentially labels each individual shipment with an origin, a destination, and certain constraints to be fulfilled, but this framework provides complete freedom on how to transport the shipment from origin to destination. This flexibility allows to extensively take advantage of bundling operations and idle transportation capacity. The name of the concept is derived from its analogy to the digital internet, in which the user is not concerned with how information is transferred precisely, but only with its reliable and timely arrival. More specifically, the Physical Internet relates to IPv4, an internet protocol that frequently fragments and reassembles information packages during the transmission from sender to receiver. For an in-depth analysis of the Physical Internet, we refer to Chap. 31.

The large flexibility of the Physical Internet implies that routes are fairly complex. Routes planned in the spirit of the Physical Internet typically consist of multiple modes and are typified by frequent bundling and unbundling at transfer hubs. The

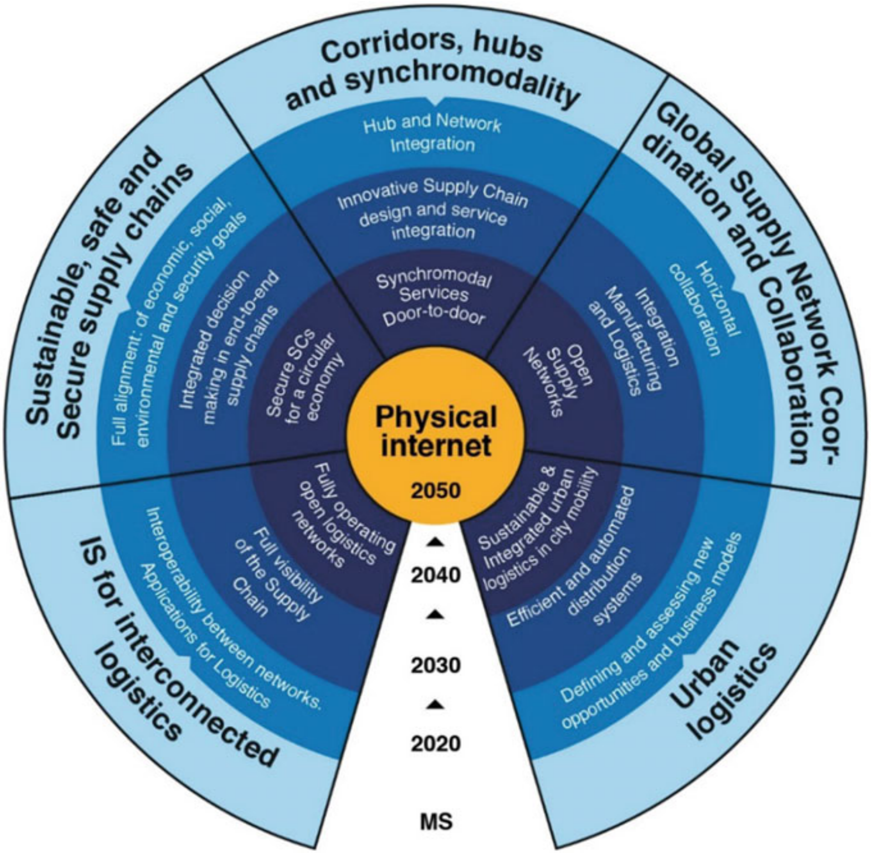

Fig. 21.3 Roadmap to the Physical Internet (European Technology Platform ALICE)

key difference between the Physical Internet and the concept of synchromodal transportation as described in Sect. 21.2, is the absence of a central control mechanism. Although synchromodal transportation also seeks to find the optimal route for each individual order through an intermodal network, it typically relies on a single decision maker, e.g., a 4PL orchestrating the transportation. In contrast, the Physical Internet assumes a decentralized control mechanism, with automated and real-time dispatch decisions taking place during the execution of the routes.

Figure 21.3 provides a roadmap to the Physical Internet, presenting the main challenges per decade on various subdomains that should ultimately converge to a truly seamless logistics system. The eventual goal of the system is envisioned to be realized by 2050. Collaboration, integration, and automation are key components of the roadmap. The steps required to develop the Physical Internet present an ambitious view on the future of transportation management.

Although a vast amount of research is conducted within the subdomains of the Physical Internet, research on the concept itself is still in its infancy. However, some trends may already be identified. Crucial to the success of the Physical Internet is the availability of smart containers that communicate real-time information and can be transferred easily between modes. Montreuil et al. (2010) describe the required modularity and interconnectivity of such containers to handle various dimensions of goods and to suit different types of handling equipment, varying from quayside cranes to retail equipment. Such modular containers are supposed to reduce handling costs, as they do not have to deal with goods of many different shapes and sizes.

Aside from suitable transportation units, the facilitating role of transfer hubs is also essential. Efficient processing of modular containers is important to minimize the time and costs spent on handling operations. On the technological side, real-time information exchange is a major topic. Especially in harsh environments, such as at sea, timely and reliable information exchange might be a considerable trial. Another important challenge that must be solved for the Physical Internet to be successful is its resilience with respect to disruptions, such as congestion or inaccessibility of a hub. Some customers require higher service levels than others, yet planning robust routes is challenging when considering decentralized decision-making. Depending on the willingness to pay, distinct risk profiles may be assigned to differentiate goods, thus creating a trade-off between efficiency and robustness. The categories that we mentioned in Sect. 21.2.1 for research directions on synchromodal transportation (physical, information, financial) are undoubtedly relevant for the Physical Internet as well.

Research on the Physical Internet seemingly lacks direct applications, yet the long-term vision is vital to properly direct the research efforts of transportation management in integrated networks. The topics of network integration, decentralized decision-making, real-time information exchange, and non-financial criteria will be prominent research branches in the future of transportation, prompting a drastic break with the traditional view on transportation management.

21.4 Further Reading

We conclude this chapter with a number of suggestions for further reading. For Sect. 21.1, we highlight the following works. The book of Bektaş (2017) provides a general introduction into freight transportation, delving deeper into the topics covered in this chapter. Crainic (2000) focuses on the mathematical analysis of transportation management and provides a review of modelling efforts in the field of Service Network Design. The literature review of SteadieSeifi et al. (2014) summarizes and classifies planning methods applied in intermodal transportation.

We point out four works relevant to Sect. 21.2, covering the topics of long-haul transportation, last-mile transportation, and synchromodal transportation. Crainic (2003) provides an overview of modelling efforts in long-haul freight transportation. A generic model of the two-echelon capacitated routing problem is presented by

Dellaert et al. (2016). Van Heeswijk et al. (2017b) focus on the dispatching problem of a transfer hub and develop an algorithm to solve this problem. Finally, Tavasszy et al. (2015) give an introduction into synchromodal transportation.

The Ph.D. thesis of Van Heeswijk (2017) consists of various planning methods for long-haul and last-mile transportation, and an agent-based simulation framework to evaluate urban logistics schemes. As such, it covers multiple topics addressed in this chapter. Macharis et al. (2010) describe the application of multi-actor, multi-criteria analysis on transportation problems, while also discussing the theoretical background of the technique. Montreuil et al. (2010) provide an introduction to the Physical Internet and point out various research directions relevant for the future of transportation management.

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