Chapter 11
Inbound Logistics

Stefan Minner

Abstract In this chapter, we discuss selected concepts and decision support models for inbound logistics. Inbound logistics comprises all activities that secure supply for manufacturing, assembly, and retail operations. The associated information and materials flow involve different strategic and operational decisions that will influence transportation, handling and inventory costs. They depend on various parameters, such as the variety and volumes of material requirements, the supplier base and respective locations. Section 11.1 introduces the basic concepts, key performance indicators, and problem parameters. Section 11.2 presents advanced decision support models for the design, implementation and operation of the concepts. Section 11.3 includes a case study. Selected state-of-the-art research and recent advances are discussed in Sect. 11.4.

11.1 Concepts of Inbound Logistics (Basic)

Logistics is integral for operating global supply chains. Therefore, the design and operations of supply chains as part of an overall operations strategy needs to consider the planning of locations and capacity at the strategic level and transportation and inventory management at the operational level. Transportation logistics connects the different levels of a supply and distribution network. A typical transportation process that connects two locations in the network consists of the steps of loading, pre-carriage, main haul, on-carriage, and unloading. In this chapter, we will focus on inbound logistics, i.e. on the design and operations of incoming material flows and the associated information (and financial) flows.

A typical automotive final assembly plant such as the one at BMW in Leipzig, Germany, produces about 800 cars each day and receives some 500 truck deliveries from its suppliers per day. Because of these large volumes, the optimization of the inbound transportation with high volume and high product variety is mandatory if we wish to minimize cost and achieve logistics efficiency. Strategically, the delivery con-

S. Minner (✉)
School of Management, Technical University of Munich, Munich, Germany
e-mail: stefan.minner@tum.de

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cept, including supplier and parts segmentation, needs to be decided. Operationally, scheduling and sequencing to avoid queues and waiting times for the carriers and a smooth capacity utilization represent challenging planning tasks.

For the design and operation of inbound logistics processes, we strive for achieving efficiency, but at the same time want to allow for flexibility and reactiveness. Securing a steady and reliable supply is core to manufacturing and sales processes, in particular when low inventories are kept to buffer against variability and volatility. When environmental conditions change either gradually or as a result of disruptions, efficiently organized manufacturing and assembly processes, such as those that we find in the automotive industry, might face significant challenges. Just-in time (JIT), just-in-sequence (JIS) supply systems for materials are very common in the automotive industry. Suppliers locate at a certain distance from the OEM plants to be able to secure a continuous and stable delivery of materials. The performance of inbound logistics can easily be at risk when required environmental conditions change significantly due to disruptions.

During the refugee crisis in Europe in 2016, the vulnerability of these JIT and JIS systems became obvious. Border controls were reintroduced by Austria in September. This resulted in longer waiting times at the border to Germany. If such controls were in place permanently, OEMs and suppliers would need to consider reorganization of the JIT delivery processes between Eastern European supply plants and OEM plants in Germany. Prognos expected significant losses for European economies as a consequence of changes to the Schengen Agreement, which allows for free border crossing between the countries that signed the agreement (Prognos 2016).

11.1.1 Definition and Performance Criteria

Inbound logistics comprises all activities that secure the supply for manufacturing and assembly or sales. These activities range from order placement and order allocation between suppliers to a chosen delivery and transportation concept for the receipt and storage or immediate use of the materials. When multiple plants or warehouses of a company and multiple suppliers are involved, we consider a many-to-many logistics system; when multiple suppliers deliver to a single warehouse, it is a many-to-one system (see Daganzo 2005). The large amount and increasing variety of goods received by plants and warehouses led to different delivery and transportation concepts that will be introduced in the following. The evaluation of and choice between concepts is typically based on the following key performance indicators:

- Transportation costs
- Handling costs

- Inventory costs
- Service level agreements

For transportation, we distinguish between full truckload (FTL) and less-than truckload (LTL) deliveries. One trade-off to be solved when deciding between these two options is the involved transportation frequency, i.e. more frequent deliveries require less inventory but might not lead to full truckloads, whereas less frequent deliveries result in inventories both at origins and destinations, but they use transportation capacity efficiently. In the first case, incoming trucks need to be scheduled and sequenced. In the second case, delivery concepts aim at overcoming the problem by consolidating LTL deliveries from multiple suppliers. For inventory replenishment, synchronization of demand and supply is typically found in just-in-time systems with frequent transportation and low inventory, whereas batch ordering and replenishment to stock is another option with larger inventories but lower transportation quantities.

Incoterms (International commercial terms) are standardized terms between the supplier and the buyer that specify the responsibility to organize the transportation, with delivery ex-works, EXW, or delivery and duty paid, DDP, as the two extremes where full responsibility is with the buyer in the former case and with the supplier in the latter case. Besides transportation, these standardized terms further specify at which point of the transportation chain risks transfer from the supplier to the buyer and who is responsible for paying taxes, insurance, and duties.

11.1.2 Delivery and Transportation Concepts

In the following, we introduce the main delivery and transportation concepts, along with their advantages and disadvantages. The delivery concept distinguishes between direct delivery from a supplier to a consumption point and the delivery to a warehouse for storage, regrouping and onward transportation. Just-in-time (JIT) and just-in-sequence (JIS) systems are widely used direct delivery concepts. For example, the BMW plant in Leipzig receives 30% of its supplies by direct delivery for various modules to 36 different delivery points within the plant (Klug 2010). This is a typical example of high volume, high frequency JIT/JIS. It avoids high inventories in environments with a large product variety by superior organization concepts, but requires significant organization, coordination, and reliability of inbound logistics processes. Figure 11.1 schematically illustrates a direct delivery structure with four supply factory origins and one destination factory. Where necessary, warehouses indicate intermediate handling nodes.

Just-in-time implies that materials are delivered very close to the time of consumption, thereby avoiding inventories and reducing lead times. Just-in-sequence is an organizational concept that also delivers a variety of materials in the sequence required for further processing or assembly. However, JIT/JIS logistics requires stable volumes and sequences and is therefore typically limited to supply from geo-

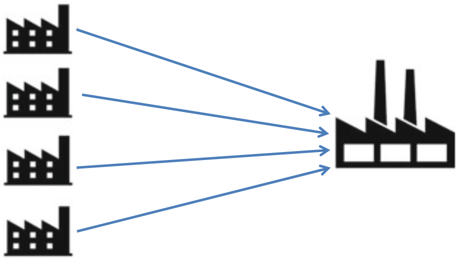

Fig. 11.1 Direct delivery

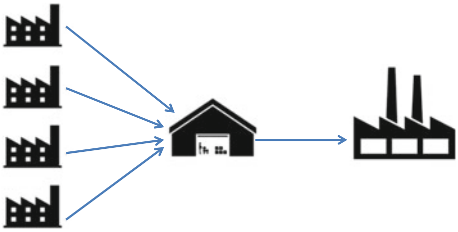

Fig. 11.2 Consolidation hub

graphically close supplier locations. The main advantage of direct delivery is its simplicity in coordination and the reduction of inventories for the buyer. A disadvantage may be that no full truckloads can be used when less-than-truckload volumes are required within an allowed time frame, together with the vulnerability to disruptions. In Sect. 11.2, we present a simple decision model for finding the transportation frequency for direct delivery that resolves the trade-off between inventories at origin and destination on the one hand and capacity utilization, i.e. full truckloads, on the other hand.

A major disadvantage of direct deliveries is a potentially large number of transportation links between many suppliers and many destinations, which results in a low utilization of transportation resources when volumes do not allow for full truckloads. Therefore, another concept for inbound logistics with the aim of coordinating freight consolidation has been introduced. It utilizes consolidation hubs as shown in Fig. 11.2. Here, suppliers do not have sufficient volume or delivery frequencies are too low for direct deliveries with full truckloads. To avoid a number of poorly utilized shipments and to achieve further economies of scale through the use of higher capacity transportation resources, smaller shipments can be collected at consolidation hubs and then jointly shipped to the destination. The main advantage of this approach is a higher utilization of transportation capacities; however, the concept causes additional coordination and handling costs for carrying out the consolidation.

In a milk-run system, less-than truckload deliveries from multiple suppliers are collected by a truck to achieve a higher fleet utilization and continuous supply. As opposed to the consolidation system, a truck consecutively visits several supplier locations to pick up goods, whereas the consolidation system still involves multiple (smaller) trucks for shipments between the suppliers and the consolidation point and larger capacities between the consolidation center and the destination. As a

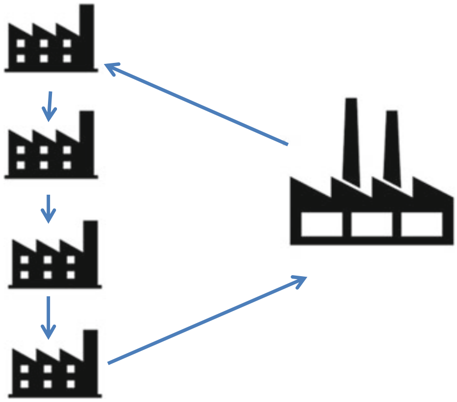

Fig. 11.3 Milk-run system

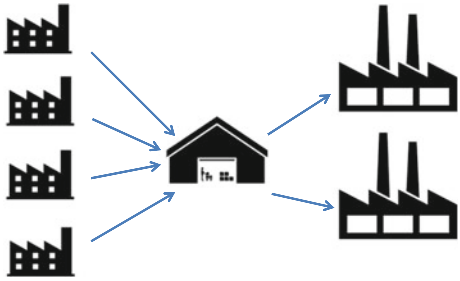

Fig. 11.4 Cross docking system

disadvantage, more loading operations and coordination of routing are necessary. A milk-run system results in a vehicle routing problem for the pickups or, if multiple suppliers and destinations are involved, in a combined pickup and delivery problem (see Toth and Vigo 2014). If combined with the pickup frequency at suppliers, we face a special form of an inventory routing problem (see Coelho et al. 2014). Besides the plant-milk-run as shown in Fig. 11.3, another option is to do milk-runs starting and ending at consolidation points, by potentially using smaller vehicles, then consolidate the collected volumes and to send full truckloads using transportation means with even larger capacities to the common destination.

When multiple suppliers service multiple plants, an important logistics concept in many-to-many distribution is cross-docking, which is also widely used in retail transportation logistics. Multiple suppliers deliver pre-packed goods to a cross-docking point where the packs are routed to the outbound deliveries for multiple destinations. A coordinated arrival from the suppliers and departures to the destinations reduces inventories and at the same time enables full truckloads, both at the inbound and outbound stages. While each supplier only ships less-than-truckload volumes to each customer plant or warehouse, aggregating the shipments for multiple destinations allows full truckloads to the cross dock and, after sorting and re-grouping, again full truckloads from the cross-dock to the multiple destinations. This inbound concept, however, requires more coordination efforts and handling processes (Fig. 11.4).

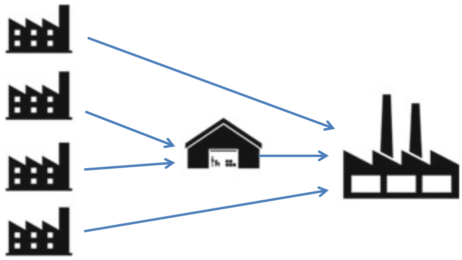

Fig. 11.5 Hybrid system with direct and consolidated shipments

Remaining smaller/smallest deliveries are typically handled through carriers using groupage concepts, which usually need to allow for larger lead times so that these providers can bundle shipments along with other business.

Due to the size of supply networks and the involved product variety in practice, a pure concept as illustrated above is seldom found. Instead, hybrid systems as shown in Fig. 11.5 combine the advantages and avoid the disadvantages by segmenting suppliers and products. For example, suppliers with large shipment volumes can easily fill a single container or several containers every week (without loss of generality assuming this is the intended shipping frequency) and directly supply the customers' manufacturing plants. Suppliers with a smaller weekly volume will deliver to a consolidation point where full containers or trucks are generated and then forwarded to the customer.

The segmentation of suppliers and/or products shipped directly or via a consolidation hub represents a non-trivial optimization problem that first needs to allocate suppliers or individual products of a supplier to a certain shipment mode and secondly must build shipment units to satisfy loading constraints. One instrument to support such segmentation is ABC analysis. In a typical ABC classification, the A-category includes suppliers with high volumes that can be organized with direct deliveries at high frequencies, i.e. multiple trucks every day. In category B, less-than truckload shipment volumes require some consolidation either via consolidation hubs or through being organized as milk-runs, whereas category C includes small shipments operated through third-party carriers in groupage.

11.2 Planning and Decision Support for Inbound Logistics (Advanced)

In this section, we present decision support for strategic, tactical, and operational problems in inbound logistics.

11.2.1 Network Design

The network design problem for the concepts introduced in the previous section includes several choices. The number of stages, the number of facilities at each stage and their location, as well as capacities and the adjustment of facilities and capacities over time need to be determined. Simultaneously, the delivery and transportation concepts are defined, ideally even anticipating the operational decisions and cost impact (see Schneeweiß 2003 for a hierarchical and distributed decision making framework). Melo et al. (2009) give an overview on supply chain design models. With regard to the above delivery and transportation concepts, this means the decision about the number and location of consolidation centers and cross docks and the optimization of FTL and LTL transportation and routing operations.

11.2.2 Inventory and Freight: Frequency Optimization

Next, we introduce a simple transportation frequency optimization problem for inbound logistics that builds on the assumptions of the Economic Order Quantity (EOQ) model. It illustrates the trade-offs between inventories and transportation costs and also investigates full truck loads versus economic load factors (see Burns et al. 1985). Assume a single link supply chain with a supplier, a buyer and direct delivery. Over an infinite planning horizon in continuous time, N products are produced at the supplier at rate p_i and consumed at the buyer at rate d_i ($i = 1, \ldots, N$). Backorders are not permitted. For long-term stability, we require $d_i = p_i$. Goods stored at the supplier and the buyer are subject to inventory holding costs per unit and unit of time of h_i^s and h_i^d. Every unit of product i requires a_i units of transportation capacity. The single available truck has a capacity of W units and every shipment between the supplier and the buyer causes fixed costs of c. For simplicity of exposition, we assume negligible transportation times and empty detours free of charge. The decision to be taken is the optimal time between two consecutive shipments T that minimizes the average cost per unit of time. To satisfy the demand between consecutive shipments, the shipment quantities q_i for each product have to equal demand during that period of time, i.e. $q_i = d_i T$.

Figure 11.6 illustrates the inventory development for a single product at the origin (supplier) and the destination (buyer), with both of them following the well-known saw-tooth pattern of economic lot-sizing models. At the source, inventory is zero after truck departure and increases with the production rate p_i until the next departure. At the destination, inventories of all products equal $q_i = d_i T$ after truck arrival and deplete at rate d_i until the inventory level reaches zero and the next truck will arrive. Under these assumptions, the cost function is given as follows. There are fixed costs per shipment of c, i.e. transportation costs per unit of time are $\frac{c}{T}$. The average inventory holding cost of every product, including origin and destination, is $\frac{(h_i^s + h_i^d) d_i T}{2}$. Note that this holding cost assignment uses a centralized perspective,

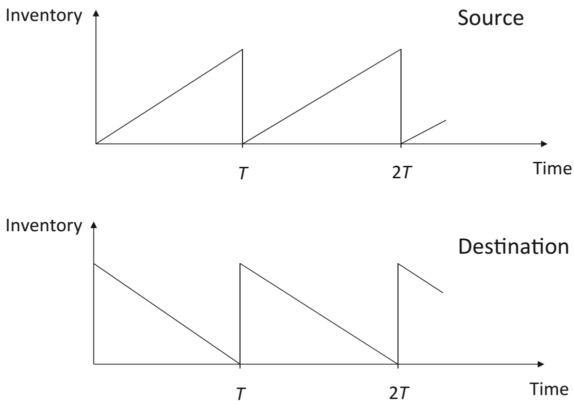

Fig. 11.6 Inventory development at origin and destination

i.e., includes both the impact on the supplier's and the buyer's cost. When taking a decentralized perspective for a single entity, one can set one of the two holding cost parameters to zero.

The average cost per unit of time as a function of the time between two shipments then becomes

$$C(T) = \frac{c}{T} + \frac{1}{2}\sum_{i=1}^{N}(h_i^s + h_i^d)d_i T. \quad (11.1)$$

Figure 11.7 visualizes the (total) average cost per unit of time as a function of the time T between two shipments and its two components, inventory holding costs and transportation costs per unit of time. When we increase the time between shipments, i.e. we decrease the transportation frequency, holding costs increase linearly due to the storage of more units at the origin and destination while transportation costs decrease. For the numerical values, we assume the following example data. The cost per truck going from origin to destination with capacity $W = 66$ is $c = 500$. We consider $i = 1, 2$ products with demand and supply rates $d_1 = 10$ and $d_2 = 15$ and define holding costs $h_i = h_i^s + h_i^d$ using values $h_1 = 5$ and $h_2 = 3$, and transportation capacity consumptions of unit size.
The transportation capacity constraint is

$$\sum_{i=1}^{N} a_i d_i T \leq W, \quad (11.2)$$

i.e., the minimum of either the time needed to fill the truck or the economic optimum. The above optimization problem minimizes a convex objective function under a linear constraint. Using a Lagrange multiplier approach, the optimal time between two shipments is given by

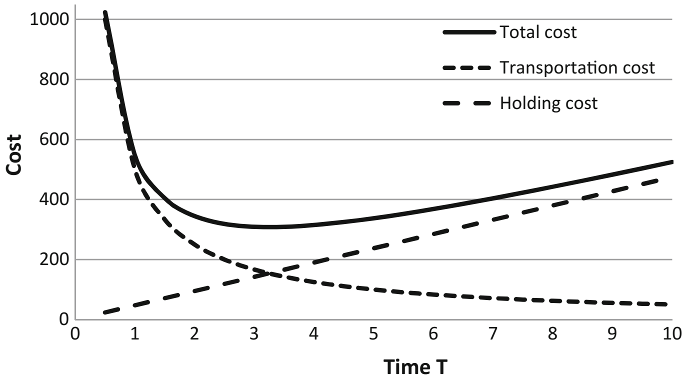

Fig. 11.7 Cost trade-offs and transportation frequency

$$T^* = \min\left\{\frac{W}{\sum_{i=1}^{N} a_i d_i}, \sqrt{\frac{2c}{\sum_{i=1}^{N} h_i d_i}}\right\}. \tag{11.3}$$

For the introduced numerical example, the cost-optimal delivery time T^* is 3.24, which, however, is not feasible as a truck is already filled after 2.64 periods.

Figure 11.7 further illustrates the well-known property that the cost-optimal solution of such a kind of lot-sizing model is rather robust, i.e. even significant errors in parameters that lead to larger deviations of the chosen transportation frequency from the optimal one only result in moderate cost increases as the total cost curve is very flat around the optimum. This basic model can be adapted to more realistic assumptions (see Burns et al. 1985 and Blumenfeld et al. 1985). Here, it serves to illustrate the basic trade-off between more frequent deliveries resulting in less inventories but higher transportation costs and the opposite scenario.

The previous models assume deterministic demands. To cope with supply uncertainty, various strategies are available, the most popular being safety time and safety stock. A widely used (text-book) formula for setting safety stocks (SST) in an environment under stochastic demands and lead times, simultaneously assuming independent normally distributed random variables and a non-stockout probability constraint is given by:

$$SST = k\sqrt{L\sigma_D^2 + \mu^2\sigma_L^2} \tag{11.4}$$

where $k = F_{0,1}^{-1}(\alpha)$ is the required safety factor for achieving a non-stockout probability α, $F_{0,1}^{-1}(x)$ denotes the inverse of the standard normal distribution, μ is the mean demand per period, σ_D^2 the variance of periodic demand, L the mean lead time, and σ_L^2 the variance of the lead time (see e.g. Silver et al. 2017).

11.2.3 The Joint Replenishment Problem

Another type of decision support model that allows for more realistic assumptions in inbound coordination is the joint replenishment problem. The model assumes discrete time periods $t = 1, \ldots, T$ within a finite planning horizon of length T. Multiple products $k = 1, \ldots, K$ with dynamic demands d_{kt} are considered. Backorders are not permitted, i.e. inventory levels at the end of the period have to be non-negative. As before, inventories are subject to holding costs h_k for product k per unit per unit of time. Note that, in the following formulation we only take the perspective of the buyer, i.e., holding costs only include the buyer's inventory. The main difference between joint replenishment problems and simple single-product lot-sizing models is the fixed cost structure, which for the joint replenishment problem includes a major setup cost A independent of the number of products included in the replenishment and minor setup costs A_k for each product replenished in a period but independent of the order quantity. The major setup cost therefore addresses the replenishment, e.g. truck delivery, whereas the minor setup costs address the handling and processes per product. The solution of the model coordinates the inbound logistics across products, i.e. which products to replenish together and at what frequency. The following mixed-integer linear program supports such joint and coordinated replenishments.

Decision variables

- q_{kt} order quantity of product k in period t
- γ_t binary indicator if there is any (major setup) order in period t
- u_{kt} binary indicator if there is an order (minor setup) for product k in period t
- y_{kt} inventory level of product k at the end of period t, initial inventories y_{k0} are given

Optimization model

$$\min \quad \sum_{t=1}^{T} (A\gamma_t + \sum_{k=1}^{K} (h_k y_{kt} + A_k u_{kt})) \tag{11.5}$$

$$s.t. \; y_{kt} = y_{k,t-1} + q_{kt} - d_{kt}, \; t = 1, \ldots, T, k = 1, \ldots, K \tag{11.6}$$

$$q_{kt} \leq u_{kt} M, \; t = 1, \ldots, T, k = 1, \ldots, K \tag{11.7}$$

$$u_{kt} \leq \gamma_t, \; t = 1, \ldots, T, k = 1, \ldots, K \tag{11.8}$$

$$q_{kt} \geq 0, \; y_{kt} \geq 0, \; u_{kt} \in \{0, 1\}, \; \gamma_t \in \{0, 1\}, \; t = 1, \ldots, T, k = 1, \ldots, K \tag{11.9}$$

The objective function (11.5) minimizes the sum of major and minor transaction costs, as well as inventory holding costs for all products k and periods t. Constraint (11.6) is the inventory balance equation, which enforces that the final inventory at the end of a period is equal to the initial inventory plus delivered units minus demanded units. Constraints (11.7) and (11.8) represent logical constraints that ensure that an order quantity of a product can only be positive if the corresponding indicator is equal to one and the product-specific indicator itself can only be one if the major indicator is one. M defines a sufficiently large number. Non-negativity and binary variable constraints (11.9) complete the model.

This mixed-integer-linear programming formulation can be solved by respective solvers. To do so, it might be advantageous to use a different model formulation, see Narayanan and Robinson (2006). While this basic formulation assumes dynamic but deterministic and therefore known demand, this assumption might not be realistic and requires extension, in particular for retail inbound logistics. For extensions, we refer to Minner and Silver (2005) and Minner (2009).

11.2.4 Inventory Routing Problems

Inventory routing combines the two fundamental problems in logistics, inventory management and transportation. The basic dynamic multi-period single-product lot-sizing model is combined with the vehicle routing problem. For a literature review, see Coelho et al. (2014).

The following model formulation combines the two traditional mixed-integer linear programming models for lot-sizing and vehicle routing. All deliveries to customers $i = 1, \ldots, n$ originate from a single central depot $i = 0$. Customer demands d_{it} for periods $t = 1, \ldots, T$ need to be satisfied, i.e. backorders are not permitted. Transportation between nodes i and j causes distance dependent transportation costs c_{ij} and trucks of a homogenous fleet have a limited capacity of W. Inventories at customer i at the end of a period are subject to holding costs h_i per unit and unit of time. In every period t, decisions are taken about whether to supply customer i (if $\gamma_{it} = 1$) or not ($\gamma_{it} = 0$), about supply quantities q_{it}, non-negative inventory levels at the end of period y_{it}, and vehicle routing variables x_{ijt} that decide whether a truck goes from node i to j in period t.

Decision variables

- γ_{it} delivery to customer i in period t
- q_{it} delivery quantity to customer i in period t
- y_{it} inventory level of customer i at the end of period t
- x_{ijt} routing variable if truck goes from customer i to j in period t
- u_{it} remaining capacity of a truck after supplying customer i in period t

The optimization model is

$$\min \quad \sum_{t=1}^{T}\left(\sum_{i=0}^{n}\sum_{j=0}^{n} c_{ij}x_{ijt} + \sum_{i=1}^{n} h_i y_{it}\right) \tag{11.10}$$

$$s.t.\ y_{it} = y_{i,t-1} + q_{it} - d_{it},\ i = 1,\ldots,n;\ t = 1,\ldots,T \tag{11.11}$$

$$\sum_{i=0}^{n} x_{ijt} = \gamma_{jt},\ j = 1,\ldots,n;\ t = 1,\ldots,T \tag{11.12}$$

$$\sum_{j=0}^{n} x_{ijt} = \gamma_{it},\ i = 1,\ldots,n;\ t = 1,\ldots,T \tag{11.13}$$

$$q_{it} \le M\gamma_{it},\ i = 1,\ldots,n;\ t = 1,\ldots,T \tag{11.14}$$

$$u_{0t} = W,\ t = 1,\ldots,T \tag{11.15}$$

$$u_{jt} \le u_{it} - q_{it} + (1 - x_{ijt})M,\ t = 1,\ldots,T, i, j = 0,\ldots,n;\ i \ne j \tag{11.16}$$

$$x_{ijt} \in \{0,1\},\ i, j = 0,\ldots,n, i \ne j, t = 1,\ldots,T \tag{11.17}$$

$$q_{it} \ge 0, u_{it} \ge 0, y_{it} \ge 0, \gamma_{it} \in \{0,1\},\ i = 1,\ldots,n;\ t = 1,\ldots,T \tag{11.18}$$

The objective function (11.10) minimizes the sum of transportation and inventory holding costs. The constraints for every period t represent inventory balances (11.11) with y_{i0} denoting the initial inventory, truck arrival and departure at locations that require delivery during that same period (11.12) and (11.13), and logical constraints that limit supply quantities to those days that are scheduled for delivery (11.14). Loading capacity constraints and the avoidance of sub-tours are achieved through (11.15) and (11.16).

As for the vehicle routing problem, several extensions (see e.g. Toth and Vigo 2014) are possible to this model, i.e. time windows and forbidden days, the combination of pickup and delivery when multiple suppliers deliver to multiple plants, etc. Turan et al. (2017) present a variable neighborhood search (VNS)-approach for a perishable (newsvendor-type) product with an option for resupplying stock once during the sales day. The inbound coordination problem is the combined routing, delivery timing and resupply quantity allocation problem.

11.3 Case Study

An automotive supplier is concerned about its transportation cost spent for inbound logistics. A first analysis revealed that the current situation is far from best in class. The management therefore discusses the introduction of a state-of-the-art Transportation Management System (TMS) that makes use of the latest technologies in measuring, analyzing, visualizing, and optimizing world-wide transportation flows. In a first study, the following problem areas for improvement were detected:

- Insufficient load factors of trucks supplying material to the plants

- Unclear rules for deciding about direct shipments from large suppliers to plants
- Significant waiting times of trucks when unloading at the plant warehouses
- No company-wide guidelines for tendering transportation services
- No clear rules for consolidation of shipments and deciding about transportation lot-sizes
- A mix of multiple contracts with logistics service providers to pickup supplies even within a single region
- No clear segmentation of suppliers and part numbers with regard to volume and frequency of pickup and supply

When discussing available tools for the digitalization of inbound logistics, the responsible logistics managers criticize that the technology for monitoring and administering inbound transportation is only part of the problem. The effort necessary to parameterize such software systems in such a way that they can create and maintain a reliable and up-to-date data base is often underestimated and might offset the benefits achieved by increasing variability. There is also a lack of human resources that are able to design and execute data analysis capabilities and turn these into optimization benefits. The amount of available data would need more automation and careful analysis to find patterns for designing future tenders and to build regions for assignment. The question is further about the frequency at which to revise the inbound logistics network due to changing product generations, a different supply base, changing volumes, and increasing volatility.

11.4 Research for Inbound Logistics (State-of-the-Art)

Increasing computing capabilities, data availability and advanced optimization methods allow for extended decision support beyond the simple models presented in the previous section. A recent trend in transportation optimization is the incorporation of uncertainty, i.e. to include fluctuations in volumes and/or transportation times. Initial system configurations, such as the locations of consolidation points and cross docks, need to be selected in a robust way, which will operationally allow for some flexibility when it comes to adjusting to changing environments. In retail, with its expanding multi-channel strategies, the load and capacity utilization changes considerably over time, exhibiting large peaks towards end of the year. This requires more flexible and adjustable logistics systems. Another problem at the operations-finance interface are multiple options to finance inventory. If inbound logistics is outsourced to logistics service providers, so can be the replenishment and financing involving a bank. When outsourcing inbound logistics, an important design problem is the duration of the contract and the organization of the tendering process. This, of course, depends on the selected inbound logistics strategy and the resulting transportation and warehousing service required.

In response to many supply chain disruptions recently observed, many proactive and reactive risk management strategies have been proposed, in particular strategies that use multiple and backup suppliers (Minner 2003; Yao and Minner 2017). While inventory and availability criteria have been considered in respective research, the impact on transportation and transportation consolidation still requires additional investigation, in particular when we consider multi-stage supply chains. Following the idea of data-driven optimization, i.e. using past demand data for optimization, rather than decoupling the planning problem into a forecasting and replenishment optimization problem, Taube and Minner (2017a) determine replenishment patterns for retail operations, i.e. they determine what products should be replenished on what days in order to guarantee availability. At the same time they smooth handling capacities at stores and a central warehouse.

11.4.1 The Loading Dock Waiting Time Problem

One of the challenges in inbound logistics is the problem of coordinating truck arrivals and unloading to avoid waiting times at loading docks. The problem is caused by the uncoordinated arrival of trucks delivering material and the non-synchronized warehouse capacity at warehouse gates, for example because many carriers prefer deliveries in the early morning. This, according to the Bundesamt für Güterverkehr (2011), a federal agency for monitoring freight traffic in Germany, leads to considerable waiting times of 1–2 h per truck and warehouse. One solution that has been suggested for this problem are time slot management systems where carriers have to book certain delivery time windows at a certain fee (see Elbert et al. 2016). Providers of such solutions are for example Mercareon (www.mercareon.com) and Transporeon (www.transporeon.com). However, as this system primarily works as a first-come-first serve booking platform, the planning flexibility of carriers is limited by the slots that have to be booked ahead of time and might not be a good fit with their preferred truck routing.

To improve the situation, various supply chain coordination mechanisms are available that need to be tailored to the problem at hand. A first approach is to share information with carriers about expected waiting times at each hour of the day, thereby giving them a better basis for their delivery planning. Research-wise, this information reduces the uncertainty about the stochastic service times for waiting and unloading in a stochastic vehicle routing problem. Lemke et al. (2014) show that sharing information can be an effective means by which to improve waiting times if enough, but not all, carriers pick up this information. A disadvantage if too many carriers use the information in the same way is that they all will adjust their plans towards other (the same) time windows and thereby not avoid but only shift the problem. A solution recently proposed in Karänke et al. (2015) is the use of auction mechanisms for allocating available warehouse unloading time slots to carriers following their bids for certain routes. Carriers can submit routes and bids to a clearance platform that then selects and awards proposed routes to the carriers, at the same time balancing the utilization at the warehouse gates. Different auction mechanisms for truthful bidding are presented and compared in a numerical experiment to show their effectiveness in achieving coordination between the carriers. Another way to solve the problem is the use multi-agent systems, similar to, e.g., the barge-terminal visit problems in the Port of Rotterdam (see the case in Chap. 27).

11.4.2 Sequencing and Resequencing

In order to organize inbound logistics, trucks delivering material, as well as items being delivered for operations, require sequencing to achieve operational efficiency and to satisfy JIS constraints. On the one side, incoming trucks need to be sequenced in order to minimize waiting times, on the other hand, the utilization is increased at the loading docks. In a stochastic version of this problem where arrival and processing times are random, this system can be seen as and analyzed by queuing systems with a single or with multiple servers. In a deterministic version, it can be modelled as a scheduling problem for minimizing the cycle time to process all incoming trucks in minimum time (see Boysen et al. 2010).

In just-in-time, just-in-sequence systems, the buyer orders a certain number of products for a certain time frame or with the next delivery truck. For high product variety environments, the components need to be provided in a sequence, which might not necessarily be the optimal one for the supplier to produce. In such cases, resequencing operations can be beneficial and there are various organizational possibilities for resequencing, storage and sorting to rebuild the original sequence (see Boysen et al. 2012). Taube and Minner (2017b) present an approach for effectively organizing the restoration of an original OEM sequence of parts that is produced in another sequence to achieve different efficiency goals at the supplier. The resequencing strategy is shown in Fig. 11.8, where an original sequence needs to be delivered just-in-sequence to the OEM. The different products can be resequenced, which essentially represents a sequencing problem using a travelling salesman formulation, with the additional constraint that, after production, the products can be put into different storage lanes and pulled from there to restore the required sequence without interim buffering. The assignment of products to lanes is essentially a vehicle routing problem, where the lanes represent the vehicles with loading constraints.

Combining the two subproblems, the production sequence (TSP) and lane storage (VRP) can be formulated as a straightforward mixed-integer-linear program. For larger problems, Taube and Minner (2017b) suggest and evaluate a simple look-ahead method that performs well with short computation times.

11.5 Further Reading

Gudehus and Kotzab (2012) provide an exhaustive coverage of logistics. A comprehensive collection of material on inbound logistics can be found at the website www.inboundlogistics.com. For aspects of modeling and solving vehicle rout-

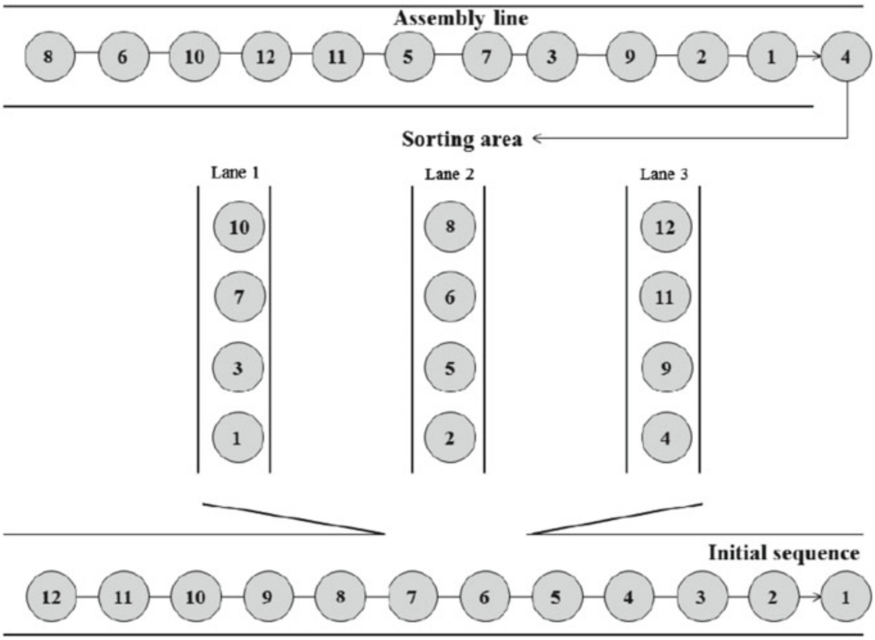

Fig. 11.8 Resequencing in JIS assembly (Taube and Minner (2017b))

ing problems, the interested reader is referred to the collection by Toth and Vigo (2014), while a broad coverage of inventory management aspects and references is provided in Silver et al. (2017). For more details on transportation markets and transportation data analysis, please see Ben-Akiva et al. (2013) and Washington et al. (2011). Sinha and Labi (2007) is a textbook reference for details on transportation performance evaluation, whereas Chandra and Grabis (2007) introduce concepts, solutions and applications for supply chain configuration in general. As for many other sectors, logistics is currently undergoing (disruptive) changes caused by the fourth industrial revolution (Industry 4.0). Developments and research requirements are summarized by Delfmann et al. (2017).

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