Summary

How to distribute goods is a question that is faced daily by many companies and, therefore, these questions are solved regularly in practice either with or without supporting technologies. A general aim is to keep costs low and customer service high, for example, by minimizing delivery costs and making sure that customer demand is satisfied. Increasing resource utilization and transportation efficiency can lead to cost savings and service improvements for all parties involved (e.g., manufacturers, transportation companies and customers). Efficiency can, for example, be enhanced by finding improved distribution plans, i.e., plans with lower costs, or by exploring new distribution strategies. This dissertation focuses on gaining insight in fundamental distribution problems, developing efficient distribution strategies and analyzing the benefit of novel distribution strategies.

Chapter 2 investigates which aspects influence the computational complexity of the Inventory Routing Problem (IRP) by looking for complexity proofs for several variants of the problem. The IRP combines the optimization of inventory management and routing of the vehicles that perform the replenishments for a set of customers over a given time horizon. Understanding the computational complexity of problems helps to reveal the structure of a problem which contributes to the development of solution methods. The Travelling Salesman Problem (TSP) is a special case of the IRP and since the TSP is NP-hard, it can immediately be concluded that the IRP is NP-hard. However, the underlying routing problem is not necessarily the only complicating aspect in the IRP. Therefore, Chapter 2 studies the IRP on metrics on which the TSP is easy or even trivial, hence NP-hardness through the TSP is avoided. First, problem variants on a point and on a half-line are studied. The problems differ in the number of vehicles, the number of days in the planning horizon and the service times of the customers. The main result is a polynomial time dynamic programming algorithm for the variant on the half-line with uniform service times and a planning horizon of two days. Second, for nearly any problem in the class with non-fixed planning horizon, we show that the complexity is dictated by the complexity of the Pinwheel Scheduling Problem, of which the complexity is a long-standing open research question. Third, NP-hardness is shown for problem variants with non-uniform servicing times. Concluding, the analysis shows that, next to routing, also the time horizon, service times, the customer demand combined with vehicle capacity, and the number of available vehicles contribute to the complexity of the IRP. Finally, we prove strong NP-hardness of a Euclidean variant with uniform service times and an easily computable routing cost approximation, avoiding immediate NP-hardness via the TSP.

In Chapter 3 a vendor-managed inventory setting is considered in which a supplier determines the timing and size of replenishments for its customers and the deliveries are
outsourced to an external carrier. In practical settings, it is sometimes the case that the supplier pays the transportation company a fixed fee per performed delivery. Geldmaat, the business partner of this Ph.D. project is such a supplier. Geldmaat decides upon the replenishment of ATMs in the Netherlands and issues replenishment orders to Cash-in-Transit companies. In the terminology of the replenishment literature: Geldmaat acts as a supplier that outsources delivery of goods. Chapter 3 considers an outsourcing cost structure in which a fixed fee is incurred per customer replenishment and per day on which at least one replenishment takes place. The corresponding optimization problem faced by the supplier is a Dynamic-Demand Joint Replenishment Problem (DJRP).

Because of the fixed fee cost structure, there is no incentive for the supplier to schedule replenishments for nearby customers in the same period. As a result, the carrier is forced to perform inefficient delivery routes which leads to higher transportation costs, which will result in higher fixed transportation fees for the supplier in future contracts. Moreover, if the carrier has a limited fleet, it can occur that not all customers can be served on the same day due to longer travel times between distant locations. To assess the efficiency improvement if customer locations would be considered by the supplier, in Chapter 3 the DJRP is extended to the DJRP with Approximated Transportation Costs (DJRP-AT). Finding actual transportation costs requires to solve a routing problem. However, such problems are relatively hard to solve and for the purpose of this chapter, it is not necessary to know the sequence of the customers in a route as the deliveries are outsourced to an external carrier. Therefore, in Chapter 3 the transportation costs to service a given set of customers is approximated. A solution approach for the DJRP-AT based on branch-and-cut-and-price is validated using test instances from the literature. The distribution plans and costs found by solving the DJRP and the DJRP-AT are compared. The results show that significant cost savings can be achieved by deviating from the DJRP cost structure by considering the proximity of customers. Results show improvements of 4% on average and up to 14.4% for individual instances compared with the DJRP.

Chapter 4 addresses an approach for inventory replenishment in which customers can fulfill (part of) the demand of a nearby customer. If the customers are located relatively close to each other, one has the opportunity to satisfy a part of the demand of a customer by the inventory stored at another nearby customer. This redirection option can be included in the optimization of the customer replenishments in the Inventory Routing Problem to lower total costs. This idea can for example be applied to ATMs in urban areas where an ATM-user, who wants to withdraw money, can be redirected to another ATM which is within walking distance. One ATM then satisfies part of the demand of another ATM in close proximity. To the best of our knowledge, the possibility of redirecting end-users (e.g., ATM-users) is new to the Operations Research literature and has not been implemented, but is being considered in the industry. In Chapter 4 the so-called Inventory Routing Problem with Demand Moves (IRPDM) is defined and formulated in which demand moves represent the redirection of end-users between customers. For each demand move a service fee/cost is incurred which depends on the distance between the involved customers and quantity moved. A branch-price-and-cut solution approach is proposed to solve the IRPDM. The results show that substantial cost improvements can be achieved compared with the IRP. The results also indicate that only a limited number of demand moves per day is applied in the solutions. For instances from the literature cost improvements of the IRPDM over the IRP of up to
10% are observed with average savings around 3%.

In Chapter 5 the Vehicle Routing Problem with Partial Outsourcing (VRPPO) is introduced. In the Vehicle Routing Problem a set of customers that each have a certain demand need to be served in one day by a set of capacitated vehicles. In the VRPPO, a customer can either be served by a single private vehicle (a vehicle owned by the supplier), by a common carrier (the delivery is fully outsourced), or by both a single private vehicle and a common carrier. As such, it is a variant of the Vehicle Routing Problem with Private Fleet and Common Carrier (VRPPC) in which the delivery to a customer can either be fully outsourced or not. We propose two different path-based formulations for the VRPPO and solve these with a branch-and-price-and-cut solution method. For each path-based formulation, two different pricing procedures are designed. To assess the quality of the solution methods and gain insight in potential cost improvements compared with the VRPPC, tests are performed on two instance sets with up to 100 customers from the literature. Analyzing the cost difference between the VRPPO and the VRPPC shows higher cost improvements of the VRPPO over the VRPPC if customer demand is close to or higher than the vehicle capacity. Furthermore, if customers are located in clusters, cost improvements are lower than if customers are randomly spread over an area. Visualization of some solutions shows that a VRPPO solution can contain completely different routes than the corresponding VRPPC solution.

This dissertation studies the computational complexity of a class of distribution problems, models both fundamental and more practical distribution problems, and develops exact solution methods for such problems. The problems are inspired by real-life optimization problems from a cash supply chain, but are more widely applicable. The studies provide insight in problem structures and solution aspects, and contribute to the development of alternative solution methods.