A Continuous-time Service Network Design and Routing Problem

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Distributing commodities from different pickup points to various delivery points is a core problem in logistics. To improve efficiency and benefit from economies of scale, consolidation and transshipments of commodities at hubs are common practices. The transportation network is thus made up of a set of pickup points, a set of delivery points and a set of hubs. It can be divided into three layers, as illustrated by Figure 1. The pick-up network contains long-distance trans-regional full-truckload transportation linking pick-up points and hubs. The inter-hub transportation network links all the hubs together to allow transshipments of commodities. The delivery network contains the regional daily final distribution of commodities from hubs to corresponding delivery points. Direct deliveries from a pick-up point to a delivery point are also possible.

In the literature, the Service Network Design Problem (SND) considers the tactical or strategic planning of the trans-regional long-distance distribution of commodities (see [1] for a general review). Operational route planning of daily local commodity distribution results in the well-known Vehicle Routing Problems (VRPs). Classic solution methods to the SND divide the planning horizon into periods and solve a network design model for each period. Recently, in [2], a powerful Dynamic Discretization Detection (DDD) algorithm is designed to solve the SND in continuous time without dividing the horizon into periods. The integrated problem of long-haul and local transportation planning is rare and is first studied in [3] under the name of Service Network Design and Routing Problem (SNDRP). In this paper, we propose an extension to [3]. Different from [3], where the allocation of pickup or delivery points to hubs is fixed and the DDD is used as a black-box algorithm for the solution, in this paper, additional decisions on assignment of pick-up and delivery points to hubs is taken into consideration and it extends the DDD to solve this integrated problem in continuous time.

FIG. 1 – Service network
In the Continuous-time Service Network Design and Routing Problem (CTSNDRP), a set of commodities is to be transported in the service network. Each commodity is defined by a quantity, an origin pick-up point with an earliest available time, and a destination delivery site with a due time. A set of delivery routes is also given in the network. Each route is defined by a set of points (pick-up, delivery or hub) with a capacity, a fixed duration between each two points, a fixed total transportation cost. Commodities can be consolidated and transferred from one route to another at hubs, which takes a certain duration and a variable cost proportional to the quantity. The problem is to plan delivery paths using the pre-defined routes so that each commodity is picked up and delivered in time, while the total transportation and consolidation cost is minimized.

The problem is solved by an extension of the DDD algorithm with a predefined set of routes. The general scheme is shown in Figure 2.

![FIG. 2 – General scheme of the DDD for the CTSNDRP](image)

It is first modelled on a route-time-expanded network derived from the physical transportation network according to information on commodities and routes. A partially expanded network is defined as a route-time-expanded network where not all timed routes are present, so infeasibilities might exist. The continuous time network is one which contains all the timed copies of routes needed for deliveries of commodities. Given a route-time-expanded network (partially-expanded or not), a service network design model (abbreviated SNDR) can be constructed. It is proved that, under certain condition, the solution of the SNDR on a partially route-time-expanded network is a relaxation of the solution of the SNDR on the continuous time network. The algorithm first solves the SNDR on a partially expanded network, and attempts to derive a feasible solution to the problem on the continuous time network by linear programming. If a feasible solution can be obtained, the algorithm terminates. Otherwise, it detects the infeasibility introduced by the partially expanded network and repair the network by adding more timed copies with a Mixed Integer Programming model. The algorithm terminates with an optimal solution to the CTSNDRP.

We illustrate the CTSNDRP with a case study in the retail area. Numerical experiments show that our approach can help decision makers to design logistics networks, validate synchronization rules and optimize transportation plans in multi-level networks.

**Références**

