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Cyclic versus reactive planning for inventory routing

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Abstract

For the Inventory Routing Problem (IRP), two research streams are found in the literature. One stream assumes stochastic demands at the customers and adopts a reactive, dynamic approach in which new routes are designed every day to replenish customers that are almost out of stock. The second research stream assumes constant demand rates and adopts a static, cyclic approach in which customers are partitioned into subsets and then periodically replenished in routes with optimized cycle times. In this paper, we link these two research streams by investigating the validity of the cyclic approach for stochastic customer demand rates. We show that a cyclic, static approach is still valid under fluctuating customer demands, by carefully providing sufficient slack through a combination of safety stock at the customers and spare capacity in the replenishment routes. The advantage of the cyclic approach is that replenishment frequencies and vehicle routes remain the same over time. As such, the cyclic approach takes better advantage of the variability pooling effect, and the demand variability is buffered in the distribution stage, resulting in a reduced bullwhip effect in the upstream stages. Illustrative examples comparing the cyclic and reactive approaches confirm that the cyclic approach indeed offers cost efficient solutions with limited variability dissipation to upstream stages.

Keywords: Inventory routing; Cyclic planning; Reactive planning; Variability pooling.

1. Problem description

Under vendor-managed inventory (VMI), the distributor takes responsibility for managing customer inventories, which allows for coordination of replenishments across all customers. The distributor is then confronted with the integrated problem of deciding replenishment timing and quantities for all customers on the one hand, and designing vehicle routes for these replenishments on the other hand. This integrated problem is

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known in the literature as the Inventory Routing Problem (IRP). Simply put, this literature on the IRP can be divided into two research streams that we will denote as research on ‘reactive’ and ‘cyclic’ approaches.

In the reactive approaches, stochastic demands at the customers are assumed. A reactive approach consists of designing new vehicle routes every day to replenish a set of critical customers. This set of critical customers includes all customers that do not have enough stock left to cover the day’s demand (i.e., the customers that must be replenished today), supplemented by customers that are less critical today but that can be added to the day’s routes at relatively low costs. Adding some of the less critical customers today avoids them from becoming more critical the next day. This can help reduce transportation costs if they can be included in one of today’s routes at a low additional cost and there is no need to dispatch a vehicle to that customer’s region the next day. Seminal papers for this research stream are those of Federgruen & Zipkin (1984) and Golden et al. (1984). A detailed overview of the literature can be found in the recent review of Andersson et al. (2010). Interesting recent contributions in this research stream are found in Benoist et al. (2011), Solyali et al. (2012), and Yu (2012).

In the research stream around cyclic planning, an infinite planning horizon and constant demand rates at the customers are assumed. Most of these approaches adopt the fixed partition policies as introduced by Anily and Federgruen (1990). This means that customers are partitioned into subsets, after which a vehicle route (or a set of vehicle routes) is designed per subset. All these vehicle routes are periodically repeated with an optimized cycle time, balancing the vehicle routing costs with the customer inventory holding costs in an EOQ-like manner. Again, a detailed review of the literature is available in Andersson et al. (2010).

In this paper, we adopt the cyclic planning approach, but step away from the assumption of constant customer demand rates. We argue that a cyclic, static approach can still be valid even when customer demand rates are fluctuating, by carefully providing sufficient slack through a combination of safety stock at the customers (to deal with higher than average demands) and spare capacity in the vehicle routes (to deal with larger than average replenishment quantities). This cyclic approach with safety stocks and slack vehicle capacities is explained below in Section 2.

When demand variability levels are high, sticking to the cyclic planning approach will result in high levels of safety stocks, and in high levels of spare capacity in the vehicles resulting in low average vehicle utilization. This could indicate that resources (i.e., the vehicles) are no longer efficiently deployed to serve customers, and that a reactive planning approach that redesigns vehicle routes every day to ensure high utilization, is more appropriate. In a simulation experiment, described in Section 3, we will investigate for which levels of demand variability the reactive or cyclic approach is more appropriate (and more cost efficient). The main advantage of the cyclic approach over the reactive approach is that replenishment frequencies and vehicle routes remain the same over time. Only the replenishment quantities are adjusted across consecutive replenishments. As such, the cyclic approach can take better advantage of the variability pooling effect than the reactive approach, and the demand variability is buffered in the distribution stage. This leads to a reduction of the bullwhip effect (and significant cost savings in the upstream stages), as discussed in the concluding Section 4.

2. Cyclic planning for inventory routing under demand uncertainty

The solution approach that we use for cyclic planning is based on the procedure described in Raa & Dullaert (2007). It heuristically partitions the customers into subsets and builds a single route per customer subset. For every route, the optimal cycle time is determined that minimizes the total cost rate, consisting of the distribution costs and the inventory costs. Once all routes have been constructed and optimized using local search, the final set of routes is allocated to vehicles in order to minimize the required vehicle fleet. This fleet sizing aspect is also heuristically solved with a two-phase construct-and-improve procedure, details of which can be found in Raa (2013). In the following paragraphs, the route design is described, together with how a route cycle time can be optimized to minimize its cost rate.