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An inventory control model for modal split transport: A tailored base-surge approach

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ABSTRACT

Firms are increasingly interested in transport policies that enable a shift in cargo volumes from road (truck) transport to less expensive, more sustainable, but slower and less flexible transport modes like railway or inland waterway transport. The lack of flexibility in terms of shipment quantity and delivery frequency may cause unnecessary inventories and lost sales, which may outweigh the savings in transportation costs. To guide the strategic volume allocation, we examine a modal split transport (MST) policy of two modes that integrates inventory controls.

We develop a single-product–single-corridor stochastic MST model with two transport modes considering a hybrid push–pull inventory control policy. The objective is to minimize the long-run expected total costs of transport, inventory holding, and backlogging. The MST model is a generalization of the classical tailored base-surge (TBS) policy known from the dual sourcing literature with non-identical delivery frequencies of the two transport modes. We analytically solve approximate problems and provide closed-form solutions of the modal split. The solution provides an easy-to-implement solution tool for practitioners. The results provide structural insights regarding the tradeoff between transport cost savings and holding cost spending and reveal a high utilization of the slow mode. A numerical performance study shows that our approximation is reasonably accurate, with an error of less than 3% compared to the optimal results. The results also indicate that as much as 85% of the expected volume should be split into the slow mode.

1. Introduction

In recent years, companies have identified the potential of modal split transport (MST) for optimizing the allocation of cargo into more than one transport mode. Rather than shipping all the cargo by truck, there is an increasing interest in moving transport volumes to trains or barges. There are numerous reasons for this prospective paradigm shift. First, road transport is generally more expensive per unit of cargo shipped, and its cost is still forced upward by factors such as congestions and empty running (American Transportation Research Institute, 2014; McKinnon & Ge, 2006). Second, the shortage of truck drivers is limiting the supply of truck capacity and causing structural fleet management issues (BCG, 2015; Sheffi, 2015). Third, firms' sustainability agendas and carbon reduction targets facilitate the shift to "greener" transport modes that favor trains or ships over trucks (Dekker, Bloemhof, & Mallidis, 2012; Dey, LaGuardia, & Srinivasan, 2011).

Despite the increasing emphasis that MST receives, shifting volume away from the road remains challenging. Statistics demonstrate that since 1995, there has been no significant change in modal split ratios among road, rail, and waterway in the EU-28 zone (EUROSTAT, 2015). In contrast, rail transport on certain routes had to be closed after several years of operation because the rigid schedule could not cope with the practical demand changes (Lammgård, 2012). Shippers hesitate to implement train transport due to the concern that there will not be sufficient volume to secure a cheap price (Pallme, Lambert, Miller, & Lipinski, 2014). The timetable of rail or barge is rigid, and it is therefore almost impossible to send an extra train when demand surges (Reis, Meier, Pace, & Palacin, 2013). Compared to other transport modes, truck transport is still the most flexible mode in terms of delivery time, routes, and quantity.

To obtain further insights into the challenges of MST, we partnered with a consumer goods company that further inspired our research. This company currently consigns almost all of the transport volume into trucks. On a daily basis, the distribution centers (DC) order inventory from the plant and expect instant deliveries within a short lead time. Such a "pull" inventory system al-

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lows the DCs' to easily adapt their orders from day to day in line with demand; however, this creates high fluctuations in shipment volume. The company is interested in shifting more transport volume from trucks to trains or barges with the intent of saving cost and operating more sustainably. From interviews with managers, a practical challenge with the implementation of MST is to synchronize the more rigid slow transport modes with the more flexible fast transport mode without harming service levels or increasing inventories.

More specifically, train or barge operations are subject to restrained schedules and often have lower delivery frequencies than trucks. These schedules generally remain fixed over a long period (e.g., half of a year to 1 year), and firms are required to commit a fixed loading quantity over the period in advance to obtain a low transport cost. For example, a shipper needs to fix ten containers on the train from Antwerp (Belgium) to Hamburg (Germany) every Monday for the entire calendar year. Therefore moving from truck transport to MST also implies a change in the inventory control policy from a pure "pull" strategy to a hybrid "push–pull" strategy. Due to the long-term commitment, the slow mode shipments can be viewed as the inventory that is pushed to the DCs, while the more flexible fast mode shipments contain inventory that is pulled by the DCs. Against this background, we develop an MST policy that should consider the simultaneous usage of both modes, i.e., trucks and trains/barges in a single transport corridor, and incorporate the costs from inventory management. Although transport and inventory decisions require an integrated approach, practitioners often struggle to holistically implement the required policies. The fundamental objective of this research is to develop an insightful and easy-to-implement modal split policy to guide practitioners in real-world MST problems.

In this paper, we develop a single-product–single-corridor stochastic MST model with two transport modes considering a hybrid push–pull inventory policy. The model covers the following setting. A firm delivers a product from a plant to a DC and has to decide how to split the delivery quantity into two transport modes: a slow mode that is rather rigid in terms of time and delivery quantity, i.e., the firm has to commit to a fixed quantity to be shipped at specific time points, and a fast mode that operates every period and has full flexibility in terms of delivery quantity but also at higher transport cost than the slow mode. Whereas the "fast mode" in our research clearly indicates truck, the "slow mode" is not necessarily a certain mode but can also mean a mixed strategy using trucks and trains/barges. The firm aims to minimize the expected transport- and inventory-related costs by optimizing the fixed slow mode quantity that is committed in advance (push) and the delivery policy for the more flexible fast mode (pull).

Our MST model has a structural form comparable to the tailored base-surge (TBS) model studied in the dual-sourcing literature where firms split their orders into a fixed "base" quantity ordered from a cheap oversea supply source and a flexible "surge" quantity ordered from a more expensive but fast supply source (Allon & Van Mieghem, 2010).

The primary difference between our MST model and the classical TBS model is that the TBS model assumes that both slow mode and fast mode orders have identical delivery frequencies. Our MST model considers different delivery frequencies of the two modes based on the fact that trains/barges operate less frequently than trucks. Therefore, our MST model is a generalization of the classical TBS model. To the best of our knowledge, this is the first paper that makes this generalizing assumption.

However, previous studies have shown that the TBS model is not amenable to exact analysis, mainly due to the tractability of the expected overshoot analysis (e.g., Allon and Van Mieghem, 2010; Janakiraman, Seshadri, and Sheopuri, 2014; Janssen and de Kok, 1999, and Boute & Van Mieghem, 2014). The authors exclusively rely on a "heavy traffic" analysis in a GI/G/1 queue to derive a closed-form expression for the expected overshoot. Unfortunately, this "heavy traffic" phenomenon cannot be guaranteed in our MST model since slow mode deliveries are less frequent than fast mode deliveries. The different delivery frequencies result in all periods within a cycle (the time between two slow mode deliveries) being structurally different in a steady state. Therefore, the approximations of the classical TBS problem do not successfully work for the more general MST problem.

To obtain an analytical solution that is applicable in a practical environment, we use the deterministic benchmark (i.e., demand is perfectly known) as a starting point to identify key drivers and determinants of the volume allocation between the two transport modes. Based on these findings, we propose different tailored approximations of the cost function for different ranges of cost parameters (mainly with respect to transportation cost savings and inventory holding cost). These approximations allow us to derive closed-form expressions for the modal split policy, i.e., a fixed shipment quantity allocated to the slow mode and a base stock policy for the fast mode, which is an easy-to-implement tool for supply chain managers.

A numerical performance study with a wide range of parameters, suggested by the company, reveals that our approximation has sufficient accuracy compared to optimal solutions calculated using complete enumeration. On the test bed, the approximation error is less than 3%, and the computing time is only a fraction of the complete enumeration.

The analytic characterizations of our results capture the key trade-off of the MST problem: a *commitment effect* and a *cycle stock effect*. The commitment effect refers to the long-term commitment of the constant quantity in the slow mode enabling the reduction of transport cost compared to the fast made. The cycle stock effect refers to the higher shipping quantity in the slow mode that potentially increases the inventory holding cost. Interestingly, the marginal effects can be simply determined by two parameters that frame the solution for the MST problems. We characterize these key drivers of volume allocation in the slow mode as follows: (i) the unit transportation cost savings of the slow mode compared to the fast mode and (ii) the volatility of the stochastic demand. This appears counterintuitive to many supply chain managers' beliefs: they often assume that the size of this fixed volume should not exceed the lower bound of the demand over the entire period when committing a constant volume in the slow mode in the long run. The presumption is that the volume that is delivered in the slow mode should always be consumed before the next slow mode delivery arrives. This is a major disadvantage of the practitioners who only treat MST as a pure transport problem.

Further insights from the numerical study reveal that for a typical "Runner" product of the industry with high expected demand and low demand variability (Relph & Milner, 2015), the optimal volume allocated to the slow mode could be as high as 85% of the expected demand. This surprisingly high ratio supports our findings and indicates that a holistic approach to jointly decide on inventory and transport mode is essential.

The remainder of this paper is organized as follows. In Section 2, we review the relevant literature. Next, we formulate the MST model in Section 3. In Section 4, we analyze the MST policy and derive approximate analytic solutions. In Section 5, we provide numerical results that highlight the error of our approximation and the potential volume split for both modes. We also present a model extension that considers volume-dependent transportation cost. In Section 6, we summarize our research and discuss further avenues of MST.