Optimal dynamic order scheduling under capacity constraints given demand-forecast evolution

Abstract: Mitigation of supply-demand mismatches is instrumental in increasing and sustaining profitability of manufacturers. Callioni et al. (2005) estimated that the mismatch costs account for 8-14% of total revenue for a computer manufacturer. It would be possible to reduce these mismatch costs by developing market-responsive supply chains for products with highly uncertain demand. However, the ability to implement market-responsive strategies is limited by capacity constraints. On one hand, manufacturers with limited production capacity may need to start production well in advance of the realization of actual demand to minimize lost sales. On the other hand, postponing production allows manufacturers to work with more accurate demand forecasts. In a multi-product setting, manufacturers may optimize their capacity usage by reserving the capacity during off-peak periods (i.e., speculative capacity) for products with predictable demand while using the capacity during peak periods (i.e., reactive capacity) for products with highly uncertain demand (Fisher and Hammond 1994, Fisher et al. 1997, Cattani et al. 2008). Although some fashion retailers successfully implemented this strategy and achieved a significant reduction in supply-demand mismatches (Fisher et al. 1997), it might actually be optimal to produce a portion of standard (innovative) products with predictable (uncertain) demand by using the reactive (speculative) capacity. Cattani et al. (2010) suggested that companies manufacturing customized products may fill their idle capacity with standard product to smooth production and effectively amortize high fixed costs. We develop an analytical model to answer the question: How can manufacturers optimally allocate their production capacity between different products with evolving demand forecasts?

We develop a dynamic programming (DP) model to solve the dynamic scheduling problem of manufacturers. We use both additive and multiplicative versions of the martingale forecast-evolution process to model the evolution of demand forecasts. We first develop a
stochastic dynamic optimization model and provide expressions for the optimal production schedules for a single-product problem under a capacity constraint. We show that manufacturers with low production capacity can realize most of their potential profits by slightly increasing their production capacity.

Building a facility close to the market is expected to be costlier than building one far away from the market. Thus, manufacturers that are willing to build a production facility should often choose between a high-capacity facility far away from the market and a low or moderate-capacity facility close to the market. We show that companies can benefit more from a low-capacity but responsive facility than a high-capacity facility far away from the market even for the product with moderate demand uncertainty. In practice, however, capacity expansion is considered more effective than lead-time reduction in reducing mismatch losses when companies rationalize their decisions on long-distance sourcing. Therefore, our results can be considered as counter-intuitive in practice.

We later extend our results to the multi-product problem and derive expressions for the optimal schedules under a shared capacity constraint. We apply our derivations to a two-product model and show that the more positively correlated the demand for the products, the more utilized the capacity in earlier periods. We interpret this result such that the probability of observing demand peaks for all the products is relatively high under positive correlation. Therefore, it is optimal to utilize the capacity more in earlier periods under positive correlation in order to mitigate potential stock-out risks. Under negative correlation, the changes in demand forecasts are expected to be in opposite directions, allowing the manufacturer to profitably postpone production and to get more benefits from accurate demand forecasts.
References:


