A Risk Sharing Coordination Mechanism for Customized Mass Production

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Abstract

Market demand for consumer goods is typically met by a supply network whose members should provide extremely high service level and operate, at the same time, with mass production's efficiency. The paper presents a new supply coordination mechanism that minimizes the system-wide expected total production and logistic costs, even if decisions are made locally. By sharing the risk of serving an uncertain market, the mechanism drives the partners towards truthful information sharing and making rational production related decisions.

1 INTRODUCTION AND RELATED WORK

In customized mass production, one of the main requirements is to satisfy end-customer demands at a high service level. Since acceptable delivery times are usually much shorter than actual throughput times, enterprises must plan their production and procurement based on forecasts. Forecasts are, however, uncertain and this uncertainty leads to either over- or underproduction, which cause unsaleable obsolete inventory or additional costs (e.g., lost sales, backorder, production in overtime, etc.). The uncertainty in the demand is hard to avoid or decrease, and in addition to that, the partners in the supply chain further deteriorate the network's overall efficiency if their individual objectives are not aligned with the ultimate objective of serving customer markets at the lowest possible cost.

The idea of coordinating supply chains with contracts has got into the center of the interest in the last decade. Almost every model assumes the so-called newsvendor-type problem, because it is sufficiently rich to study the most important questions of coordination, despite its simplicity. An exhaustive review on this subject is presented in [1]. A generic framework for all the most widespread contract types, like *backup agreement*, *quantity flexibility contract* and *pay-to-delay capacity reservation* is developed and analyzed in [2]. This approach is further studied in [3], where information asymmetry is introduced into the framework.

In our previous works, we introduced a *logistics platform* which supports information sharing and coordination in supply chains. We took a decomposition approach: the platform detaches the short-term decisions for providing *high service level* and the medium-term decisions for *efficient production*. We also developed algorithms that take into consideration the market uncertainty and support lot sizing decisions on a multi-period horizon [4,5]. Furthermore, we presented a newsvendor-type model for determining production quantity: it minimizes the expected total cost by finding a trade-off between the risk of producing obsolete inventory and a potential extra setup caused by *emergency production* [6].

In this paper—after a brief review and further analysis of the newsvendor model—we introduce a *risk sharing contract* between the supplier and the manufacturer. This model guarantees *channel coordination*, i.e., aligns the local objectives of the partners with the supply chain's overall objective. With such a mechanism, distributed decisions lead to improved efficiency in the whole supply chain.

2. THE CENTRALIZED NEWSVENDOR MODEL

The standard newsvendor model (see e.g., [7]) describes the inventory problem of perishable goods, when stocks cannot be carried from one period to another. This can be used in the situation, when a manufacturer purchases components from suppliers and assembles the end product. Since the market demand is unpredictable, either shortage or excess may occur. Both incur a cost that is proportional to the deviation from the purchased quantity. This means, that there is no fixed cost in case of shortages. It is also assumed, that the supplier can satisfy all demand.

We started from this model to examine the end of product life-cycle—which is fairly frequent in case of customized products. We regard high service level the primary objective, hence the manufacturer has to satisfy all market demand. This may necessitate an additional ordering from the supplier and paying another setup. To model this case, the standard newsvendor should be modified accordingly.

In our model, the manufacturer determines the order quantity (q) and purchases q . We assume the demand ξ is a random variable from *logistic distribution* with parameters m and b , whose expectation value and variance are m and $\sigma^2 = \pi^2 b^2 / 3$ respectively. If $q < \xi$, the demand can be satisfied only with an additional order. So the expected total cost consists of the expected cost of setup, purchase, obsolete surplus and emergency setup. As we have shown earlier [6], the optimal quantity, which minimizes the expected total cost exist uniquely if $b < c_s / c_p$:

$$q^* = m - b \ln\left(\frac{bc_p}{c_s - bc_p} \right), \tag{2.1}$$

where c_s is the setup cost and c_p is the purchase price per item. Taking a particular industrial example with $m = 65553$, $c_s = 45331$ and $c_p = 3.29$, the shape of the expected total cost function can be seen in Figure 1.1.

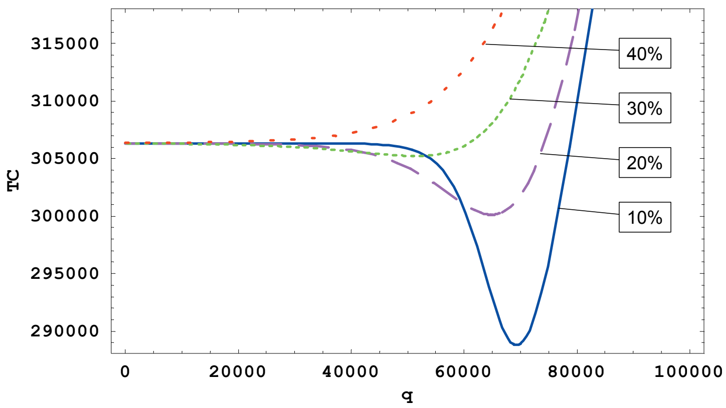

Figure 1.1. Deterioration of the cost function.

The percentage numbers (p) express the relative deviation from the expected demand, i.e., we determine the b parameter as $b = \sqrt{3}pm/100\pi$. When the deviation is low (e.g., $p = 10\%$), then an incorrect lot size causes significant raise in the expected total cost. The shape of the curve can be explained in the following way:

- there is a unique optimum given by eq. 2.1,
- decreasing q starting from the optimum increases the probability of the additional setup cost, however, the expected obsolete inventory is decreasing, therefore the function is bounded, and
- increasing q starting from the optimum, decreases the expected additional setup cost, but the expected obsolete inventory increases arbitrarily.

As the diagram shows, the minimal expected total cost grows together with the relative deviation. The curve with $p = 40\%$ —where $b > c_s / c_p$ —is *degenerated* in the sense, that it has no positive optimum. Note that the model is applicable also in case of production instead of purchasing, when c_p represents the production cost.

3. THE DECENTRALIZED NEWSVENDOR MODEL

In this chapter we consider a more realistic situation: a *two-echelon supply chain* with an end manufacturer and a supplier, having asymmetric information. The manufacturer is familiar with the end-product market, thus it makes forecast and estimates the distribution of the demand (m and b). A component is produced by the supplier, who knows the actual production and setup costs (c_p and c_s). The decentralization can effect suboptimal overall system performance, materialized in more obsolete inventory or unnecessary additional setup. The system-wide optimum (eq. 2.1)—the so-called *first-best solution*—provides a *lower bound* to the optimal achievable cost by any decentralized system.

Below we present such a *channel coordination mechanism*, which guarantees achieving the optimal lot size. We propose that the lot sizing decision has to be made by the supplier, who can schedule its own production, is responsible for holding the inventory and provides 100% service level towards the manufacturer. The mechanism also supports the *distribution of risks and benefits* fairly between the supplier and the manufacturer. The protocol of the purchasing is as follows:

1. The manufacturer *signal*s forecast information towards the supplier, but this may differ from its real knowledge (e.g., it can inflate forecast in order to avoid shortage). We denote these parameters by m' and b'.
2. The supplier decides about the lot size (q) and produces this quantity.
3. The manufacturer faces the demand (ξ), calls-off this quantity from the supplier and pays according to the payment function described below.

Note that if there is no information distortion (i.e., $m' = m$ and $b' = b$) and this is a common knowledge, the supplier is facing the centralized newsvendor problem with all required information, hence its rational lot sizing decision is also optimal on the system level. We introduce a payment scheme and prove that it inspires the rational manufacturer to truthful information sharing, thus coordinates the channel.

Since the supplier not only offers products, but also *flexibility* as a *service*, we propose a *composite payment scheme*: the manufacturer must pay not only (i) for the quantity called-off, but also (ii) for the deviation from the forecast, as well as (iii) for the forecast uncertainty. This payment compensates the supplier for the eventual obsolete inventory or the additional setup. Thus the partners share the cost caused by market uncertainty. The total payment scheme is the following:

$$P(m',b',\xi) = c_0\xi + \frac{c_1}{b'} d(m',\xi) + c_2(b'), \tag{3.1}$$

where c_0 and c_1 are constants: the pre-arranged unit prices for required components and inappropriate demand estimation, respectively. The term $d(m',\xi)$ is the deviation between the communicated and the realized demand and $c_2(b')$ is the compensation term for uncertainty. Note that the payment depends only on commonly known parameters.

A possible choice for measuring the deviation is the squared difference: $d(m',\xi) = (m'-\xi)^2$. In this case, the expected value of the payment becomes:

$$E\left[P(m',b',\xi)\right] = c_0 m + \frac{c_1}{b'}\left((m')^2 + m^2 - 2m'm + \frac{\pi^2 b^2}{3}\right) + c_2(b'). \tag{3.2}$$

This follows from the equation

$$E\left[(m'-\xi)^2\right] = \int_{-\infty}^{\infty}\left((m')^2 + x^2 - 2m'x\right)\phi(x)dx = (m')^2 + E\left[\xi^2\right] - 2m'm \tag{3.3}$$

where ϕ is the probability density function of the logistic distribution and $\sigma^2 = \pi^2 b^2 / 3 = E\left[\xi^2\right] - m^2$. Since the income of the manufacturer depends only on the demand and the market price, and is independent from its decision about m' and b' , therefore it can maximize its profit by minimizing the expected payment. The partial derivatives of the expected payment functions must be zero:

$$\frac{\partial E\left[P\left(m',b',\xi\right)\right]}{\partial m'} = \frac{c_1}{b'}\left(2m' - 2m\right) . \tag{3.4}$$

This equals zero iff $m' = m$, independently from choosing b' . As the second derivative test shows, this is a minimum. The other partial derivative must also equal to zero:

$$\frac{\partial E\left[P\left(m',b',\xi\right)\right]}{\partial b'} = \frac{\partial c_2\left(b'\right)}{\partial b'} - \frac{c_1 \pi^2 b^2}{3\left(b'\right)^2} , \tag{3.5}$$

where we have already exploited that $m' = m$. If we define the compensation for uncertainty as $c_2\left(b'\right) = c_1 \pi^2 b'/3$, the derivative becomes zero iff $b' = b$. The second derivative is positive again, therefore it is a minimum. Summing up, the payment function $P\left(m',b',\xi\right) = c_0 \xi + c_1 \left(m' - \xi\right)^2 / b' + c_1 \pi^2 b'/3$ inspires the manufacturer to signal the best known forecast parameters, therefore our protocol achieves channel coordination, i.e., optimal overall performance.

4 DISCUSSION

The solution concept of the centralized newsvendor was tested on real industrial data of customized components of consumer products at the end of their life-cycles. In lack of space, we refer to [6], where some test results can be found.

We also made sensitivity analysis of the decentralized model by varying all its parameters. In Figure 4.1 an illustrative example can be seen, where m varies, while other parameters are fixed ($c_s = 5000$, $c_p = 3$, $c_0 = 5$, $c_1 = 1$ and $b = 300$). Every bar denotes a mean made on 100 simulation runs. The wide bars represent the payments, which consist of the price of the delivered components (the majority of the payment), the compensation for the deviation (the middle part) and the compensation for the uncertainty (on the top). The narrow bars are the measured costs for the supplier. As the figure shows, m strongly influences the profit of the supplier: decreasing m —together with the supplier's commitment to 100% service level—leads to serious deficit. This could be compensated only by increasing c_0 or c_1 , but our model assumes that these prices are fixed before the forecast is known. However, the model should be applied at the end of the product life-cycle, when the losses are often unavoidable. Hence, it can inherit the cost parameters from the multi-period problem, which will be examined as future work. Moreover, such simulations help the supplier estimating cost and determining prices in advance.

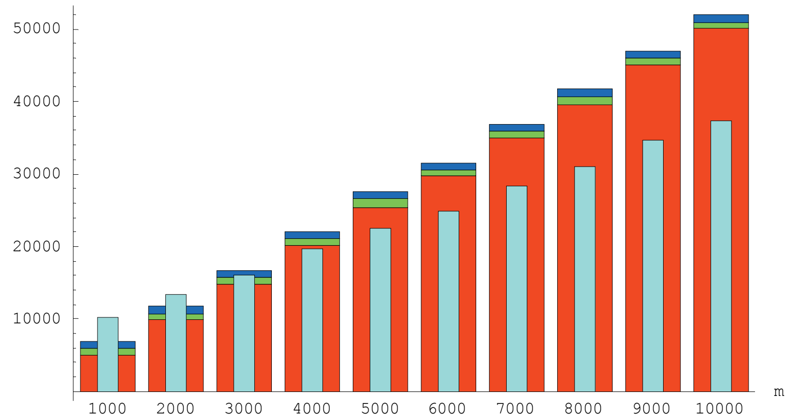

Figure 4.1. The forecasted quantity's impact on the payment and cost.

In the future, we will continue our study of the decentralized model with asymmetric information on multi-period horizons. In this case, the medium term forecast is updated periodically and does not provide any statistical information such as variance. First, we need a measurement of the *forecast stability*, which should be in accordance with the expected cost of production, as we have examined in [5]. Then a similar coordination mechanism should be developed, which provides the manufacturer incentive to communicate undistorted information and compensates the supplier for the forecast instability.

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