Optimising Procurement Portfolios to Mitigate Risk in Supply Chains

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1 Introduction

In recent years the management of risk in supply chains has become an important issue in the scientific literature. This aspect is of primary interest in market side decisions of a company such as in the procurement of materials. So far, traditional supply chain planning methods solely focus on improving cost efficiency and reducing inventory buffers in supply chains. These approaches are successful as long as the assumption of a stable supply chain environment holds. But when risks on the demand side and on the supply side occur these approaches become contraproductive and make the supply chain more vulnerable. What is needed now are new concepts which improve the flexibility of supply chains even in uncertain environments. In this work we will investigate a mid-term procurement decision where the buyer has to agree with his suppliers on supply contracts while facing demand and supply risk. We assume that the buyer negotiates with multiple suppliers who can supply products with the same quality. The problem we are dealing with is how to design a portfolio of optimal supply contracts in a mid-term planning horizon (e.g. one year) by specifying minimum and maximum quantities of a product in a contract. The objective of our planning problem is to minimise the total expected cost of supply.

The related literature to this work can be divided into four streams. The first stream deals with the question of optimal supply contracts (e.g. [1]). Mainly, the authors use extensions of the newsvendor model and analyse optimal parameter settings of contracts within a supply chain. The second stream of literature is about supplier selection problems where the optimal number of suppliers is determined.

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Jayaraman et al. [3] developed a decision model for the supplier decision problem and also incorporated the allocation of supply into the contracted supplier pool. Harrison et al. [2] analyse the optimal number of suppliers in presence of volume discounts. They explicitly consider in their model the failure of suppliers and use different compensations to include this effect. The third stream of research covers the problem of optimal procurement planning and thereby selecting suppliers in the short-term (e.g. [8]). They consider suppliers where the buyer can order from different discount levels. The question which arises in this setting is to determine the optimal purchasing quantity and time of various suppliers simultaneously. Their approach fits best with models from the lot sizing literature and is suitable for high volume and low value (C type) products. The last stream of literature covers the problem of optimal procurement portfolios with supply options. Martinez de Albeniz and Simchi-Levi [6] first developed a portfolio approach where they combine different supply options for commodity products. In [7] a procurement risk management system is described which was developed at Hewlett-Packard (HP) when they were facing risks on the procurement markets of flash memories.

Our contribution is to provide a new portfolio approach for the mid-term procurement problem to optimise costs and mitigate risks. As opposed to previous portfolio approaches we consider supply and demand risks for multiple periods and address the issue of the supply chain context more precisely.

2 A Portfolio Approach

The fundamentals of Modern Portfolio Theory go back to the work of Markowitz [5]. Markowitz showed that a well selected combination of securities (financial contracts) outperforms every security on its own with respect to return and volatility of an investment. Grounded on this theory today many investors construct their optimal portfolios. Compared to the situation on financial markets the procurement market is not that different. Here, purchasing managers have to make their investments in supply contracts. They have to weigh the cost of the contract against the risk and the flexibility a supply contract provides. Supply disruptions caused by supplier failure or even supplier bankruptcy have to be taken into account as well as uncertainties from the demand side when the available inventory runs out. Especially the problem of supplier failure often leads purchasing managers to choose more than one supplier. Another way to hedge against risks is to hold safety stocks for production but this will result in higher capital costs. Although the management literature uses portfolio techniques to analyse the procurement situation in this case they provide only limited decision support for a profound decision. To get a deeper understanding of supply contracts we will look at the components of a supply contract.

According to [6] we can distinguish between two kinds of contracts: First, fixed (commitment) or long-term contracts are agreements with suppliers where a certain amount of goods is bought in advance. The advantage of these contracts are a higher degree of planning certainty for the suppliers. Hence, suppliers can optimise their production planning and are able to offer better prices to the buyer. To give the buyer an incentive to buy higher volumes in advance suppliers often give some volume-dependent discounts. Second, short-term contracts are negotiated after an inquiry from the buyer for additional quantities is submitted that goes beyond the scope of the fixed contracts. In order to be prepared for this situation suppliers have to hold some inventory buffer. Another possibility for short-term supply are supplies from non-contracted suppliers or even from the spot market if existent when contracted suppliers cannot provide the requested amounts. Mostly, the price of this short-term transaction can be assumed to be higher than in the case of long-term contracts.

Besides these two kinds of contracts supply options combine aspects of both types of contracts. A supply contract is a right but not an obligation to buy up-to a certain amount of quantities within a pre-defined time to a previously agreed price. It is a powerful means to quantify the supply flexibility needed. Similar to fixed contracts supply options have to be purchased in advance before the actual demand occurs and the suppliers have enough time to considers this in their production planning. The buyer of the supply option has to pre-pay only a fraction of the total price to the supplier up-front, this is called the reservation price. If the buyer requests the reserved amount he has to pay an additional fee, the so-called strike price. All in all the costs of sourcing by supply options tends to be lower than a short-term transaction[1].

If we look at contract agreements in practise they typically have the form of quantity flexible contracts (cf. [1]) where the buyer agrees with the supplier on a minimum and a maximum amount of quantities to purchase. One can express a quantity flexibility contract as a combination of a fixed contract plus a corresponding supply option contract. The minimum quantity can be explained by a fixed or long-term part of this contract. The difference between the minimum and the maximum amount can be considered as the flexible part which can be modeled as supply options and added to the fixed contract. As we can see one can model various kinds of contracts by just specifying the fixed part and the flexible part. The question that appears at this point is whether a portfolio of different contracts from multiple suppliers can be optimised in terms of supply costs and risks from demand and supply side. In the following we strive to formalise this problem by an exact decision model.

3 Model Formulation

In this section we model our portfolio approach for procurement markets as a mathematical programming model. For the sake of simplicity we consider only a procurement problem with one product. We assume that we have a pool of S suppliers where each of the suppliers $s \in \{1..S\}$ submits an offer for the minimum and maximum quantity over the whole planning horizon of T periods. On the basis

[1] From a modeling perspective short-term contracts can also be regarded as a specialised supply option where the buyer does not have to pay a reservation price in advance.

of our previous observation an offer consists of two parts. The first part specifies the pricing of the fixed quantities the buyer will purchase. Depending on the purchased quantities the supplier can offer up-to L discount levels. The second part of the offer specifies additional flexible quantities by supply options. For each amount of supply that the supplier has to reserve the buyer has to pay a reservation price Rp. In case these amounts are called an additional payment of Sp has to be made (strike price). A supplier s can offer V_{sl} different option contracts depending on the chosen discount level $l \in \{1..L\}$ for the fixed part.

In every time period $t \in \{1..T\}$ demand and supply processes take place. For both kinds of processes we assume that they are stochastic and can be expressed as a series of scenarios $r \in \{1..R\}$ where R is the total number of scenarios. We denote by D_t^r the demand in period t that has to be fulfilled in scenario r. Furthermore, we express the supply uncertainty due to supplier failures by a random factor Ω_t^{sr} in each period of a scenario. This value describes the fraction of a purchasing order that is actually delivered. Since we express the uncertainty of the model parameters by scenarios we are able to model our procurement decision problem as a stochastic linear programming (SLP) model. SLP enhances the well-known class of linear programming problems by stochastic elements. For further information see [4].

We employ a two-stage stochastic programming model where at the first stage the decision about the supplier selection and minimum and maximum quantities is taken. As described earlier we allow suppliers to give volume discounts which we model using a mixed integer technique proposed by Stadtler [8]. On the second stage purchasing order allocations are computed for given realisations of the uncertain parameters. This stage serves as an anticipation of a more detailed purchasing order decision in short-term planning in the sense of hierarchical planning. The deterministic equivalent SLP model of our mid-term purchasing planning problem can be stated as follows:

$$
\begin{aligned}
Min \sum_{s=1}^{S}\sum_{l=1}^{L} F^{sl}\cdot y^{sl} + \sum_{s=1}^{S}\sum_{l=2}^{L} p^{sl}\cdot Q^{s(l-1)}\cdot y^{sl} + \sum_{s=1}^{S}\sum_{l=1}^{L} p^{sl}\cdot q^{sl} + \sum_{s=1}^{S}\sum_{l=1}^{L}\sum_{v\in V_{sl}} Rp^{slv}\cdot o_{max}^{slv} \\
+ \sum_{s=1}^{S}\sum_{l=1}^{L}\sum_{v\in V_{sl}}\sum_{r=1}^{R} \pi_r\cdot Sp^{slv}\cdot o^{slvr} + \sum_{t=1}^{T}\sum_{r=1}^{R} \pi_r\cdot h\cdot I_t^r
\end{aligned}
\tag{1}
$$

subject to

$$q^{s1} \le Q^{s1}\cdot y^{s1} \qquad \forall s = 1..S \tag{2}$$

$$q^{sl} \le (Q^{sl} - Q^{s(l-1)})\cdot y^{sl} \qquad \forall s = 1..S, l = 2..L \tag{3}$$

$$\overline{q}^{s} = \sum_{l=2}^{L} Q^{s(l-1)}\cdot y^{sl} + \sum_{l=1}^{L} q^{sl} \qquad \forall s = 1..S \tag{4}$$

$$0 \le o^{slvr} \le o_{max}^{slv} \le M^{slv}\cdot y_{sl} \;\forall s = 1..S, l = 1..L, v \in V_{sl}, r = 1..R \tag{5}$$

$$\sum_{t=1}^{T} x_t^{sr} = \overline{q}^s + \sum_{l=1}^{L} \sum_{v \in V_{sl}} o^{slvr} \qquad \forall s = 1..S, r = 1..R \tag{6}$$

$$0 \leq x_t^{sr} \leq Cap_t^s \ \forall s = 1..S, r = 1..R, t = 1..T \tag{7}$$

$$I_t^r = I_{t-1}^r - D_t^r + \sum_{s=1}^{S} \Omega_t^{sr} \cdot x_t^{sr} \qquad \forall t = 1..T, r = 1..R \tag{8}$$

$$y^{sl} \in \{0,1\} \ \forall l = 1..L \succ SOS1, s = 1..S \tag{9}$$

The objective (1) is to minimise the expected total costs of supply, i.e., of decisions taken in the first and second stage. The binary decision variables y^{sl} represent the decisions about the supplier selection and the appropriate discount level. The subsets of variables associated with each supplier form Special Ordered Sets of Type 1 (SOS1) since only one discount level of a supplier can be valid at a time (Eq. 9). However, a portfolio of more than one supplier is possible.

The first stage costs are displayed in the first line of the objective function. The first term contains fixed costs F^{sl} associated with supplier discount level l ($y^{sl} = 1$, otherwise $y^{sl} = 0$). The next two terms represent the minimum purchase cost at the limits of the discount interval Q^{sl} plus the fixed purchase amounts q^{sl} within the discount intervals both incurring a purchase cost p^{sl} per unit. The last term in the first line expresses costs for additional flexible quantities o_{max}^{slv} caused by the supply option with the reservation price Rp^{slv} .

The second stage costs (the second line) comprise the expected costs when the amount of supply options o^{slvr} are called at the strike price Sp^{slv} in scenario r and the expected holding costs that are charged for the on-hand inventory I_t^r at the end of period t for each scenario r . Here, h denotes the unit holding costs per period and π_r the probability for scenario r .

Inequalities 2 and 3 describe the discount intervals proposed by the suppliers. The total minimum quantity per supplier $\overline{q}^s$ is calculated in Equation 4. The flexibility modeled via supply options is restricted in Equation 5. The actually called quantities o^{slvr} from an option $v \in V_{sl}$ are limited by the supply options o_{max}^{slv} and the maximal available amount M^{slv} . The ordering quantities x_t^{sr} from a supplier s in period t have to be part of the supplier's agreed contract with fixed and flexible quantities $\overline{q}^s$ and o^{slvr} , respectively. In each period t , these quantities must not exceed the capacity boundary Cap_t^s of the supplier (Eq. 7). The inventory level I_t^r is balanced in Equation 8. Note, that supply risk has to be considered at this point and therefore not all ordered quantities can be used to fulfill the demand.

4 Numerical Example & Conclusion

To illustrate the effects of the proposed model we will use a simple numerical example. We consider a procurement situation with $S = 4$ suppliers where each of them offers $L = 3$ discount levels. Our planning horizon for contracts is $T = 50$. To keep this example simple we further assume an independent failure rate ω for all suppliers leading to random factors $\Omega_t^{sr} \sim B(1, 1-\omega)$ and identical supply costs[2]. The demand D_t^r for each period follows an independent Normal distribution with $D_t^r \sim N(100, \sigma^2)$. Table 1 shows the results of the numerical examples with $R = 30$

	$\sigma = 33$				$\sigma = 66$				$\sigma = 100$			
ω	avg # supl	avg. obj	avg fix qty	avg flex qty	avg # supl	avg. obj	avg fix qty	avg flex qty	avg # supl	avg. obj	avg fix qty	avg flex qty
0	1	238,816	2025	2947	1	244,509	2021	2955	1	251,026	2020	2971
0.01	1	236,525	2000	3137	1	242,448	2000	3303	1	249,393	2004	3485
0.05	1.91	240,025	2039	3370	1.79	245,305	2032	3813	1.73	252,621	2044	4259
0.10	2.69	246,034	2074	3374	2.66	251,649	2065	3860	2.46	258,361	2077	4342

Table 1 Results of the numerical example

scenarios. The values are computed as an average over 100 simulation runs. With an increasing supplier failure rate ω the number of contracted suppliers increases. This is intuitive since the buyer can diversify the contracted suppliers to ensure supply. Interestingly, with an increasing demand volatility the number of suppliers seems to decrease. This observation can be explained by the suppliers' commitment to more flexibility when the fixed volume increases.

In this work we presented a portfolio approach for the mid-term procurement problem, which can be seen as a first step towards a quantitative evaluation of procurement strategies when risk hedging mechanisms have to be considered explicitly.

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[2] $p^{s1} = 100, p^{s1} = 98, p^{s3} = 95$ with $Q^{s1} = 500, Q^{s2} = 1000, Q^{s3} = 5000$ and only one supply option ($\|V_{sl}\| = 1$) for each price level $Rp^{s1} = 21, Rp^{s2} = 14, Rp^{s3} = 12$ with $Sp^{s1} = 92, Sp^{s2} = 92, Sp^{s3} = 92$ and flexibility limits $M^{s1} = 0, M^{s2} = 1000, M^{s3} = 5000$