**ABSTRACT**

Hospitals derive the benefits of economies of scale by single sourcing from large distributors of medical/drug supplies. However when shortage hits the supply chain, procurement managers buy from secondary market with a very high premium that increases the service providers’ total cost. In this paper, we analyze the benefit of diversifying distributor into multiple tiers for the service provider (hospital) under stochastic shortage when the medium-sized distributor promises a ‘cut-out’ or additional allocation of purchase volume. We model the problem using two stage-stochastic programming and conduct complete enumeration for the first stage objective function to obtain optimal volume mix. We find that there is an interaction effect between the amount of cut-out from medium-sized distributor and availability on the optimal purchase volume between the tiered distributors when shortage cost is low. As the amount of cut-out increases, its impact on cost savings becomes greater.

**Keywords:** Distributor Diversification, Healthcare, Supply Chain, Collaborative Relationship

**INTRODUCTION**

Procurement managers in health care industry are trying to find efficient and cost competitive ways to minimize supply chain costs. Single sourcing medical/drug supplies through technological collaboration such as JIT and EDI substantially increases the benefit of economies of scale (HIDA 2012). However, in recent years, a number of reports show that unexpected shortages in the supply chain have caused havoc in the U.S. health care system (Mitchell, 2012; Kane, 2011; Field, 2011). When shortages occur, hospitals and pharmacists are forced to buy the required products at double the rate or turn to secondary market with a high premium (even as high as 650% for life-saving drugs), and sometimes with safety concerns (Premier, 2011; Kane, 2011; Rosenthal, 2012).

Large hospitals or networks of small hospitals have created close relationships with a primary distributor leading to collaborative practices (Schneller and Smeltzer, 2006; Gnanlet and Choi, 2013) such a JIT and electronic purchase order. Under collaborative relationship distributors would have a long-term close interaction with the service provider. Single sourcing through collaborative relationships using a large distributor (e.g., Cardinal Health Systems, McKesson Corporation, AmeriSource Bergen Corp, Value Expectations, 2010) may be effective and convenient when orders are completely available for fulfillment, but are not effective when shortages occur. During periods of shortage, procurement managers’ only choice is to expedite vital supplies and drugs from secondary market.
This research has been initiated based on interviews with purchasing managers of a large hospital in California which has an annual purchasing budget over 10 million USD. Further interviews with large and small hospitals indicated that hospitals are exploring an option of creating transactional relationships with medium-sized distributors (e.g., Premier Health Services (PHS), Owens & Minor, Inc., Medtronic International Ltd.). Transaction relationship is generally a short-term relationship and tends to incur low initial set-up cost, but would have high purchase-based transaction cost (Schneller and Smeltzer, 2006). This leads to a question: What would be the impact of distributor diversification on service provider’s purchasing cost when the service provider sources from a large distributor through collaborative relationship and from a medium-sized distributor through transaction relationship, who is willing to offer a ‘cut-out’ (additional allocation) during shortages when the service provider promises a portion of the yearly purchase order to medium-sized distributor. Medium-tier distributors may offer the hospitals additional allocation called ‘cut-outs’ over the commonly available order quantity when shortage hits.

In this paper we analyze the following research questions: What is the benefit of distributor diversification into multiple tiers on service providers’ cost and varying conditions of shortage and availability? What is the optimal volume mix that the service provider should decide between large distributor (Distributor 1) and medium distributor (Distributor 2) based on purchasing relationship and available inventory when the cut-out is offered by the medium-sized distributor during shortages. A large service provider would be willing to promise a portion of their yearly purchase volume to a medium-sized distributor in return for safety stock during shortages called ‘cut-out’.

We assume shortages that hit the supply chain is stochastic, and we develop a two-stage stochastic programming model that minimizes the total purchasing cost of the service provider including the initial set-up cost based on collaborative or transaction relationship, the expected shortage, and the purchase cost. Our preliminary analysis shows that under no shortage situation, distributor diversification is still beneficial for the service provider. We also find that there is an interaction effect between the cut-out amounts and availability on the optimal volume mix when shortage cost is low. As the amount of cut-out increases, its impact on cost savings becomes larger. In the remainder of the paper, we formulate the model, present preliminary numerical experimentation, discuss results, and conclude this paper.

**PROBLEM DEFINITION AND MODEL FORMULATION**

In this section, we define the notations and formulate the model. A large service provider sources from two distributors, a large distributor, identified as Distributor 1 and a medium-sized distributor, identified as Distributor 2. The decision variable, \( v_{m1} \) represents the proportion of annual purchase volume (i.e. volume mix) ordered from distributor i. The large distributor, Distributor 1 using collaborative relationship has an annual purchase order volume of \( v_{m1} \cdot PO \), where \( PO \) is the total annual purchase order volume from service provider while medium-sized distributors’ annual purchase volume is \( v_{m2} \cdot PO \) (where \( v_{m1} + v_{m2} = 1 \)).

Distributor 1’s use of high technology to maintain collaborative practice will incur high initial setup cost (\( sc1 \)) but lower unit purchase price (because of economies of scale) while distributor 2’s transaction based strategy will incur lower initial setup cost (\( sc2 \)) but higher unit purchase price. Due to service provider’s increased use of technology for ordering higher volumes from
Distributor $I$, we assume $sc_I$ to be a convex increasing function of $vm_1$. On the other hand, due to lower transaction cost per order transaction when ordering from Distributor 2, we assume $sc_2$ at the service provider decreases at a decreasing rate over $vm_1$. As the proportion of purchase volume ($vm_I$) increases for Distributor $I$, the proportion of purchase volume ($vm_2$) for Distributor 2 decreases.

*Notations:*

- $vm_i$: proportion of purchase volume allocated to distributor $i$ or volume mix
- $PO$: yearly purchase order quantity for service provider
- $sc_i(v_1)$: setup cost based on transaction or collaborative relationship for distributor $i$
- $P_{avg}$: average unit price when purchased from distributor $I$
- $pf_i(v_1)$: discounted price factor for distributor $i$
- $p$: ratio of shortage cost (or penalty cost for buying from secondary market) to average unit price
- $c$: cut-out amounts from distributor 2
- $\alpha$: realization of stochastic availability
- $\Phi$: probability distribution for the random variable availability, $\alpha$

$P_{avg}$ represents the average price per unit when the service provider purchases from Distributor $I$. Distributor $I$ and Distributor 2 provide varying price discounts in view of their purchasing relationship, and volumes. The discounted price factors for the per-unit price are represented by $pf_i$ for distributor $i$ and is a decreasing function of $vm_i$. We assume the discount price schedule for each distributor to be identical in this paper. Variations in price schedules are presented in the full paper.

Service provider orders the total purchase volume of $(vm_1 + vm_2) \cdot PO$ (or just $PO$ since $vm_1 + vm_2 = 1$). When shortages hit the supply chain, the amount that the service provider would receive is less than $(vm_1 + vm_2) \cdot PO$ and is equal to $\alpha \cdot (vm_1 + vm_2) \cdot PO$, where $\alpha$ is a random variable between 0 and 1 representing availability with probability density function $\Phi$. When a part of the order $((1 - \alpha) \cdot PO)$ is not delivered, the service provider will buy the shortage amount at a very high premium ($p$) from the secondary market, where $p$ represents the ratio of the shortage cost to average price per unit.

To alleviate the problems due to shortages, the service provider diversifies to medium-sized Distributor 2, who is willing to supply an additional cut-out, $c \cdot PO$, on top of the common availability $\alpha \cdot PO$. The medium-sized Distributor 2 would appreciate the expected business from service provider and provide additional incentive for the large service provider by offering the cut-out, $c \cdot PO$ during shortages.

The sequence of events is explained as follows: In stage 1, service provider invests in set-up cost for each distributor $i$, $sc_i(vm_i)$, with the expectation of buying an annual volume of $vm_i \cdot PO$. In the process of meeting the purchase orders, distributors face unexpected events of shortage and are unable to deliver the total order quantity. Therefore, in the second stage, only a portion of the order $(\alpha \cdot vm_i \cdot PO)$ is delivered to service provider from distributor $i$. In addition, Distributor 2 provides the cut-out $(c \cdot vm_2 \cdot PO)$ to the service provider when shortage hits. At the end of the period, we determine the service provider’s total procurement cost of diversifying distributors under unexpected shortages.
Objective function:

\[
\min_{v_i} \sum_i s_{ci}(v_1) + PO \cdot P_{avg} \cdot E\{p[(1 - \alpha) \cdot v_1 + (1 - (\alpha + c)) \cdot v_2]\}
+ [\alpha \cdot v_1 \cdot pf_1(v_1) + \alpha \cdot v_2 \cdot pf_2(v_1) + \min((1 - \alpha), c \cdot v_2) \cdot pf_2(v_1)]
\]

(1)

subject to \quad 0 \leq v_i \leq 1 \quad \& \quad \sum_i v_i = 1, \quad i = 1, 2

Equation (1) represents the first stage objective function: the sum of initial set-up costs either due to collaborative or transaction relationship and expected second stage cost which includes the relevant expected shortage cost and expected purchase cost. When a shortage hits, distributors will deliver a portion of the order quantity \(\alpha \cdot PO\) re-written as \(\alpha \cdot vm_1 \cdot PO + \alpha \cdot vm_2 \cdot PO\). The shortage amount that the service provider incurs is \((1 - \alpha) \cdot vm_1 \cdot PO\). Since Distributor 2 promised a cut-out amount \(c\) to the service provider in addition to the common availability \(\alpha\) the effective shortage from Distributor 2 is expressed as \((1 - (\alpha + c)) \cdot vm_2 \cdot PO\).

When distributor \(i\) delivers \(\alpha \cdot vm_i \cdot PO\) to the service provider, the purchase cost for service provider is \(\sum_{i=1}^2 \alpha \cdot vm_i \cdot PO \cdot pf_i(vm_i) \cdot P_{avg}\), where \(pf_i(vm_i)\) is the discounted price factor set by distributor \(i\) depending on volume mix \(vm_i\). The service provider will also incur a purchase cost for the additional allocation of \(c \cdot vm_2 \cdot PO \cdot pf_2(vm_1) \cdot P_{avg}\) at a discounted price factor of \(pf_2(vm_1)\) from Distributor 2.

We found that the second stage objective function is linear in its decision variables and we obtained optimal allocations for the second stage. We substitute the optimal second stage solution in the first-stage objective function. Since the first stage function is hard to solve, we perform complete enumeration to obtain the optimal first-stage decision variable, volume mix.

**EXPERIMENTAL DESIGN**

Our preliminary experiment is limited in its scope in order to observe the model’s behavior before we extend it to full-factorial experiment. We design a three factor, two level experiment: low and high levels for the shortage cost ratio \(p\), the availability \(\alpha\), and the cut-out amount \(c\). The shortage cost is \(p \cdot P_{avg}\) where \(p\) is the ratio of penalty mark-up price for the service provider buying from the secondary market to average price per unit. We look at two levels, low and high as multiples of the average market price per unit, \(P_{avg}\). Research shows that mark-ups offered in 96% of cases are at least 200% their normal price, and 45% are at least 1000% the normal price. For our analysis, we assume \(p\) to be 2 for low and 8 for high, representing 200% and 800% of the average price per unit.

We assume availability of the order \(\alpha\) follows a general, continuous distribution. However, to gain insights at this stage, we evaluate a deterministic model with two levels of \(\alpha\): low (0.2) and high (0.8). This indicates that 20% or 80% of the total order placed by the service provider will be available for delivery from the distributors. \(c\) is the cut-out from distributor 2 to the service provider when shortages occur and the two levels of \(c\) are 0.05 (low) and 0.15 (high). This indicates a cut-out amount of 5% and 15% over and above the purchase volume from distributor.
2. Table 1 summarizes the parameter values for the experimental design.

**PRELIMINARY RESULTS AND DISCUSSIONS**

We present some results here. The complete set of results from full-factorial experiment is presented in the full paper.

**Base Case Scenario**

Initially, we analyze a simple base case where availability $\alpha$ is 1 (no shortage). The value for cut-out is not relevant because of no shortages. In the base case, the optimal proportion of volume purchased from Distributor 1 is much higher ($v_1^*=0.82$) than the volume purchased from Distributor 2 ($v_2^*=0.18$) (see Figure 1). This shows that the benefit of establishing collaborative relationship between the service provider and Distributor 1 which results in a higher purchase volume from Distributor 1.

![Figure 1 Base case cost curve](image1.png)

**Figure 1 Base case cost curve**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cut-out, $c$</td>
<td>0.05</td>
<td>0.15</td>
</tr>
<tr>
<td>Availability, $\alpha$</td>
<td>0.2</td>
<td>0.15</td>
</tr>
<tr>
<td>Shortage cost ratio, $p$</td>
<td>2</td>
<td>8</td>
</tr>
</tbody>
</table>

**Table 1: Parameter values for experimental design**

<table>
<thead>
<tr>
<th>$c$</th>
<th>$\alpha$</th>
<th>$%$ Cost Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.2</td>
<td>0.65</td>
</tr>
<tr>
<td>0.05</td>
<td>0.2</td>
<td>0.525</td>
</tr>
<tr>
<td>0.15</td>
<td>0.2</td>
<td>0.33</td>
</tr>
</tbody>
</table>

**Table 2: Optimal volume mix cut-out and availability increases.**

<table>
<thead>
<tr>
<th>$c$</th>
<th>$\alpha$</th>
<th>$%$ Cost Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.72</td>
<td>-</td>
</tr>
<tr>
<td>0.05</td>
<td>1.555</td>
<td>3.50%</td>
</tr>
<tr>
<td>0.15</td>
<td>0.29</td>
<td>14.15%</td>
</tr>
</tbody>
</table>

**Table 3: Optimal volume mix and percentage cost savings for a given $c$ compared to $c=0$**

<table>
<thead>
<tr>
<th>$\alpha$</th>
<th>$%$ Cost Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>0.72</td>
</tr>
<tr>
<td>0.15</td>
<td>0.29</td>
</tr>
</tbody>
</table>

**Table 4: Optimal volume mix as when shortage cost ratio increases.**

![Figure 2: Cost curves for availabilities and shortage costs.](image2.png)
Impact of Availability on Volume Mix

We observe an interaction effect between cut-out and availability on the optimal volume mix at a low shortage cost. As depicted in Figure 2, as availability increases at low shortage cost and low cut-out (refer dashed lines in Figure 2.A and Figure 2.B), the optimal volume mix increases, and the service provider purchases large volumes from Distributor 1. However, at high cut-outs, the optimal volume mix decreases as availability increases (refer dotted lines in Figure 2.A and Figure 2.B). The optimal values are presented in Table 2. When $c$ is low (0.05) and availability increases from 0.2 to 0.8, optimal volume mix increases from 0.525 to 0.715. However, when $c$ is high (0.15), the optimal volume mix decreases from 0.330 to 0.255 as availability increases showing an interaction effect between cut-out and availability on volume mix. Furthermore, when availability increases at higher shortage cost, we do not find such interaction effect, but the optimal volume mix continuously decreases for any given cut-out amount $c$ (see Figure 2.C and Figure 2.D).

Impact of Cut-out on Volume Mix and Total Cost

We observe that as $c$ increases from zero (refer Figure 2), the optimal volume mix $v_1^*$ shifts toward the lower end of $v_1$. As $c$ increases further, optimal volume mix continuously decreases. This shows that the service provider gains the benefit of cut-out from Distributor 2 by purchasing a higher volume from Distributor 2. The numerical values for average shortage cost and availability is shown in Table 3. Due to collaborative relationship with Distributor 1, when $c$ is zero, optimal volume mix $v_1^*$ is 0.720. When $c$ increases from zero to 0.05, the optimal volume mix quickly reduces from 0.720 to 0.275 largely favoring Distributor 2 because of the cut-out amount that helps mitigate shortages. In addition, the percentage cost savings for the service provider when cut-out $c$ increases from zero to 0.05 and from 0.05 to 0.15, increases at an increasing rate that is from 3.60% to 14.16% (refer second column of Table 3). Therefore, as the amount of cut-out amount increases, its impact on cost savings becomes greater.

Impact of Shortage Cost on Volume Mix

Table 4 shows that as shortage cost ratio increases, the optimal volume mix decreases (except when $c = 0$) because the cut-out amount from Distributor 2 becomes more valuable to the service provider. When there is no cut-out offered ($c = 0$), the optimal volume mix stays at the same level ($v_1^* = 0.720$) for all levels of shortage cost ratios.

CONCLUSION

In this paper, we derive the benefits of distributor diversification when a large service provider is hit with shortages. Compared to a typical strategy of single sourcing in health care, we analyze a policy where a service provider sources from dual distributors. A large purchase volume from a large distributor with collaborative practices; and a small proportion of purchase volume from medium-sized distributor practicing transaction relationship that offers an additional cut-out during shortages. We formulate the model using two stage stochastic programming and present an optimal solution through complete enumeration for the deterministic case. We find that
 diversification is beneficial even without any shortages. We observe an interaction effect between cut-out and availability on optimal volume mix at low shortage cost. As the amount of cut-out increases, its impact on cost savings becomes greater.

REFERENCES


