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FLEXIBILITY AS A FUNCTION OF ORDER QUANTITIES AND LEAD-TIMES IN SUPPLY CHAIN

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ABSTRACT

It is assumed that a good supply chain distributes the uncertainties of both parties evenly between the partners. Supply chain flexibility is introduced as the relationship between the buyer and supplier under varying supply conditions. A higher flexibility relationship allows for more consistent procurement pricing regardless of changing supply condition. The flexibility is measured with respect to varying order quantities and supply lead times in which an estimate of the procurement price is determined through procurement behavior. Through survey, it was determined that order quantities and supply lead-time are the most common parameters that are critical in the buyer-supplier relationship. Using the model proposed in this paper, a buyer can estimate the flexibility of the potential suppliers and make a decision based on the measurements of this parameter to best fit the business.

Keywords: Order Quantity, Supply Chain, Lead Time, Cycle Time.

1. Introduction

Today, supply chain is a result of advancing information technology that makes the communication between customers and producers more efficient. Managers must plan to adjust the uncertainties and variations. Those uncertainties range from customer behavior to process quality problems. Decision makers must cautiously evaluate potential suppliers and make smart choices. A good supply chain is that customers and suppliers are willing to adjust the uncertainties and variation in business. Ideally, one would want a supplier that provides the customer with the needed flexibility to adjust their supply process. A variety of companies believe that most supply chains have only limited flexibility, and are able to only adjust low level uncertainties.

The need to adjust uncertainty in the supply process refers to the issue of flexibility. Das. (1996) and Abdel – Malek et al. (2000) define manufacturing flexibility. Further, this adjustment must occur with little penalty, effort or operational performance. Supply chain flexibility is defined as the elasticity of the buyer-supplier relationship under changing supply conditions. In an inflexible relationship, a supplier will only accept these orders at a much higher unit price. In a survey of manufacturing managers Abdel – Malek et al. (2000)observe that over 90% of the respondents emphasized that manufacturing flexibility was a key component of their strategy to maintain competitiveness. This validates the need for an affective model to track and evaluate supply chain flexibility.

In this paper, a model supply chain flexibility in the supply contract negotiated between a customer and a supplier is discussed. A highly flexible relationship is one in which there is little fluctuation in the procurement price. A supply chain flexibility was usedto develop a supplier selection model. Using this model, a customer is able to estimate the flexibility of supply chain partners, and make a choice.

2. Background information

A related literature in the context of vendor selectionwas reviewed.Braglia and Petroni (2000) observe that the increased concern for supplier selection is caused by the fact that supplier selection may be the most important decision in the procurement process. Managers evaluate supplier performance in order to retain and meet their requirement. Six points used as performance criteria and used in a study by mummalanenietal . (1996). These points are: on-time delivery, quality, price/cost targets, professionalism, responsiveness to customer needs, and long term relationships with the purchasingcompany.Deng and Wortzel (1995) conducted a study of the supplier selection criteria in three merchandise categories. The most important criteria were price and product quality, followed closely by on-time delivery.

Lambert et al. (1998) describes one method on how to evaluate and compare several suppliers. The first step is to identify all suppliers. Second, determine the relevance factors. Every supplier and every factor will be assigned a rating, 1-5 and 5 is the highest. Each factor will also be assigned a weight to determine the relative importance of the factors.

Wilson (1994) found that price tends to be less important in the supplier selection criteria. Quality and service tend to dominate price.Verma and Pullman (1998), on the other hand, point out that their choice is based largely on cost and delivery performance. Furthermore, the importance placed on the different attributes was found in accordance with the differing cultural aspects of society.

In the area of demand uncertainly and supply chains, Jung et al. (1999) focus on the capacity in flexible facilities, and demand management strategies. They found that a supplier who faces a smaller demand with high variation would invest more in flexible facilities. They also found that when the lot size is increased it mitigates the correlation of purchase orders.

Higginson and alam (1997) address several issues related to supply chain management. Seven issues are identified: inventory levels, quality, information sharing, number of supplier, cycle times, commitment, and relationship.Narasimhan and Das (2000) observe that for a company to compete through flexibility, the sourcing or supply practices are quite important. Flexibility plays a major role in the performance of supply chains. However, insufficient attention has been given to that of whole supply chain.Swamidass and Newell (1987) in a study confirmed that flexibility improved performance in uncertain environments.Gerwin (1994) observes that generic strategies for success in flexibility implementation should focus on uncertainty experienced by the company's manufacturing operations.Olhager and West (2001) have recognized the importance of extending the notion of flexibility beyond the factory floor linking it to market requirement and customer needs.

3. Defining Supplier Contract

The flow process in the supply chain is of three parts. The first one is being the physical part component, the secondis the supply contract, and the third part is the information link. The supply contract is a legally binding document that defines the parameters within which the two parties are working with. This document which is negotiated at the start of the relationship is setup to protect both parties in case of disagreement. The information link is the link between the supplier and the manufacturer that transmits data consisting of production orders, delivery dates, quality reports, inventory levels, and accounting data. The reliability and utility of this information is the key enabling technology in the relationship. The relevant data is transmitted through supply chain management system in which assumes immediate transfer. The supply chain management is done through software solution and allows the production risks to be shared between both parties, for the case of manufacturer being the customer uncertainty. Although traditional methods of inventory stocks to counter uncertainty, a good supply contract must have sufficient flexibility to consider the risk of uncertainty of both parties.

3.1 Shared Risk in supply chains

Supply chains are setup such that the change in customer demand behavior is rapidly transitioned up the chain, and hence the uncertainty risk is shared across the chain. Risk includes both capital investments and lost opportunities. There are different approaches to risk distribution: traditional risk graded risk and uniform risk. In the traditional setup, the highest risk taker is at the chain's end, the final product assembler. The risks are shared between the partners but at different proportions. Tier-1 supplier has a production capacity according to the higher demand rates whereas tier-2supplier has a production capacity equal to mean demand rates, and thus tier-2 has a lower risk level than tier-1 supplier.

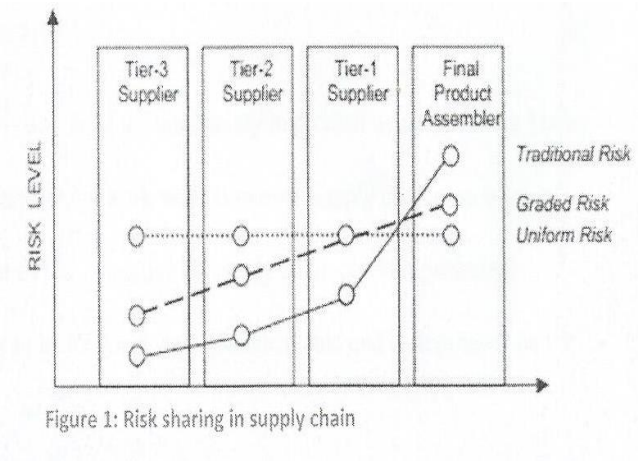

Figure 1: Risk sharing in supply chain

The most modern type of supply chain is the graded risk model, which follows a linear pattern of the net risk (sum of the individual risk levels of each partner). The slope of the graded model is the Risk deterministic measure of involved partners. The third model which is the uniform risk is the rare case in which there is a uniform distribution of the net risk. In the case of sharp decline in sales the uniform risk model equates the risk level of the supply chain entities. Through better communication, coordination and planning the supply chain are expected to reduce the net risk.

3.2 Supply Contract

Two demand conditions will be considered in our model of buyer-supplier relationship: decreasing customer demand, and delayed market data. We ignore the cases of increased demand and supply quantities as the supplier are happy to use overtime to meet the demand. To model the supply chain flexibility, we will present the relevant parameters:

'P' :the supply price per unit- is the price at which the supplier will deliver the component to the buyer and is in effect for the life of the contract

'T' :the order cycle time-is the fixed interval in which will release production orders to the supplier that is proportional to the geographical distance of the supplier to buyer

' L_{min} ' : the minimum lead time, when orders needed quicker than L_{min} then there is a penalty imposed.

'Q_{min} ' : the minimum order quantity quarantined by the buyer in each cycle in which if below, penalty is imposed.

The above four parameters sufficiently define the supply contract given the buyer is confident that the contract limits are unlikely to be violated. In the case of possibility of the violation of the contract, the following additional parameters will be used in the supply contract:

'a' : the expedited delivery penalty – is the proportional increase in the unit price per unit time reduction in the lead-time below the 'L_{min}'

'β' : the maximum penalty paid by the buyer in any cycle where the order quantity is below the'Q_{min} '.

These six parameters are used to determine the flexibility of the buyer-supplier relationship and hence the supply contract.

4. Modeling the component demand

The most important motivation for flexibility of supplier is the uncertainty in product demand. As we know, un steady demand conditions, the supply chain relationships work well. However, supply chains are used in non-steady demand conditions now, and this requires the evaluation of supply contracts projected component demand uncertainty can be modeled from statistical data and is dependent on the cycle.

Let $f(DT)$ be the probability density function representing the component demand experienced by the buyer during a period T. Let μDT andσDT represent the mean and standard deviation of the component demand during the order cycle time T. We make no assumption about the nature of this distribution, but expect it can be approximated by a normal distribution. Let $f(L_T)$be the probability density function representing the component demand lead-time experienced by the buyer during the period T. Let μL_T and σL_T represent the mean and standard deviation for the lead-time. We expect f(lt) will generally describe a lognormal behavior, through we approximate it by a normal distribution. Figure 2 shows the relationship between T and L_{min} in which typically T will be greater than μL_T. When this is not true the supply relationship is infeasible. One can expect that companies will have sufficient historical data to generate reliable estimates of the component demand behavior.

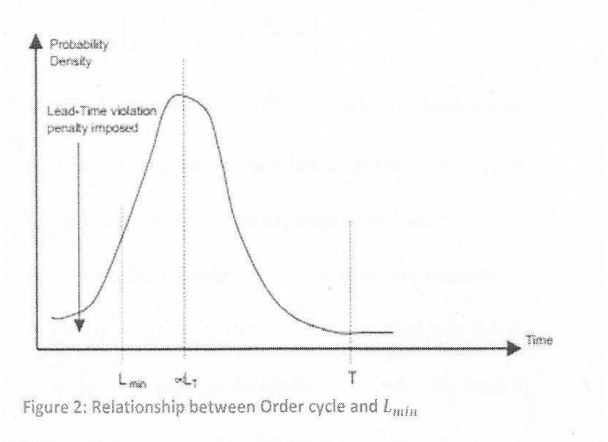

Figure 2: Relationship between Order cycle and L_{min}

5. Supply chain flexibility

Product demand uncertainty leads to component demand uncertainty, which requires a flexible supply chain relationship. The less flexible the relationship, the more likely the buyer will face cost penalties when demand condition change. The parameters L_{min}, Q_{min}, a and β are the primary determinants of the supply chain flexibility. Observe that the most flexible supply contract is one where either $L\_min = Q\_min = 0$ *or* $a = \beta = 0$. In either case no limits are imposed on the supply process and the buyer can demand instant supply or no supply at any time with no penalty. Depending on their production capabilities, a supplier will demand higher levels of L_{min} and Q_{min}.A supplier with very flexible production capabilities experiences little unit cost increases withorder quantity reduction or expedited delivery, and will therefore agree to lower a and βrates.

A flexible supply chain may therefore be defined as one where little to no constraints are placed on the expected quantity and timing of supply orders. Based on this definition we propose the following measure for the supply chain flexibility:

$$(\Psi)= w_T\left[1-\frac{L_{min}\sqrt{a}}{\mu L_T}\right]+W_Q\left[1-\frac{0.8\beta}{p(\mu D_T)}-\frac{0.6Q_{min}}{\mu D_T}\right](1)$$

$W_T$and$W_Q$are the relative importance assigned to the two components of Ψ. the lead-time flexibility is inversely proportional to the product of L_{min} and$a$. to accelerate this inverse relation- ship the root of $\sqrt{a}$ is used. This is logical since the buyers discomfort to higher values of a can be expected to increase geometrically. A high a makes even a small request for expedited delivery to be expensive. The quantity flexibility declines as each of these ratios increases, clearly, the quantity flexibility is high when both β &Q_{min} are very low. In situation where the setup costs are high, for example in the supply of castings, W_Q tends to be higher. Conversely, where the capacity utilization is high and therefore scheduling the order is more difficult thenW_Q tends to be higher. In the unlikely case where β is very close to P(μD_T) the neqative values may be obtained, in these cases Ψ is reset to zero. Operationally a value ofΨ = 1 indicates that all demand conditions can be met with no supply penalties being exposed and as such the supplier shares the risk with the buyer. As the value of Ψ decreases the penalty costs start to increase, and at low values of Ψ they could became excessive. Form the above measure we see that there are four parameters that can be negotiated to increase the flexibility of the relationship. The above measure indicates the system flexibility (Das, 1996), and a buyer must evaluate this in the context of the needed flexibility. When $\sigma L_T$and $\sigma D_T$are both close to zero there is little assumed uncertainty in the system, and the need for flexibility is thus assumingly low.

6. Selecting the supplier

When buyer is selecting a supplier, the buyer must balance the price of the product with the penalties. Usually neither the supplier with greatest flexibility nor the supplier with the lowest unit price is the best choice. What's the most important, all the contractparameters for all the supplier options must be known. However, the data will not be given until the supplier is selected. What's more, the uncertainty in the component demand behavior for quantity and lead-time should have a reliable estimation. Under different supply conditions, little deterioration in

the procurement price can be seen in a highly flexible relationship. Let i =1 to N be the possible suppliers and then the annual procurement cost for each supplier is :

$$\Omega_i = \left[\frac{1}{T} p\mu D_t + 0.5\beta \int_0^{Qmin} f(D_T)dD + 0.5PL_{min}\ a \int_0^{L_{min}} f(L_T)dL\right]$$

The above formula is the summation of the expected component cost, the expected quantity penalty and the expedited delivery penalty respectively. In which the selected supplied

$$i^* = Min\ \Omega_i | i$$

7. Illustrative example

To give the evidence of the proposed measure we consider an example case between two companies that are establishing a component supply relationship. The original supply contract data is shown in Figure 2. Component demand behavior is known to be described by μD_T= 1700 units/ T and σD_T = 320 units. The demand lead-time behavior is μD_T = 4.5 weeks and σD_T= 1.8 weeks. After we substitute this data into Eq. (1) we find that the supply chain flexibility for this example is 0.72. this indicates a limited amount of penalties will be imposed on the buyer due to the inflexibility of the contract.

Parameter	Contract value
P	$135/unit
T	6 weeks
L_{min}	2 weeks
Q_{min}	1250 units
α	5%/week
β	$15,000

Figure 3: Supply contract data.

Increasing expedited delivery penalty					
α	5%	10%	15%	20%	25%
ψ Flexibility	0.72	0.70	0.69	0.68	0.67
Increasing order quantity reduction penalty					
β	$15,000	$20,000	$25,000	$30,000	$35,000
ψ Flexibility	0.72	0.71	0.70	0.69	0.68
Increasing minimum delivery lead time					
L_{min}	2 weeks	2.5 weeks	3 weeks	3.5 weeks	4 weeks
ψ Flexibility	0.72	0.71	0.70	0.69	0.68
Increasing minimum order quantity					
Q_{min}	1,000	1,150	1,300	1,450	1,600
ψ Flexibility	0.72	0.69	0.65	0.62	0.59

Figure 4: Sensitivity of supply-chain flexibility

Figure 4 demonstrates the sensitivity of the supply chain flexibility to increase in the two penalty rates. Obviously, the flexibility drops consistently with an increase in each parameter. The most marked drop happens as a response of an increase inQ_{min} . This occurs because we can expect a greater likelihood that there will be order belowQ_{min} .

i	P	Q_{min}	β	L_{min}	α	Part cost	Quantity penalty	Delivery penalty	Ω_i
1	$135	1,450	$30,000	3.5	0.09	$229,500	$3,270	$10,519	$243,289
2	$142	1,400	$32,000	3	0.09	$241,400	$2,784	$6,616	$250,800
3	$130	1,450	$28,000	4	0.1	$221,000	$3,052	$17,238	$241,290
4	$130	1,600	$40,000	3.5	0.11	$221,000	$7,560	$12,380	$240,940

Figure 5: Comparison of multiple supplier contracts

Figure 5 documents the contract details of four expected supplier. In order to simply the problem we assume that all of these four contracts have the same value of T. Substituting the data into Eq. (2) the expected net supply cost per cycle is derived for the competing suppliers. We find that in spite of supplier 4 and 3 both have the lowest part costs, the supplier 4 also has the lowest overall cost, which more favorable compare to others. The selected supplier though actualizes the highest limit on the order quantity, and from figure 5 we see that the quantity penalty is at least doubles that of any other supplier. Supplier 3 also has the greatest restriction on the delivery lead-time and has an expected delivery penalty of $17,328 this in affect denies its Q_{min} advantage over supplier 4.

In many examples the supplier with the lowest cost will not be selected. From figure 5 we see that supplier 2 has lowest total penalty costs, and would leads attraction to a risk averse buyer.

8. Summary

In this paper, we mainly introduced a method for estimating the level of supply flexibility in a supply chain. This measure is a function of the restrictions on delivery lead-time and order quantities imposed by both the supplier and the buyer. The proposed flexibility measure was extended to derive the annual purchasing cost for each potential supplier. We use this cost to evaluate the options of different supplier based on their supply chain flexibility. By using the proposed model a buyer can estimate the flexibility of potential supply chain partners, and hence make a quantifiable choice. The measure itself can be specified in the supply chain contract. Furthermore, this model provides not only gives a parametric representation of the buyer's procurement behavior, but also the estimate of the annual purchasing cost in a given buyer-supplier relationship. Obviously, supplier selection decision also needs several other factors, and this model is intended to support and complement a comprehensive selection process.

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