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THE USE OF TOTAL COST OF OWNERSHIP FOR STRATEGIC PROCUREMENT: A COMPANY-WIDE MANAGEMENT INFORMATION SYSTEM

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The Use of Total Cost of Ownership for Strategic Procurement: A Company-wide Management Information System

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ABSTRACT

We present a general company-wide management information system for defining procurement strategies. We believe that existing practices for determining purchasing strategies can be improved and develop a new approach. The system uses total cost of ownership information. We argue that mathematical programming models should be used for exploiting this information when evaluating the firm's strategic procurement options. Our research method corresponds to the innovation action research concept. Implementations at Usinor, a European multinational steel company, validate our approach by showing an average reduction in total cost of ownership of about 10% for the different product groups considered.

INTRODUCTION

In today's business world characterized by intense global competition, cost management is an important strategic weapon. External purchases of products and services account generally for more than 60% of the total costs for most companies. Consequently, significant cost savings can be realized by effectively determining procurement strategies. Strange enough, while there has been much attention paid in the accounting literature to activity based management and customer profitability analysis, there has been far less notice taken of purchasing. Considering the importance of external purchases, it is indeed rather surprising that most of today's activity based costing systems are mainly focused on activities that are related to products, services, departments and customers (Foster and Swenson 1997 ; Swenson 1997) and not on the determination of procurement strategies.

In the purchasing literature and in practice we have noticed the existence and use of simple, subjective and incomplete approaches for supplier selection (for an overview see Degraeve, Labro and Roodhooft 2000). Indeed, for many years, procurement has been an undervalued activity in its contribution to corporate performance improvement and value for money management. Inadequate planning, poor communication between departments involved in the procurement of materials and equipment and weak performance measurement are typically problems related to existing procurement practices.

In this article we present a general management information system using total cost of ownership information for this problem. The system uses a dynamic mathematical programming model that derives a purchasing strategy by minimizing the total costs associated with the problem taking into account the relevant constraints. The essential function of the model entails converting available information into usable knowledge. Specifically, it leads to a management decision support system that calculates the total cost of ownership and thus achieves objectivity in the selection process.

Our research method corresponds to the concepts of innovation action research (Kaplan 1998) and constructive research (Kasanen et al. 1993). Previous research (Degraeve and Roodhooft 2000) describes the basic theoretical ideas of our approach. In that paper we documented shortcomings in existing purchasing practices and identified the total cost of ownership approach as a plausible solution. This typically coresponds to the first step in an innovation action research cycle (Kaplan 1998). We have applied this theoretical framework to several industrial cases at Usinor, a European multinational steel producer (Degraeve and Roodhooft 1998, 1999a, 1999b). For these different cases we had developed case specific total cost of ownership approaches and mathematical programming models. For these studies we worked with an organization to test our emerging total cost of ownership framework. As a result of these analyses Usinor changed its procurement strategy for the product groups considered. This field work allowed us to learn more about the theoretical framework itself and the requirements for its successful implementation, an important step in every innovation action research program.

In this article we advance our theory one step further and discuss a general company-wide decision model for strategic procurement that does not focus on a specific product group but is applicable to a wide range of different product groups of a company. As will be shown in this article these refinements result from the feedback loop from theory to practice and back to theory. The article is structured as follows. The next section describes the total cost of ownership framework. The third section describes the company-wide management information system at Usinor. This is a mathematical programming model resulting in a procurement strategy that minimizes the total cost of ownership for a given product group so as to meet the demand for the different products over the period under consideration. The fourth section discusses the results of this approach at Usinor. The results show an average reduction of 10% in total cost of ownership and thus validate our innovative action approach. In the last section we present our conclusions.

THE TOTAL COST OF OWNERSHIP FRAMEWORK

Total cost of ownership measures all the costs and benefits of a firm's relationships with its suppliers. Just as customer profitability analysis provides the insight that the largest revenue customers may not be the most profitable ones because they may demand excessively costly special treatment and delivery conditions, the total cost of ownership often reveals that the cheapest suppliers may impose additional high costs on the firm because of, for example, quality problems, discount practices and payment procedures.

The total cost of ownership framework developed in this paper is based on the principles of total cost of ownership as described in Carr and Ittner (1992), Ellram (1995) and Roodhooft and Konings (1997). The total cost of ownership reflects the resources consumed in performing the purchasing-related activities. This implies that prices and all other costs generated by the suppliers in the purchasing company's value chain are involved in the analysis. In a first step every activity that is related to the strategic purchasing policy needs to be determined. A next step involves the allocation of the costs over the different identified activities. This is a typical part of every activity based costing analysis. In a final step the influence of the different suppliers on the activities in the value chain of the purchasing company is determined. The objective of this approach is to minimize the total cost of ownership when developing a procurement strategy.

Defining procurement strategies is more than selecting one supplier for one order. Decisions pertaining to which vendors to use, what to buy from them and which ones to drop are not as simple as finding the best single source for each part (Akinc 1993).

Mathematical models can then be used to solve more complex problems. Also Shapiro (1999) advocates the use of mathematical models for analyzing strategic decisions. He states that activity based costing defines the current or future situation with respect to a company's resources. To optimize its resource decisions this company should then analyze this information by means of a mathematical programming model.

In this article we study a company-wide mathematical programming model based on total cost of ownership information that enables purchasing managers to determine their procurement strategies. The total cost of ownership framework was developed in cooperation with the purchasing managers of Usinor, a European multinational steel company. In a first workshop we explained the principles of our approach to the different purchasing managers of the company. Then, we conducted interviews with these managers in order to discuss the relevance of total cost of ownership elements and constraints to their product groups. On the basis of these interviews we developed a first list of cost elements and constraints that was discussed during a meeting with the purchasing director and the purchasing managers. After this meeting we constructed a final total cost of ownership matrix that included the relevant elements for the different product groups at Usinor. This systematic process corresponds to other procedures such as the implementation of the balanced scorecard (Kaplan and Norton 1996). The resulting total cost of ownership matrix is given in Figure 1.

In our approach we recognize three strategic dimensions in the total cost of ownership framework. A first dimension, depicted in the columns of Figure 1, is the place of the activity and its associated cost within the value chain of the purchasing company. This dimension represents the life cycle costs of the products or services that were externally bought. Shields and Young (1991) argue that life cycle costs that a purchaser incurs after buying a product are becoming a larger percentage and are thus increasingly important in purchase decisions. With respect to the value chain dimension we distinguish costs of acquisition, reception, possession, utilization and elimination.

The costs of acquisition are related to all activities that take place before goods and services are received. Examples are costs related to negotiation, signing contracts and testing suppliers. Also the price and the different kinds of discounts are part of this dimension. The costs of reception are related to the reception of incoming goods, the process of invoicing and payment and the inspection of products that enter the company. Costs of possession are costs made between the moment of reception and the moment of utilization of the purchased goods. Inventory holding costs are a typical example. Costs of utilization are costs related to activities associated with the use of the products or services. Examples are the cost of installation of products, costs resulting from production failure and costs of training the personnel in order to use the products. Finally, the costs of elimination are incurred at the end of the lifecycle of the purchased goods. Examples of these costs are waste and environmental costs.

Activities and their associated costs can also be categorized on the basis of their hierarchical level, shown in the rows of Figure 1. The activity based costing literature defines different cost hierarchies for a company (Cooper 1990; Kaplan and Cooper 1998) and applies these hierarchies to manufacturing, marketing (Foster and Gupta 1994) and research and development expenses. This literature argues that this hierarchy provides a framework for understanding cost behavior. In our approach we tailor this hierarchy to the specific purchasing context. This allows us to evaluate the total cost of ownership implications of different procurement strategies.

Since a typical procurement strategy involves the selection of suppliers for different products in different periods, we can distinguish five levels of activities and costs in our framework. The first level is the supplier level. Activities at this level are only performed when a certain supplier is being used over the time horizon and are not affected by the number of different products, the number of orders or the number of individual products or services purchased from that particular supplier. The sole fact of using a supplier gives rise to certain costs. Examples of supplier level costs are costs of quality audits, follow up costs and negotiation costs. Activities and costs at the product level are typically related to the procurement of a given product from a given supplier and are independent of the number of orders placed and units bought. Typical examples are costs of system adaptation for the use of a product from a given supplier and additional training costs for the personnel of the purchasing company for using a specific product from a given supplier. Activities at the order level, the third hierarchical level, need to be executed every time an order is placed with a particular supplier. The costs at this level are not related to the number of different products and units purchased in this particular order. Such costs are, for instance, costs of reception, invoicing and transportation. At the product-order level we find activities and costs that relate to the placement of an order for a specific product from a given supplier. Examples are the costs of quantity and quality tests for a product bought from a specific supplier. Activities at the unit level, the fifth hierarchical level, are performed for one unit of a product in a specific order placed with a given supplier. The latter are for example additional setup costs resulting from product failures at the purchasing company caused by a component from a given supplier. Another example are the inventory holding costs that have to be traded-off against the order level costs.

The third dimension of the total cost of ownership framework, depicted in a subdivision of the rows of Figure 1, is related to the difference between flexible and committed resources (Kaplan and Cooper 1997). Flexible resources are resources that the purchasing company can acquire just as needed. The cost of supplying these resources equals the cost of using them. A reduction in their use because of another purchasing strategy generates a cash saving. For example, price decreases or a better use of discounts lead to immediate cash savings. With respect to committed resources, an organization acquires the capacity before it is actually used. This means that the costs related to these resources are incurred whether the resources are used or not. Typical examples include employees and buildings and equipment. When the demand for these resources declines, the unused capacity will be increased but no immediate cash saving will be noticed. Cash savings will only be realized when this unused capacity can be used for other purposes or when the supply of these resources can be reduced.

The details of the different cost elements and their associated activities are given in Figure 1. "Other costs" are included at all levels to make the model as general as possible. If a typical cost for a specific product group is not explicitly considered in the total cost of ownership matrix, buyers can resort to those other costs, label them using the philosophy of our matrix and quantify them. As such, the buyers can take them into account in their analysis.

The aim of our approach is to minimize the total cost of ownership so as to meet the demand for a given product group over the period under consideration. When determining its strategic purchase policy for a product group, a company has to select suitable suppliers and market shares for these suppliers. This will be studied in the following section.

THE COMPANY-WIDE MANAGEMENT INFORMATION SYSTEM

The total cost of ownership framework developed in the previous section allows purchasing managers to collect information for managerial decision making. Shapiro (1999) argues that this is a descriptive rather than normative methodology and that activity based costing or related systems can and must be extended in natural ways to mathematical programming models. Given the complex environment where purchasing managers buy multiple products from different suppliers in different periods and given the hierarchy in activities related to procurement, the use of a mathematical programming model will be crucial in our total cost of ownership framework. This model will generate a strategic procurement policy that minimizes the total cost of ownership indicating the most suitable suppliers for different components over the decision horizon. The approach also allows us to take into account several constraints.

In the general mathematical programming model we study the procurement strategy for a product family consisting of several different types of products. Multiple suppliers can deliver some or all of the various products in the product group. As purchasing is a dynamic process occurring over time, we consider a time horizon consisting of a specific number of discrete time periods, also called time buckets. Modeling the different discounting schemes often turnes out to be particularly challenging. We include both discounts on total purchases for the product group as well as discounts on the purchases of its individual products. Moreover, both all units and incremental units quantity discounts are explicitly modeled. In essence, the formulation is a dynamic lotsizing model. Lotsizing models have been extensively researched in the operations research literature. One of the first introductions was by Wagner and Whitin (1958). The Wagner-Whitin model determines optimally how much to order of one product from one supplier in each time bucket of the decision horizon trading-off inventory holding costs with ordering costs. We extend this model for the multi-product, multi-supplier case incorporating relevant industrial side constraints and the activity based costing hierarchy in the objective function.

For strategic purposes, the purchasing managers at Usinor defined various constraints that should be incorporated in the decision support model. A first condition specifies minimum and maximum inventory positions for products. As a second constraint, a purchasing company may want to work with a minimum number of suppliers in order to maintain a certain level of independence. A maximum number could also be set if too many suppliers would lead to management problems. Another constraint is related to minimum and maximum purchasing quantities from specific suppliers. For instance, the supplier may have capacity limitations that would make it impossible to produce and deliver more than a specific quantity over a given time period. Discounts must also be accurately modeled. For example, suppliers often give a percentage discount on the total purchase price of a set of different components, independently of the combination of products. In this case, every supplier specifies a given number of discount intervals, with minimum and a maximum quantity limits and characterized by a discount percentage valid within the two associated limits.

Figure 1. TCO matrix for Usinor

		Acquisition	Reception	Possession	Utilization	Elimination	Other
Supplier level	*Cash*	Total purchases discounts					
	Non Cash	Supplier quotation cost Contract cost Supplier follow-up cost Supplier change cost					
Product level	*Cash*				Replacement cost		
	Non Cash				Cost of personnel training Cost of adaptations		
Order level	*Cash*	Payment delay	Transportation cost				
	Non Cash	Order cost	Reception cost Invoicing cost Litigation cost				
Product order level	*Cash*						
	Non cash		Cost of quantity tests Cost of quality tests				
Unit level	*Cash*	Price Price evolution Product discounts			Intrinsic efficiency	Waste valorization	
	Non Cash	Service cost Product Testing cost		Inventory holding cost	Costs of production failure Costs of product failure Maintenance cost Installation cost Cost of quality control		

Before stating the model, we give the notations that will be used in the mathemathical formulation. We define the following sets:

S : set of suppliers, index i,
P : set of products, index j,
T : set of time periods, index k,
DT_i : set of discount intervals for total purchases from supplier i, index l, $\forall i \in S$,
DP_{ij} : set of discount intervals for purchases of product j from supplier i, index l, $\forall i \in S, \forall j \in P$.

The decisions and cost parameters will be given in different sections below representing the total cost of ownership matrix as outlined before. The decision variables represent the key decisions to be made.

The decision variables at the supplier level are as follows:

z_i $=1$, if supplier i is selected, 0, otherwise, $\forall i \in S$,
$xdjl_i$: total purchases from supplier i, $\forall i \in S$,
wj_{il} $=1$, if total purchases from supplier i are in discount interval l, 0, otherwise, $\forall i \in S$, $\forall l \in DT_i$,
xdj_{il} : total purchases from supplier i in discount interval l, $\forall i \in S, \forall l \in DT_i$,
slc : total supplier level costs.

The decision variables at the product level are as follows:

yk_{ij} $=1$, if we order product j from supplier i, 0, otherwise, $\forall i \in S, \forall j \in P$,
w_{ijl} $=1$, if purchases of product j from supplier i are in product discount interval l, 0, otherwise, $\forall i \in S$, $\forall j \in P, \forall l \in DP_{ij}$,
xd_{ijl} : total purchases of product j from supplier i in product discount interval l, $\forall i \in S, \forall j \in P, \forall l \in DP_{ij}$,
plc : total product level costs.

The decision variables at the order level are as follows:

yj_{ik} $=1$, if we order from supplier i in period k, 0, otherwise, $\forall i \in S, \forall k \in T$,
olc : total order level costs.

The decision variables at the product-order level are as follows:

y_{ijk} $=1$, if we order product j from supplier i in period k, 0, otherwise, $\forall i \in S$, $\forall j \in P$, $\forall k \in T$,
$polc$: total product-order level costs.

The decision variables at the unit level are as follows:

x_{ijk} : amount (in lots) ordered of product i from supplier j in period k, $\forall i \in S, \forall j \in P, \ \forall k \in T$,
vi_{jk} : inventory of product j at the end of period k, $\forall j \in P, \ \forall k \in T$,
ulc : total unit level costs,
$aulc$: additional unit level costs,
$purc$: purchasing costs,
$invc$: inventory holding costs,
rev : additional revenue, e.g. resulting from recycling or waste recuperation.

The parameters below represent the cost elements in the matrix. The parameters at the supplier level, cash, are as follows:

aj_i =1, if all units discount, 0, if incremental units discount applies for supplier i, $\forall i \in S$,
lbj_{il} : minimum purchases from supplier i in discount interval l, $\forall i \in S$, $\forall l \in DT_i$,
ubj_{il} : maximum purchases from supplier i in discount interval l, $\forall i \in S$, $\forall l \in DT_i$,
dcj_{il} : price discount as a percentage from supplier i in discount interval l, $\forall i \in S$, $\forall l \in DT_i$,
mij_i : minimum purchases from supplier i as a percentage of total purchases imposed by the buyer, $\forall i \in S$,
maj_i : maximum purchases from supplier i as a percentage of total purchases imposed by the buyer, $\forall i \in S$.

The parameters at the supplier level, non cash, are as follows:

qs_i : quotation cost for supplier i, $\forall i \in S$,
cc_i : contract cost for supplier i, $\forall i \in S$,
mc_i : follow up cost for supplier i, $\forall i \in S$,
rd_i : change cost for switching to supplier i due to additional research and development, $\forall i \in S$.

The other costs at the supplier level are as follows:

sa_i : other supplier level acquisition costs for supplier i, $\forall i \in S$,
sr_i : other supplier level reception costs for supplier i, $\forall i \in S$,
sp_i : other supplier level possession costs for supplier i, $\forall i \in S$,
su_i : other supplier level utilization costs for supplier i, $\forall i \in S$,
se_i : other supplier level elimination costs for supplier i, $\forall i \in S$,
sc_i : other general supplier level costs for supplier i, $\forall i \in S$.

The parameters at the product level, cash, are as follows:

ce_{ij} : replacement cost resulting from buying product j from supplier i, $\forall i \in S$, $\forall j \in P$.

The parameters at the product level, non cash, are as follows:

tp_{ij} : additional training cost on the use of product j from supplier i, $\forall i \in S$, $\forall j \in P$,
ac_{ij} : cost of systems adaptation for use of product j from supplier i, $\forall i \in S$, $\forall j \in P$.

The other costs at the product level are as follows:

pa_{ij} : other product level acquisition costs when buying product j from supplier i, $\forall i \in S$, $\forall j \in P$,
pr_{ij} : other product level reception costs when buying product j from supplier i, $\forall i \in S$, $\forall j \in P$,
pp_{ij} : other product level possession costs when buying product j from supplier i, $\forall i \in S$, $\forall j \in P$,
pu_{ij} : other product level utilization costs when buying product j from supplier i, $\forall i \in S$, $\forall j \in P$,
pe_{ij} : other product level elimination costs when buying product j from supplier i, $\forall i \in S$, $\forall j \in P$,
pc_{ij} : other general product level costs when buying product j from supplier i, $\forall i \in S$, $\forall j \in P$.

The parameters at the order level, cash, are as follows:

dp_i : price discount as a percentage due to payment delay given by supplier i, $\forall i \in S$,
tc_i : transportation cost per order when purchasing from supplier i, $\forall i \in S$.

The parameters at the order level, non cash, are as follows:

oc_i : order cost per order for supplier i, $\forall i \in S$,
rc_i : reception cost per order for supplier i, $\forall i \in S$,
pn_i : probability of having a credit note per invoice from supplier i, $\forall i \in S$,
vc_i : invoice cost per order for supplier i, $\forall i \in S$,
nc_i : credit note cost when purchasing from supplier i, $\forall i \in S$.

The other costs at the order level are as follows:

oa_i : other order level acquisition costs for supplier i, $\forall i \in S$,
or_i : other order level reception costs for supplier i, $\forall i \in S$,
op_i : other order level possession costs for supplier i, $\forall i \in S$,
ou_i : other order level utilization costs for supplier i, $\forall i \in S$,
oe_i : other order level elimination costs for supplier i, $\forall i \in S$,
oc_i : other general order level costs for supplier i, $\forall i \in S$.

The parameters at the product-order level, non cash, are as follows:

qo_{ij} : cost of quantity test for product j bought from supplier i, $\forall i \in S$, $\forall j \in P$,
qr_{ij} : cost of quality test for product j bought from supplier i, $\forall i \in S$, $\forall j \in P$,
qf_{ij} : frequency of testing on incoming orders from supplier i, $\forall i \in S$.

The other costs at the product-order level are as follows:

poa_{ij} : other product order level acquisition costs when buying product j from supplier i, $\forall i \in S$, $\forall j \in P$,
por_{ij} : other product order level reception costs when buying product j from supplier i, $\forall i \in S$, $\forall j \in P$,
pop_{ij} : other product order level possession costs when buying product j from supplier i, $\forall i \in S$, $\forall j \in P$,
pou_{ij} : other product order level utilization costs when buying product j from supplier i, $\forall i \in S$, $\forall j \in P$,
poe_{ij} : other product order level elimination costs when buying product j from supplier i, $\forall i \in S$, $\forall j \in P$,
$pocij$: other general product order level costs when buying product j from supplier i, $\forall i \in S$, $\forall j \in P$.

The parameters at the unit level, cash, are as follows:

p_{ij} : price charged by supplier i for product j, $\forall i \in S$, $\forall j \in P$,
$\overline{p_j}$: an average price of product j to apply to the inventory holding costs, $\forall j \in P$,
pe_{ij} : price evolution indicated by supplier i for product j, $\forall i \in S$, $\forall j \in P$,
a_{ij} =1, if all units discount, 0, if incremental units discount applies for supplier i product j, $\forall i \in S$, $\forall j \in P$,
lb_{ij} : minimum purchases for product j from supplier i in discount interval l, $\forall i \in S$, $\forall j \in P$, $\forall l \in DP_{ij}$,
ub_{ij} : maximum purchases for product j from supplier i in discount interval l, $\forall i \in S$, $\forall j \in P$, $\forall l \in DP_{ij}$,
dc_{ij} : price discount as a percentage for product j from supplier i in discount interval l, $\forall i \in S$, $\forall j \in P$, $\forall l \in DP_{ij}$,
mi_{ij} : minimum purchases of product j from supplier i as a percentage of total purchases of product j imposed by the supplier, $\forall i \in S$, $\forall j \in P$,
ma_{ij} : maximum purchases of product j from supplier i as a percentage of total purchases of product j imposed by the supplier, $\forall i \in S$, $\forall j \in P$,
re_{ij} : efficiency of product j from supplier i relative to demand, $\forall i \in S$, $\forall j \in P$,
rb_{ij} : percentage of used product j from supplier i that can be recycled, $\forall i \in S$, $\forall j \in P$,
pb_{ij} : refund for used product j from supplier i for recycling, $\forall i \in S$.

The parameters at the unit level, non cash, are as follows:

se_i : percentage applied to price of supplier i for service provided, $\forall i \in S$,
qu_{ij} : testing cost per unit of product j from supplier i, $\forall i \in S$, $\forall j \in P$,
h_j : inventory holding cost of product j as a percentage, $\forall j \in P$,
if_{ij} : cost for production failure caused by product j from supplier i, $\forall i \in S$, $\forall j \in P$,
ir_{ij} : replacement cost resulting from production failure caused by product j from supplier i, $\forall i \in S$, $\forall j \in P$,
pi_{ij} : probability for a production failure caused by product j from supplier i, $\forall i \in S$, $\forall j \in P$,
ef_{ij} : cost for product failure at the customer caused by a component j from supplier i, $\forall i \in S$, $\forall j \in P$,
er_{ij} : replacement cost resulting from product failure at the customer caused by component j from supplier i, $\forall i \in S$, $\forall j \in P$,
pe_{ij} : probability for a product failure at the customer caused by product j from supplier i, $\forall i \in S$, $\forall j \in P$,
mu_{ij} : maintenance cost per unit of product j from supplier i, $\forall i \in S$, $\forall j \in P$,
iu_{ij} : installation cost per unit of product j from supplier i, $\forall i \in S$, $\forall j \in P$,
qu_{ij} : cost of quality control per unit of product j from supplier i, $\forall i \in S$, $\forall j \in P$.

The other costs at the unit level are as follows:

ua_{ij} : other unit level acquisition costs for supplier i product j, $\forall i \in S$, $\forall j \in P$,
ur_{ij} : other unit level reception costs for supplier i product j, $\forall i \in S$, $\forall j \in P$,
up_{ij} : other unit level possession costs for supplier i product j, $\forall i \in S$, $\forall j \in P$,
uu_{ij} : other unit level utilization costs for supplier i product j, $\forall i \in S$, $\forall j \in P$,
ue_{ij} : other unit level elimination costs for supplier i product j, $\forall i \in S$, $\forall j \in P$,
uc_{ij} : other general unit level costs for supplier i product j, $\forall i \in S$.

We need also some other data parameters that are not related to costs as follows:

mis : minimum number of suppliers to use,
mas : maximum number of suppliers to use,
miv_j : minimum inventory of product j, $\forall j \in P$,
mav_j : maximum inventory of product j, $\forall j \in P$,
b_j : beginning inventory of product j, $\forall j \in P$,
d_{jk} : demand of product j in time period k, $\forall j \in P$, $\forall k \in T$,
ls_{ij} : delivery lot size of product j from supplier i, $\forall i \in S$, $\forall j \in P$.

Using the notation defined above, the decision model for this problem is presented in the following section. In the objective function of the model, the aim is to minimize the total cost of ownership so as to meet the demand for a given product group over the period under consideration. As discussed, the TCO objective consists of costs at the supplier level, product level, order level, product-order level and unit level.

Objective: minimize total cost of ownership:

$$Min \quad slc + plc + olc + polc + ulc$$

The supplier level costs are defined as follows:

$$slc = \sum_{i \in S} (qs_i + cc_i + mc_i + rd_i + sa_i + sr_i + sp_i + su_i + se_i + sc_i) * z_i$$

The product level costs are defined as follows:

$$plc = \sum_{i \in S} \sum_{j \in P} (ce_{ij} + tp_{ij} + ac_{ij} + pa_{ij} + pr_{ij} + pp_{ij} + pu_{ij} + pe_{ij} + pc_{ij}) * yk_{ij}$$

The order level costs are defined as follows:

$$olc = \sum_{i \in S} \sum_{k \in T} (tc_i + oc_i + rc_i + vc_i + nc_i * pn_i + oa_i + or_i + op_i + ou_i + oe_i + oc_i) * yj_{ik}$$

The product-order level costs are defined as follows:

$$polc = \sum_{i \in S} \sum_{j \in P} \sum_{k \in T} ((qo_{ij} + qr_{ij}) * qf_{ij} + poa_{ij} + por_{ij} + pop_{ij} + pou_{ij} + poe_{ij} + poc_{ij}) * y_{ijk}$$

Finally, for the unit level costs in the TCO objective we need to introduce an additional breakdown into additional unit level costs, purchasing costs, inventory holding costs and additional revenue that could be generated. The unit level costs are then defined as follows:

$$ulc = aulc + purc + invc - rev$$

The additional unit level costs are defined as follows:

$$aulc = \sum_{i \in S} \sum_{j \in P} \sum_{k \in T} \begin{pmatrix} (if_{ij} + ir_{ij}) * pi_{ij} + (ef_{ij} + er_{ij}) * pe_{ij} + qu_{ij} + mu_{ij} + iu_{ij} + \\ ua_{ij} + ur_{ij} + up_{ij} + uu_{ij} + ue_{ij} + uc_{ij} \end{pmatrix} * ls_{ij} * x_{ijk}$$

The purchasing costs are defined as follows:

$$purc = \sum_{i \in S} xdjl_i$$

The inventory holding costs are defined as follows:

$$invc = \sum_{j \in P} \sum_{k \in T} h_j * \overline{p_j} * vi_{jk}$$

The additional revenues are defined as follows:

$$rev = \sum_{i \in S} \sum_{j \in P} \sum_{k \in T} rb_{ij} * pb_{ij} * ls_{ij} * x_{ijk}$$

The constraints model the conditions imposed and the relationships that exist in the problem and are as described below.

In essence, the demand requirements are the cause of the purchasing decision problem. Such requirements can be derived from the company's MRP records or from available demand forecasts. In each of the time buckets over the decision horizon, the demand can be satisfied either from inventory or from incoming purchases, what remains at the end of the bucket is end-of-period inventory that can then be used to satisfy the demand in a subsequent time bucket. Observe that those constraints only involve decision variables at the unit level.

$$b_j + \sum_{i \in S} \left(\frac{1}{re_{ij}} \right) * ls_{ij} * x_{ij1} - vi_{j1} = d_{j1} \qquad \forall j \in P$$

$$vi_{jk-1} + \sum_{i \in S} \left(\frac{1}{re_{ij}} \right) * ls_{ij} * x_{ijk} - vi_{jk} = d_{jk} \qquad \forall j \in P, \forall k \in T \setminus \{1\}$$

The model allows for various additional constraints to be explicitly taken into consideration. We present common examples. Typically, there are limits on the amount of inventory a company prefers to carry, a lower bound implies a safety stock, an upper bound could indicate a space constraint.

$$vi_{jk} \geq miv_j \qquad \forall j \in P, \forall k \in T$$

$$vi_{jk} \leq mav_j \qquad \forall j \in P, \forall k \in T$$

Another typical constraint is a bound on the number of suppliers used. Those constraints are especially useful for sensitivity analysis using the model. Hereby, the analyst can investigate the impact on TCO of changing the optimal number of suppliers and the resulting consequences on market share and product sourcing.

$$\sum_{i \in S} z_i \geq mis$$

$$\sum_{i \in S} z_i \leq mas$$

Quite frequently, for strategic reasons, a buyer prefers to put bounds on the total volume bought from individual suppliers. Limiting a maximum purchasing volume results into using several suppliers thereby decreasing the strategic dependency on a few vendors. Enforcing a minimum purchasing volume might be necessary for a supplier to become interested in the business.

$$xdjl_i \geq mij_i * \left(\sum_{t \in S} xdjl_t \right) \qquad \forall i \in S$$

$$xdjl_i \leq maj_i * \left(\sum_{t \in S} xdjl_t \right) \qquad \forall i \in S$$

Similar bounds can also be modeled from the suppliers' perspective. For capacity reasons, a vendor might not be able to supply the quantity demanded. The delivery quantity must then be limited by the capacity. Some vendors might also require a minimum delivery quantity to make it worthwhile for them to supply the products.

$$\sum_{l \in DP_{ij}} xd_{ijl} \geq mi_{ij} * \left(\sum_{t \in S} \sum_{l \in DP_{tj}} xd_{tjl} \right) \qquad \forall i \in S, \forall j \in P$$

$$\sum_{l \in DP_{ij}} xd_{ijl} \leq ma_{ij} * \left(\sum_{t \in S} \sum_{l \in DP_{tj}} xd_{tjl} \right) \qquad \forall i \in S, \forall j \in P$$

To correctly model the costs incurred at the various hierarchical levels, proper relationships among the discrete and continuous decision variables have to be included. The constraints below consecutively force the decision variables at higher hierarchical levels to take the correct values step by step. This process is driven by the decision variables at the unit level that are properly set to satisfy the demand requirements.

$$ls_{ij} * x_{ijk} \leq \left(\sum_{t=k}^{|T|} d_{jt} \right) * y_{ijk} \qquad \forall i \in S, \forall j \in P, \forall k \in T$$

$$y_{ijk} \leq yj_{ik} \qquad \forall i \in S, \forall j \in P, \forall k \in T$$

$$y_{ijk} \leq yk_{ij} \qquad \forall i \in S, \forall j \in P, \forall k \in T$$

$$yj_{ik} \leq z_i \qquad \forall i \in S, \forall k \in T$$

$$yk_{ij} \leq z_i \qquad \forall i \in S, \forall j \in P$$

In its general decision support system, Usinor requested the various possible discounting schemes to be included. These consist of 4 combinations, i.e. all units and incremental units discounts for the purchasing volume of both individual products and the total product group.

First, we present the constraints for the purchasing volume of the individual products. We have to compute the amount bought over all discounting intervals.

$$\sum_{l \in DP_{ij}} xd_{ijl} = \sum_{k \in T} p_{ij} * ls_{ij} * x_{ijk} \qquad \forall i \in S, \forall j \in P$$

Then, the constraints below force this amount to be within only one specific discounting interval.

$$xd_{ijl} \geq lb_{ijl} * w_{ijl} \qquad \forall i \in S, \forall j \in P, \forall l \in DP_{ij}$$
$$xd_{ijl} \leq ub_{ijl} * w_{ijl} \qquad \forall i \in S, \forall j \in P, \forall l \in DP_{ij}$$

Clearly, it is impossible to obtain a discount if we do not buy the product from the supplier as is enforced by the constraints below.

$$\sum_{l \in DP_{ij}} w_{ijl} \leq yk_{ij} \qquad \forall i \in S, \forall j \in P$$

Second, we present the constraints for the purchasing volume for the total product group. We have to compute the total purchases for each supplier over all discounting intervals. Hereby we consider the individual product discounts using proper adjustments for incremental units discounts indicated by the parameter $a_{ij} = 0$.

$$\sum_{l \in DT_i} xdj_{il} = \sum_{j \in P} \sum_{l \in DP_{ij}} (1 - dc_{ijl}) * xd_{ijl} +$$
$$(1 - a_{ij}) * \left(\left(\sum_{\substack{t \in DP_{ij}, \\ t < l}} (1 - dc_{ijt}) * (ub_{ijt} - lb_{ijt}) \right) - (1 - dc_{ijl}) * lb_{ijl} \right) * w_{ijl}$$
$$\forall i \in S$$

Then, the constraints below force this amount to be within only one specific discounting interval.

$$xdj_{il} \geq lbj_{il} * wj_{il} \qquad \forall i \in S, \forall l \in DT_i$$
$$xdj_{il} \leq ubj_{il} * wj_{il} \qquad \forall i \in S, \forall l \in DT_i$$

Clearly, for each particular supplier, we must buy within some discount interval.

$$\sum_{l \in DT_i} wj_{il} = z_i \qquad \forall i \in S$$

Finally, we compute the total purchases for each supplier. Hereby we model the total purchasing volume quantity discounts making proper adjustments for incremental units discounts indicated by the parameter $aj_i = 0$. In addition, at this point, we also consider the implied discount due to the payment delay and the relative increase in TCO due to any services provided by the suppliers.

$$xdjl_i = \sum_{l \in DT_i} (1 - dcj_{il} - dp_i) * se_i * xdj_{il} +$$

$$(1 - aj_i) * \left(\left(\sum_{\substack{t \in DT_i, \\ t < l}} (1 - dcj_{it} - dp_i) * se_i * (ubj_{it} - lbj_{it}) \right) - (1 - dcj_{il} - dp_i) * se_i * lbj_{il} \right) * wj_{il}$$

$$\forall i \in S$$

The model formulation is concluded with the definition of the bounds and integrality conditions on the decision variables.

$$z_i, wj_{il}, yj_{ik}, yk_{ij}, w_{ijl}, y_{ijk} \in \{0,1\} \qquad \forall i \in S, \forall j \in P, \forall k \in T, \forall l \in DT_i, \forall l \in DP_{ij}$$

$$x_{ijk} \in \{0,1,2,3,...\} \qquad \forall i \in S, \forall j \in P, \forall k \in T$$

Both the TCO matrix and the optimization model have been incorporated into a user-friendly software package. This management information system allows the user to define the total cost of ownership for a specific product group identifying and quantifying the various relevant costs using the TCO matrix. Once the costs are entered, the optimization will determine a procurement strategy. The specific optimization process is completely transparent for the user and LINGO (Schrage 1998) is used for that purpose. Finally, various output reports are generated providing also a rich sensitivity analysis.

RESULTS AT USINOR

At this moment the management information system has been used at Usinor for 7 product groups. Information on the demand for the different products was taken from the MRP system of the company. Usinor had recently implemented an activity based costing system for product costing purposes. Information on the cost of most of the activities in the total cost of ownership matrix was available from that costing system. For the other activities we collected cost information at the beginning of the implementation process. Information on the influence of the performances of the different suppliers on these activities was however limited. Some of these data were available from the existing supplier performance measurement system. Other data had to be collected by the multidisciplinary teams responsible for determining procurement strategies for the product group considered.

The results for these different product groups (PG1 to PG7) are presented in Figure 2. The first row gives the current total cost of ownership. It reflects the consumption of resources by the current procurement strategy. In the second row the possible total cost of ownership reduction as a percentage of the current cost is given. This cost decrease can be realized by implementing a more cost efficient procurement strategy as suggested by the management information system. In the third row we describe the major strategic implications. The final row gives the most important cost elements in the total cost of ownership matrix that are affected by the new purchasing strategy. Out of the cost elements that were included in the analysis these cost elements showed the most important relative difference when compared to the current strategy. Because of confidentiality reasons the names of the product groups and more detailed information on suppliers, market shares and composition of the total cost of ownership cannot be given.

Figure 2. Case studies at Usinor

	PG 1	PG 2	PG 3	PG 4	PG 5	PG 6	PG 7
Current TCO in $	200,000	1,200,000	2,400,000	2,500,000	22,500,000	500,000	250,000
Possible TCO reduction	16%	14%	9%	6%	12%	6%	10%
Strategic implications	Less suppliers Market shares Higher order frequency	More suppliers Market shares	More suppliers Market shares	Less suppliers Market shares	Less suppliers Market shares Lower order frequency	Market shares	More suppliers Market shares
Major cost elements	Supplier level costs Price Waste valorization Inventory holding cost	Supplier level costs Price Installation cost	Supplier level costs Price Intrinsic efficiency	Supplier level costs Price Service cost	Supplier level costs Price Intrinsic efficiency Inventory holding cost	Price	Supplier level costs Price Intrinsic efficiency

We obtained the following results. The management information system proposed alternative procurement strategies generating an average reduction in total cost of ownership of 10%. This reduction includes both cash savings and non cash savings. The average cash savings amount to 9%. This means that the reduction in total cost of ownership is mainly due to savings in flexible resources. For all business cases the model proposed substantial changes in market share repartition. For one case (PG6) the number of suppliers used remained the same. For the other cases the number of suppliers decreases or increases in comparison with the current strategy. In most of the cases single sourcing is not optimal from a total cost of ownership point of view. This shows that the optimal sourcing strategy depends on the specific characteristics of the items and suppliers involved. With respect to order policy, product group 1 and 5 require another inventory policy with respectively higher and lower order frequency. As a final result of the analysis we can see that the cost elements showing the most important relative difference depend on the product group considered. In all cases price seems to be an important element. Furthermore, decreases or increases in number of suppliers used affect supplier level costs. Depending on the specific case other cost elements show the biggest relative differences.

Usinor uses the total cost of ownership matrix and the information obtained from the management information system also for three other purposes. First, purchasing managers at the company use the output from the model as a basis for negotiations. Since the total cost of ownership approach concentrates on the financial effect of performances of suppliers on the value chain of the purchasing company, it gives purchasing managers more objective information and comparative advantage during negotiations with suppliers. Second, Usinor uses the approach for performance evaluation of purchasing managers. The company developed a software tool to follow-up reductions in total cost of ownership realized in the purchasing department. For all purchasing managers the expected savings are classified by the time of realization: savings that are immediately realized, forecasted savings for the current year and for next year. The realized savings are compared against the expected savings to analyze the deviations and to verify whether it is necessary to take actions. Third, this approach supports the strategic role of purchasing by stimulating interdepartmental interaction. The total cost of ownership approach makes the purchasing department think in financial terms and involves interfunctional communication when determining procurement strategies. There is indeed a lot of information to be provided by the several departments in the value chain of the purchasing organization.

CONCLUSION

In this article we have presented a company-wide management information system for strategic procurement. The approach is based on a total cost of ownership framework taking into account the use of flexible and committed resources for activities in different hierarchical levels and in different phases of the life cycle of the products or services externally bought. At Usinor the model realized average cost savings of 10% compared to the current purchasing strategy. The company actively uses the total cost of ownership information during negotiations and evaluates the performances of the purchasing managers on the basis of total cost of ownership savings.

There are several possible extensions of this work that are left for future research. A first extension of the model would consider future reactions of suppliers on the new procurement strategy of the purchasing company. The current framework concentrates on today's negotiations without taking into account future actions of the suppliers. Combining our total cost of ownership framework with game-theoretic elements would however give insights into these long-term relationships. Introduction of moral hazard, adverse selection and information asymmetry could give additional information on optimal ways of contracting and partnering with suppliers.

Another major contribution would provide insights about the impact of uncertainty and stochastic elements in the procurement decision. There is considerable uncertainty about almost all the required data elements in the total cost of ownership in addition to uncertainty about the procurement requirements. In the deterministic decision model that we have developed, uncertainty can be incorporated by applying the concepts and techniques developed in stochastic linear programming (see e.g. Infanger 1994 or Birge and Louveaux 1997). The strategic procurement decision can indeed be considered as a two-stage stochastic decision problem with recourse. A scenario approach can then be used to specify the uncertainties involved (see e.g.

Eppen, Martin and Schrage 1998). In a first stage, facing considerable uncertainty, the decision is essentially which subset of suppliers to choose. When it comes to the day-to-day tactical ordering operations, much of the uncertainty is being resolved and the recourse decision that remains is then the order quantities that can be placed with the vendors selected.

A third possible extension would study how different possible strategic actions can influence the total cost of ownership for a given product group (Ittner e.a. 1999). It would be interesting to consider the effects of actions such as vendor certification, the standardization of materials, the improvement of relationships with suppliers and the development of a common infrastructure on the total cost of ownership.

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