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IMPROVING THE EFFICIENCY OF THE PURCHASING PROCESS USING TOTAL COST OF OWNERSHIP INFORMATION : THE CASE OF HEATING ELECTRODES AT COCKERILL SAMBRE S.A.

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Abstract

Improving the efficiency of the purchasing process provides important opportunities to increase a firm's profitability. In this paper we introduce a mathematical programming model that uses total cost of ownership information to simultaneously select suppliers and determine order quantities over a multi-period time horizon. The total cost of ownership quantifies all costs associated with the purchasing process and is based on the activities and cost drivers determined by an activity based costing system. Our approach is motivated by the purchasing problem of heating electrodes at Cockerill Sambre S.A., a Belgian multinational steel producer. In this case quality issues account for more than 70% of the total cost of ownership making the quality of a supplier a critical success factor in the vendor selection process.

Keywords : Purchasing ; Vendor Selection ; Supply Management ; Total Cost of Ownership

1. Introduction

External purchases are a substantial expenditure for most companies. They represent an important part of the value of products. Outsourcing activities to external suppliers is a hot topic in today's business world. Notwithstanding major opportunities to increase profitability through a more efficient organization of the purchasing process, simple and inaccurate systems for selecting suppliers are currently used in practice.

From a theoretical perspective, the literature on supplier selection has been limited. Most papers deal with the selection of one supplier for a given order. However, procurement decisions involve the determination of order quantities over a multi-period time horizon with different potential suppliers. Several methodologies have been suggested to weigh the different criteria that influence the purchasing decision process (Weber and Current 1991). The weights given to the criteria and the rankings of the suppliers on the criteria reflect subjectivity and therefore introduce inaccuracy in the selection process.

In this paper we present a multi-period multi-vendor mathematical optimization model for this purpose. The model is based on total cost of ownership information. The total cost of ownership is the true cost of buying a particular good or service and consists of price and other elements that reflect additional costs caused by the suppliers in the purchasing company's value chain. The additional costs reflect the consumption of resources necessary for the supplementary activities associated with the purchasing process and are derived from the activities and cost drivers determined by the company's activity based costing system. The approach is motivated by a real life purchasing problem for heating electrodes at Cockerill Sambre S.A.. For this product group, cost issues beyond price account for more than 80% of the total cost of ownership.

The contribution of this paper is threefold. First, we introduce four hierarchical levels in the decision support system to describe the supplementary activities caused by the suppliers. These levels are similar to the production and marketing activity hierarchies developed in the activity based costing literature. Second, the model takes into account several dimensions that have not yet been modeled in the supplier selection literature. Differences in quality reflected by usage duration of the procured item, repurchasing of waste from consumed items and ordering in batches are the most important extensions. Third, the model uses a multi-period time horizon so that optimal order quantities and inventories can be determined. Contrary to the traditional approach where supplier selection and inventory management are separate, our decision model provides an integrated framework to increase the efficiency of the purchasing process.

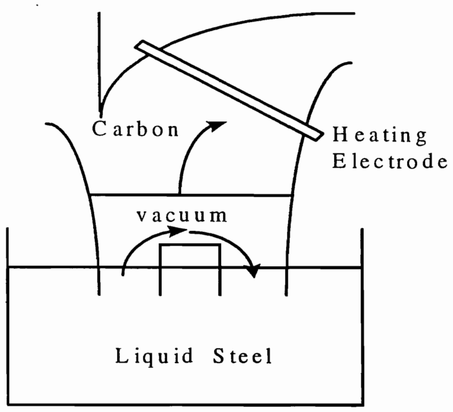
This paper is organized as follows. The second section describes the case study that motivates the model. In section three, we review the supplier selection literature and discuss the use of total cost of ownership information in procurement decisions. The decision support system is described in the fourth section. The results of our approach and the improvements achieved are discussed in section five. Finally, section six presents conclusions.

2. Description of the purchasing problem

We study the procurement of heating electrodes at Cockerill Sambre S.A., a Belgian multinational company in the steel industry with external purchases approaching $2 billion annually. Purchased goods and services represent more than 70% of total costs and offer an important potential for cost savings. The company uses more than 4000 active suppliers. Management wants to improve the efficiency of the purchasing process by realizing an important reduction in the supplier base. Our case study refers to the heating electrodes, a product selected for study by the purchasing managers of the firm.

The heating electrodes are used in a process that occurs after steel has been produced in the blast furnaces. Liquid steel is collected in a recipient and circulated in vacuum as depicted in Figure 1. The process aims essentially at reducing the carbon content of the liquid steel but it also serves to homogenize the steel composition.

Figure 1 : Usage of the Heating Electrode.



The role of the heating electrode is to provide a constant high temperature such that the steel is not cooled off too much too quickly during the circulation process. Basically, heating electrodes are long cylindrical carbon rods with a length of 2 meters and a diameter of about 80 millimeters. They loose their carbon content during use. When the electrode has lost its complete carbon content, it is fully consumed and replaced by a new one resulting in a setup. The usage duration and the failure rate or percentage defective, determine the electrodes' quality which varies among suppliers. This quality differential should be quantified and taken into consideration in a supplier selection approach.

Suppliers can be differentiated on the basis of several criteria. The most important criterion is the quality of the delivered electrodes. This quality is determined by the usage duration of the products and the probability of defects. Each replacement of an electrode requires a setup. Setup costs amount to 75% of the total cost of ownership. This means that the quality of the delivered electrodes is a critical success factor in the supplier selection process. A second criterion is price. Prices are given per batch and no quantity discounts are possible. There are important price differences among the suppliers. Furthermore, some suppliers offer a refund for used electrodes. Scrap material of consumed electrodes can be recycled for the production of new ones and is therefore repurchased by some suppliers. A third criterion is the magnitude of the imposed batch size. Some suppliers use larger batch sizes than others. This reduces the flexibility for the purchasing company. On the other hand, it also decreases reception costs per unit since at Cockerill Sambre S.A., the reception cost per batch is not affected by the batch size. A fourth important criterion is the safety time imposed by the purchasing company for delivery uncertainty. It reflects the unreliability of the suppliers with respect to delivery performances and is based on prior experience with the different vendors. A fifth criterion is the payment delay : suppliers offer different payment conditions with delays of up to 3 months. Finally, experience has shown that the time spent by a purchasing manager managing the supplier relationship if the supplier is selected differs among suppliers. If a supplier is not selected, these activities are eliminated. Additional costs such as costs associated with reception and invoicing activities are the same for all orders. They do not affect the choice among the suppliers, but influence the determination of order quantities and the total cost of ownership. Bundling of orders reduces reception and invoicing activities but increases inventory holding costs.

Today's supplier selection policy at the company is based on a subjective tradeoff between price and quality of the different vendors considered. The company has three active vendors for the heating electrodes at this moment. For strategic reasons, it wants to use at least two suppliers with a maximum market share of 80% for the major supplier. This reduces future uncertainty that could result from becoming too dependent on one supplier. For the purchasing problem presented we want to select suppliers and determine order quantities for a decision horizon of twelve months. We use a mathematical optimization model that uses total cost of ownership information.

3. Literature Review

Vendor selection and evaluation is one of the most critical activities of a company in today's competitive business world. Selection of the wrong vendors could cause important operational and financial problems for the purchasing company. Despite its importance in most companies, the rationalization of the purchasing process has received little attention in the scientific literature. Furthermore, most firms use simple and subjective and therefore inaccurate systems to select and evaluate suppliers.

Most papers on the procurement decision concentrate on the selection of one supplier for a given item in a given period. Weber and Current (1991) give an overview of the different criteria used in the selection process. They distinguish 23 quantitative and qualitative criteria that could be important for the selection of suppliers. These criteria are often in conflict with one another. For example, low prices can be offset by poor quality or delivery reliability. Several approaches have been suggested to take into account the multi-objective nature of the decision problem. Many articles discuss the weighted point plan that weighs the different criteria and determines scores of competing vendors on the criteria identified. An overall score reflects the performance of the suppliers and is the basis for selecting a supplier.

The analytical hierarchical approach (Narasimhan 1983) permits purchasing managers to select suppliers on the basis of pairwise comparisons of criteria and performances of suppliers on these criteria. Data envelopment analysis (Weber 1996) is another method that can be used to consider the different criteria simultaneously. It is a multiple input multiple output model that determines an efficient frontier.

Roodhooft and Konings (1997) argue that these methodologies are very subjective and propose to use activity based costing information to select and evaluate suppliers in an objective fashion. They quantify the different criteria in financial terms and use the total costs caused by a supplier in the value chain of the purchasing company as an evaluation tool. We follow their arguments in this paper. Recent developments in management accounting give the opportunity to determine the total cost of ownership associated with purchasing decisions (Benett 1996, Carr and Ittner 1992, Cavinato 1992, Ellram 1995a, Ellram 1995b, Ellram and Siferd 1993, Roehm, Critchfield and Catellano 1992).

The literature review described above deals with the selection of one supplier for a given item. However, in most purchasing problems the objective is to select an optimal combination of suppliers. Most of the published papers in this area concentrate on the price dimension and introduce different discount schemes. Benton and Park (1996) classify the most significant literature on quantity discount schemes and conclude that even in this area we need more complex models to examine quantity discounts when demand is time-phased.

Only a few papers introduce criteria beyond price in mathematical programming models (Akinc 1993, Chaudry, Forst and Zydiak 1993, Rosenthal 1995, Zydiac and Chaudry 1995, Weber and Current 1993). The analysis of the tradeoffs among the relevant criteria is particularly important in modern manufacturing strategies. As Weber and Current (1993) note, it is surprising that little research has been devoted to this subject. Some approaches use a weighting method where the objective function is a convex combination of different criteria determined by assigning relative weights to the criteria. This methodology is comparable to the weighted point plan in single item procurement decisions. Other approaches use the constraint method where prices are minimized subject to constraints on the other criteria. Both approaches, however, introduce subjectivity in the supplier selection process. Sadrian and Yoon (1994) introduce quality cost elements in the decision model. They however fail to incorporate other costs caused by the suppliers in the purchasing company's value chain in their decision support system. Degraeve and Roodhooft (1996) describe a general framework that uses total cost of ownership information in a mathematical programming approach for supplier selection.

In this paper we present a multi-period multi-vendor mathematical optimization model based on total cost of ownership information for the procurement of heating electrodes at Cockerill Sambre S.A.. The approach is based on the total cost of ownership concept that provides information to support decisions relating to the purchasing process. Total cost of ownership tries to quantify the costs associated with the purchasing process. It determines the costs associated with purchasing activities in the company's value chain before, during and after the purchase. Ellram (1995a) gives an overview of formal activities and potential cost drivers related to purchasing.

We introduce four hierarchical levels of activities associated with purchasing. Analogous to activity hierarchies developed in production and marketing, different levels of activities and associated costs can be distinguished with respect to the purchasing process. Supplier level costs are costs assigned to a supplier whenever this supplier is used over the time horizon considered in the procurement decision. Order level costs are incurred each time an order is placed with a supplier and typically consist of order and invoice costs. Batch level costs are related to specific batches. Finally, unit level costs refer to costs for the individual units of the products. This hierarchy will be very useful in the formulation of the total cost of ownership function in our model.

Our approach has several advantages when compared to existing methodologies. The use of total cost of ownership information permits us to reduce the subjectivity in the selection process by indicating and quantifying the supplementary activities caused by the suppliers. In addition to being strategic, our approach is also operational as it enables us to simultaneously select suppliers and determine order quantities using a multi-period time horizon. This means that inventory management is introduced in the approach. Third, the decision support system gives the opportunity to perform all kinds of sensitivity analysis suggesting improvements in the processes of buyer and suppliers and increasing the importance of interorganizational cost management. Furthermore, it forms an objective basis for negotiations between buyer and suppliers and can increase the efficiency of long term contracts between buyer and seller. Finally, the use of total cost of ownership information provides the opportunity to compare in-house production and external procurement taking into account all relevant elements. This information can support outsourcing decisions.

4. The Mathematical Decision Model

In this section, we present the mathematical programming decision model that was used for supplier selection and order quantity determination. In general, it derives a multi-period purchasing policy minimizing the total cost of ownership taking into account the different constraints relevant to the problem. The only assumption used is the fact that the company can place at most one order per time period with each supplier. This assumption is not restrictive, however, as the typical order frequency could determine the length of the time bucket to be a month, a week or even a day. Specifically for the case study, we consider a one year time horizon subdivided into twelve monthly time buckets.

Before stating the model, we give a summary list of the notation for later reference. The following primitive sets, grouping the key elements of the model, are used :

M : set of time periods, index t,

P : set of suppliers, index s.

The parameters indicate the data required. We distinguish four hierarchical levels of activities into which the parameters can be subdivided : (1) the supplier level, (2) the order level (3) the batch level and (4) the unit level. The first hierarchical level, the supplier level parameters, describe costs incurred and conditions imposed whenever the purchasing company actually uses the supplier over the decision horizon. For the heating electrodes' problem specifically we consider :

mc_s : cost of a dedicated purchasing manager for supplier s, $\forall$ s $\in$ P,

slc : total supplier level costs,

maxb : maximum percentage of total demand to be bought from a supplier,

mins : minimum number of suppliers to use,

maxs : maximum number of suppliers to use.

The second hierarchical level, the order level parameters, indicate costs incurred and conditions imposed each time an order is placed with a particular supplier. At this level specifically we consider :

vc_s : invoice cost per order placed with supplier s, $\forall$ s $\in$ P,

oc_s : order cost per order when purchasing from supplier s, $\forall$ s $\in$ P,

olc : order level costs,

st_s : number of periods safety time imposed by the buyer to compensate for delivery uncertainty when purchasing from supplier s, $\forall$ s $\in$ P, The third hierarchical level, the batch level parameters, specify costs incurred and conditions imposed related to a specific batch. For the heater electrodes' problem, we consider specifically :

rc : reception cost per batch,

p_s : price for the product per batch offered by supplier s, $\forall$ s $\in$ P,

dc_s : price discount as a percentage per month due to payment delay given by supplier s, $\forall$ s $\in$ P,

ls_s : purchasing batch size imposed by supplier s, $\forall$ s $\in$ P,

blc : total batch level costs,

Finally, the fourth hierarchical level, the unit level parameters, specify costs incurred and conditions imposed related to the individual units of the products for which a procurement decision has to be made. At this level we consider :

sc : setup cost per setup,

rf_s : refund as a percentage on purchase price per unit for used electrode repurchase given by supplier s, $\forall$ s $\in$ P,

ef_s : relative efficiency (usage duration) of an electrode from supplier s, $\forall$ s $\in$ P,

pd_s : probability of defects per unit bought from supplier s, $\forall$ s $\in$ P,

b_s : beginning inventory of electrodes from supplier s, $\forall$ s $\in$ P,

d_t : demand for the product in period t, $\forall$ t $\in$ M,

h : inventory holding cost per unit per period as a percentage of the product's price,

aulc : the additional unit level costs,

invc : the inventory holding cost,

arev : revenue generated from the repurchase of used electrodes,

ulc : total unit level costs.

As for the parameters, the decision variables can also be subdivided into the same four hierarchical levels. The supplier level decision variable models whether or not the supplier will be used by the purchasing company over the planning horizon and is as follows :

z_s = 1, if we buy from supplier s, 0, otherwise, $\forall$ s $\in$ P.

The order level decision variable models the characteristics of the individual orders placed with the suppliers used. For the heating electrodes problem, we only have one order level decision variable as follows :

y_{st} = 1, if we buy from supplier s in period t, 0, otherwise, $\forall$ s $\in$ P, $\forall$ t $\in$M.

The batch level decision variable represents characteristics of the number of batches bought per order placed with the suppliers used. We have also only one batch level decision variable as follows :

x_{st} = number of batches purchased from supplier s in period t, $\forall$ s $\in$ P, $\forall$ t $\in$M.

The unit level decision variables pertain to the units of the products for which a procurement decision has to be made and are defined as follows :

sd_{st} = consumption of electrodes bought from supplier s in period t, $\forall$ s $\in$ P, $\forall$ t $\in$ M,

inv_{st} = inventory of electrodes bought from supplier s period t, $\forall$ s $\in$ P, $\forall$ t $\in$ M.

With the notation given above, the mathematical decision model is described below.

Objective : minimize the total cost of ownership ;

$$Min \quad slc+olc+bls+ulc \tag{1}$$

The objective function (1), which is used to evaluate alternative procurement policies, is a minimization of the total cost of ownership and reflects the cost data in the four hierarchical levels distinguished.

Define the supplier level costs ;

$$slc=\sum_{s\in P} mc_s z_s \tag{2}$$

The supplier level costs are incurred whenever the purchasing company actually uses supplier s over the planning horizon, i.e. $z_s = 1$. A dedicated purchasing manager can be put to some alternative use if supplier s is not chosen, i.e. $z_s = 0$. In this case, the activities should not be considered in the purchasing decision.

Define the order level costs ;

$$olc=\sum_{s\in P}\sum_{t\in M}\left(vc_s+oc_s\right)y_{st} \tag{3}$$

The order level costs are incurred in those time periods t when an order is placed with a particular supplier, i.e. $y_{st} = 1$. They consist of the invoice cost and the ordering cost when purchasing from supplier s.

Define the batch level costs ;

$$blc = \sum_{s \in P} \sum_{t \in M} \left(p_s \left(1 - dc_s\right) + rc \right) x_{st} \tag{4}$$

The batch level costs include the total purchase cost and the reception cost. Typically in this business, the suppliers allow for a payment delay of several months. We have chosen to model the payment delay by a price discount as a percentage on the purchase price per batch per month. As such, we can quantify the difference in payment delay given by different suppliers. In addition, the batch level cost consists of the reception cost incurred due to handling and storage of each batch in inventory. The reception cost, rc, is computed by determining all costs associated with the storage of each separate batch in inventory whenever the order arrives at the warehouse.

Define the unit level costs ;

$$ulc = aulc + invc - arev \tag{5}$$

Specifically, the unit level costs consist of the additional unit level costs and the inventory holding cost. There is also an additional revenue due to repurchases of waste of used electrodes by some suppliers.

Define the additional unit level costs ;

$$aulc = \sum_{s \in P} \sum_{t \in M} sc \, sd_{st} \tag{6}$$

The additional unit level costs incurred due to ordering from supplier s in time period t depend on the consumption, sd_{st}. Additional unit level costs are incurred whenever a setup is required due to problems with the products bought from supplier s. They are computed as the product of the setup cost per setup, sc, with the actual consumption of electrodes from each supplier. The actual consumption of electrodes is affected by two phenomena. First, under the same circumstances, electrodes from different suppliers have a different usage duration, i.e. the life-span of an electrode when in use differs among suppliers. Second, electrodes offered by different suppliers also have a different failure rate which will also affect the actual consumption. Both phenomena result into supplier specific setup costs. As such, the additional unit level costs are , in fact, a quantification of a quality difference of the products offered by different suppliers.

Define the inventory holding cost ;

$$invc = \sum_{s \in P} \sum_{t \in M} h \left(\frac{p_s (1 - dc_s)}{ls_s} \right) inv_{st} \tag{7}$$

The inventory holding cost applies to the total amount of electrodes of supplier s held in inventory in each time period t, inv_{st}. A supplier selection model should consider inventories explicitly and thus be inherently dynamic, as there is the potential trade-off between ordering more and thus avoiding the order level costs and the cost of keeping the extra amounts in inventory.

Define the additional revenue ;

$$arev = \sum_{s \in P} \sum_{t \in M} rf_s \left(\frac{p_s}{ls_s} \right) sd_{st} \tag{8}$$

Additional revenue results from repurchases by suppliers of used electrodes which can partly be recycled. Repurchases are expressed by the suppliers as a percentage on the unit price to be applied to the units consumed from supplier s in time period t, sd_{st}.

This concludes the derivation of the objective function. The constraints relevant to the procurement problem of the heating electrodes are as follows.

Satisfy the demand ;

$$\sum_{s \in P} \left(\frac{ef_s}{\left(1 + pd_s\right)} \right) sd_{st} = d_t \qquad \forall t \in M \tag{9a}$$

$$b_s + ls_s \, x_{s(1-st_s)} - inv_{s1} = sd_{s1} \qquad \forall s \in P \tag{9b}$$

$$inv_{st-1} + ls_s \, x_{s(t-st_s)} - inv_{st} = sd_{st} \qquad \forall s \in P, \forall t \in M \setminus \{1\} \tag{9c}$$

First, constraints (9a) will determine the consumption by each supplier in each time period of the planning horizon, sd_{st}. Observe that the consumption is properly scaled to reflect the relative efficiency and the failure rate of the electrodes of each supplier. Relative efficiencies, ef_s, are determined by setting them equal to 1 (= 100% efficiency) for those suppliers whose electrodes last the longest and scaling the others appropriately, e.g. $ef_s = 0.5$ (= 50% efficiency) for those suppliers whose electrodes last about half the duration of the longest ones. The consumption of heating electrodes from each supplier in the first time period, sd_{s1}, modeled by constraints (9b), can be satisfied either from beginning inventory, bs, and/or from purchases from the potential suppliers, $x_{x(1-st_s)}$. The amount that remains is end-of-period inventory, inv_{s1}. To compensate for delivery uncertainty of supplier s, some companies prefer to implement a safety time offset, $1\text{-}st_s$, resulting in ordering earlier. However, a late delivery could also result in additional costs, e.g. additional planning and setup costs, additional reception and invoicing costs, which should be taken into account in the objective function either at the order level (3) or at the batch level (4), using a historic probability for late deliveries by supplier s. Constraints (9c) model the consumption from each supplier in later time periods, sd_{st}. This consumption is satisfied either from begin-of-period inventory, which equals the ending inventory of the previous period, inv_{st-1}, and/or from purchases, x_{st}. Again, the amount that remains is end-of-period inventory, inv_{st}.

Impose maximum purchasing quantity required by the buyer ;

$$x_{st} \leq \left\lceil \frac{\sum_{l \in M, l \geq t} d_l}{ls_s} \right\rceil y_{st} \qquad \forall s \in P, \forall t \in M \qquad (10a)$$

$$\sum_{t \in M} x_{st} \leq \left\lceil \frac{maxb \sum_{t \in M} d_t}{ls_s} \right\rceil z_s \qquad \forall s \in P \qquad (10b)$$

Where, for a number n, $\lceil n \rceil$ denotes the smallest integer larger than n. The conditions (10a) essentially model the logical relationship between the ordering, y_{st}, and batch size variables, x_{st}. If an order is placed with supplier s in period t, i.e. $y_{st} = 1$, then the given upper bound on the number of batches to be bought applies. In case an order is not placed with supplier s in period t, $y_{st} = 0$, then the number of batches bought from the supplier should indeed be zero. Similarly, constraints (10b) model the logical relationship between the supplier selection variable, z_s, and the total number of batches bought. If supplier s is selected, i.e. $z_s = 1$, then the total number of batches to be bought is limited by a given fraction, maxb, of the total demand. The parameter maxb is determined by company policy in order not to be too dependent on electrodes from a single supplier even in case several suppliers are selected. If supplier s is not selected, i.e. $z_s = 0$, then the total number of batches bought from this supplier should be zero.

Enforce the bounds on number of suppliers used ;

$$\sum_{s \in P} z_s \geq mins \tag{11a}$$

$$\sum_{s \in P} z_s \leq maxs \tag{11b}$$

$$z_s \leq \sum_{t \in M} y_{st} \qquad \forall s \in P \tag{11c}$$

$$y_{st} \leq z_s \qquad \forall s \in P, \forall t \in M \tag{11d}$$

The conditions (11a) and (11b) force the purchasing plan to have at least the minimum number, mins, and at most the maximum number, maxs, of suppliers over the complete time horizon. Using constraint (11c), the decision variable z_s will be equal to 0, if the model suggests not to buy from the supplier s, while constraint (11d) forces z_s to be equal to 1, if during some time period t, an order has been placed with supplier s.

Integrality and nonnegativity ;

$$z_s \in \{0,1\} \qquad \forall s \in P \qquad (13a)$$

$$y_{st} \in \{0,1\}, x_{st} \in \{0,1,2,3,...\} \qquad \forall s \in P, \forall t \in M \qquad (13b)$$

$$sd_{st} \geq 0, inv_{st} \geq 0 \qquad \forall s \in P, \forall t \in M \qquad (13c)$$

To conclude the model specification, constraints (13a) - (13c), impose the proper integrality and nonnegativity conditions that apply to the decision variables. Model (1) - (13c) is a mixed integer linear program that can be solved with specialized optimization software such as LINGO (Cunningham and Schrage 1995) on any IBM compatible 486 or higher PC. Typical computation times are in the order of minutes.

The model presented above will derive a purchasing policy over a specific time horizon indicated by the number of time periods in the set M. Rather than implementing the policy over the complete time horizon, we suggest to use the model in a dynamic, 'rolling horizon' fashion. In this way, only the purchasing policy resulting for the current period (t = 1) should be implemented as this is the decision to be taken right now. The rolling horizon procedure then implies that at the next epoch, i.e. the end of the first time period, which equals the beginning of the second time period, the model should be rerun with all the parameters updated at this time to reflect the changes that have taken place during the first time period, in order to derive a new purchasing policy over the complete time horizon. The policy found at that epoch should then be implemented only for the first time period. As such, as time goes by, period by period, the model is always resolved with updated information about costs and inventories to reflect the present state of the system and always a purchasing policy over the complete time horizon is computed of which only the first time period's policy is implemented.

There are several advantages to working in this a way. First, for our model the basic time period of one month and the resulting time horizon of twelve months, the data for twelve months out into the future is more unreliable than for the month just ahead. The rolling horizon procedure allows the company to implement the plan only for the upcoming time period while looking well into the future such that end-of-period effects are taken into account. Second, resolving the model period by period while dynamically updating the data to reflect the current situation w.r.t. costs and inventories allows the firm to take performance changes from suppliers as well as those resulting from internal improvements into account. Third, as an additional benefit of the dynamic updating inherent in the rolling horizon procedure, the company will be able to provide accurate feedback to the suppliers about how changes in their performance over time have led to changes in the company's purchasing plan. Moreover, the company will also be able to ascertain whether observed modifications to the purchasing plan resulted from internal changes or from changes in the performance of its suppliers.

In addition, the model could also be used as a tool to evaluate alternative improvement strategies for the suppliers as well as for the firm. In particular, the model can identify what and to what extend specific changes or improvements suppliers could implement in order for the company to start buying, buy more or buy a different mix of products. In short, our model gives a rigorous basis for answering all sorts of 'what if' questions related to the purchasing function.

5. Results

This section describes the results of the mathematical programming approach for the purchasing problem of heating electrodes in Cockerill Sambre S.A.. Table 1 gives an overview of computational results associated with different purchasing policies. Because of confidentiality reasons, the total cost of ownership and its components are given in percentages relative to the total cost of ownership resulting from the current policy and we will denote the actual suppliers by X, Y and Z.

The results of the current purchasing policy are given in the first column. Orders are bundled to avoid unnecessary reception and invoicing costs at the order level. Additional unit level costs amount to more than 70% of total cost of ownership indicating the importance of the quality of the heating electrodes. Inventory holding costs are 20% per unit per year. Additional revenue is generated because supplier X repurchases replaced electrodes.

The column labeled 'Optimal Policy' in Table 1 gives the results of the mathematical programming approach developed in the fourth section of this paper. From a total cost of ownership perspective it is optimal to bundle orders and use only supplier X. Single sourcing and order bundling generate a total cost of ownership decrease of 11.1% compared to today's purchasing policy. Cost savings are realized at all levels considered in the analysis. Supplier and order level activities are eliminated because of the decrease in the number of orders and active suppliers. Due to the use of a supplier with low invoice price cost reductions are generated at the batch level. The selected supplier imposes larger batch sizes than other suppliers. This reduces the flexibility of Cockerill Sambre S.A., but permits the company to realize cost savings in reception. The high quality of the heating electrodes delivered by supplier X reflected by the longer usage duration, gives rise to cost savings at the unit level. Inventory holding costs increase because of the bundling of orders in one period due to the fact that those costs are relatively unimportant. The repurchasing by supplier X of used electrodes for recycling generates additional revenue and decreases the total cost of ownership.

For strategic reasons, Cockerill Sambre S.A. wants to use at least two suppliers with a maximum market share of 80% for the major supplier. The results of this policy are given in the column labeled 'Preferred Policy'. Total cost of ownership is reduced by 8% when compared to the current policy. In this case 9 batches are ordered from supplier X in period 0 and 2 batches from supplier Y in period 9. Supplier level and order level costs are reduced because of the elimination of supplier Z as an active supplier. The decrease in batch level costs is due to the lower purchasing prices of supplier X. Supplementary cost savings are realized at the unit level and the increase in additional revenue is due to the higher market share of supplier X. There are more inventory holding costs because of the bundling of orders.

When compared to the optimal purchasing policy the strategic option to use at least 2 suppliers with a maximum market share of 80% increases total cost of ownership with more than 3%. The introduction of supplier Y causes supplementary costs at different levels. It is obvious that supplementary activities are needed at the supplier and order level. Differences at the batch level are caused by higher prices per batch for supplier Y. Additional revenues decrease since supplier Y doesn't repurchase replaced electrodes. On the other hand the additional order results in smaller inventories reflected in the reduction of inventory holding costs.

This model offers several strategic opportunities for Cockerill Sambre S.A.. First, it is a quantitative basis for determining optimal purchasing strategies since it objectively evaluates the total cost of ownership related to different policies. Second, it gives an overview of supplementary activities associated with external purchases at the different levels distinguished. Reduction of these activities can give rise to important cost savings if the resources consumed by the activities can be reduced or used for other purposes. Using our approach can lead to a fundamental reengineering of the purchasing function. Third, the results of the model can be used in negotiations with different suppliers since all important criteria related to the purchasing decision are taken into account.

Table 1 : Computational Results.

	CURRENT POLICY			OPTIMAL POLICY			PREFERRED POLICY		
SUPPLIERS SELECTED	Supplier X Supplier Y Supplier Z			Supplier X			Supplier X Supplier Y		
ORDERING POLICY	Supplier	Month	Batches	Supplier	Month	Batches	Supplier	Month	Batches
	SupplierX	0	4	SupplierX	0	11	SupplierX	0	9
	SupplierY	5	6				SupplierY	9	2
	SupplierZ	2	2						
SUPPLIER LEVEL COSTS	6.11			1.74			3.49		
ORDER LEVEL COSTS	3.69			1.23			2.46		
BATCH LEVEL COSTS	18.18			15.99			16.07		
UNIT LEVEL COSTS	72.03			69.93			69.98		
INVENTORY HOLDING COSTS	0.59			1.35			0.96		
ADDITIONAL REVENUE	0.95			2.60			2.15		
TOTAL COST OF OWNERSHIP	100.00			88.90			92.00		

6. Conclusion

In this paper we have developed and demonstrated the use of a mathematical programming approach for improving the efficiency of purchasing heating electrodes at Cockerill Sambre S.A.. Our model simultaneously selects suppliers and determines the order quantities to be placed with the suppliers selected. The case reported shows that quality as reflected by the usage duration of the electrodes should explicitly be taken into account. Our methodology allows to quantify quality, price, delivery performance, payment conditions and refunding policy differences among suppliers into a single total cost of ownership expression such that an objective tradeoff can be made. Our optimal solution realizes savings of more than 11% compared to the best possible implementation of the current policy. Satisfying additional strategic considerations of the firm, our recommended policy results in a cost decrease of more than 8%.

References

Akinc, U. (1993), "Selecting a set of vendors in a manufacturing environment", Journal of Operations Management, Vol.11, 107-122.

Bennett, P. (1996), "ABM and the Procurement Cost Model", Management Accounting, March, 28-32.

Benton, W.C. and S. Park (1996), "A classification of literature on determining the lot size under quantity discounts", European Journal of Operational Research, 92, 219-238.

Carr, L.P. and C.D. Ittner (1992), "Measuring the cost of ownership", Journal of Cost Management, Vol.6(3), 7-13.

Cavinato, J.L. (1992), "A total cost/value model for supply chain competitiveness", Journal of Business Logistics, Vol.13(2), 285-301.

Chaudry, S.S., F.G. Forst and L. Zydiak (1993), "Vendor Selection with price breaks", European Journal of Operational Research, 70, 52-66.

Cunningham, K. and L. Schrage (1995), "LINGO : The Modeling Language and Optimizer", LINDO Systems, Chicago, Illinois

Degraeve, Z. and F. Roodhooft (1996), "A Mathematical Programming Approach for Supplier Selection Using Activity Based Costing", Research Report 9659, Katholieke Universiteit Leuven, Department of Applied Economic Sciences.

Ellram, L.M. (1995a), "Activity based costing and total cost of ownership: a critical linkage", Journal of Cost Management, Vol.8(4), 22-30.

Ellram, L.M. (1995b), "Total cost of ownership: an analysis approach for purchasing", International Journal of Physical Distribution and Logistics, Vol.25(8), 4-23.

Ellram, L.M. and S.P. Siferd (1993), "Purchasing: the cornerstone of the total cost of ownership concept", Journal of Business Logistics, Vol.14(1), 163-184.

Narasimhan, R. (1983), "An Analytic Approach to Supplier Selection", Journal of Purchasing and Supply Management, 27-32.

Roehm, H.A., M.A. Critchfield and J.F. Castellano (1992), "Yes, ABC works with purchasing, too", Journal of Accountancy, November, 58-62.

Roodhooft, F. and J. Konings (1997), "Vendor Selection and Evaluation : An Activity Based Costing Approach," European Journal of Operational Research, 96, 97-102.

Rosenthal, E.C., J.L. Zydiac and S.S. Chaudry (1995), "Vendor Selection with Bundling", Decision Sciences, Vol.26, 35-48.

Sadrian, A.A. and Y.S. Yoon (1994), "A Procurement Decision Support System in Business Volume Discount Environments", Operations Research, Vol.42, 179-197.

Weber, C.A. and J.R. Current (1991), "Vendor selection criteria and methods," European Journal of Operational Research, 50, 2-18.

Weber, C.A. and J.R. Current (1993), "A Multi-objective Approach to Vendor Selection," European Journal of Operational Research, 68, 173-184.