# A Web Based Procurement Decision Support System

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*Abstract:* In many firms the value of purchased materials and components accounts for 50-80% of total cost of goods sold. Selecting suppliers in a global economical environment is not an easy task: first there is the large number of possible suppliers, many accessible via the Internet, and secondly there are the usual price and quality conditions that must be taken into account. Thus, supplier selection is a problem that includes both qualitative and quantitative factors. To address this problem, a procurement methodology and a supportive Decision Support System (DSS) are proposed. The DSS runs in a Web based environment, and is able to maintain data regarding quality for each pair supplier/product, collect proposals from the Web, and build and solve an Integer Linear Programming problem with the help of a solver.

*Key-Words:* Decision Support Systems, Business-to-Business Electronic Commerce, Procurement, Integer Linear Programming, Data Marts, Supplier Classification

### **1** Introduction

Industrial purchasing research started in the 1960s, but it was in 1983, when Peter Kraljic published a seminal article [1] focusing on purchasing as an important managerial area with a huge impact on profit, that practitioners and researchers started to pay more attention to this area. A growing tendency nowadays is that business are concentrating on core activities and outsourcing other functions to external suppliers, changing the traditional pattern of large, vertically integrated business into a complex chain of buyers and sellers. This focus on core competencies raised the importance of interorganizational practices due to cost and service quality pressures [2]. On the other hand, the ever growing of Business to Business (B2B) electronic commerce gave buyers access to a larger chain of suppliers [3]. However, the traditional price and quality criteria are still central to procurement processes, as they are the core goals for purchasing. Therefore, it is necessary to define a way in which buyers can use the benefits of web commerce, without loosing focus on these key aspects. This article aims to show a procurement methodology and supportive DSS originally proposed by [4], describing the methodology and its methods, and then showing the supportive DSS architecture, followed by the conclusions.

## 2 Proposed Methodology

The proposed methodology deals with the situation where a single buyer company faces a pool of suppliers that can be segmented into tiers according to their quality level. This is a more controlled environment, in opposition to the totally open and final consumer driven described in [5], where solutions based on incomplete information analysis are needed. Moreover, we take into account two practices: (i) implementing supplier segmentation based on quality performance, and (ii) establishing long-term contracts based on direct costs. These practices create a multicriteria problem of making a trade off between conflicting tangible and intangible factors to find the best suppliers. To face this problem, the proposed methodology creates a strategic sourcing environment, where the buyer seeks to establish value-oriented relationships with its suppliers [6]. The associated Web-based DSS, facilitates the creation of a B2B e-commerce channel between the buyer and its suppliers, supporting long-term contracts and supplier segmentation, thus collaborating to decrease risk in e-commerce transactions [7]. This methodology can be classified as a supplier portfolio model, which concept was originally developed by Markowitz in

1952, who used it as an instrument for managing equity investments [8]. Since then, many others authors proposed the application of the portfolio model to purchasing [9], as a means of optimizing the capabilities of different suppliers. This proposal focuses in analyzing each pair formed by a certain product (or even a service) with a certain supplier. In a first step each pair is classified according to a set of clear defined criteria related to the quality of services of the supplier. A second step comprises collecting proposals from previously selected suppliers and submitting the set of proposals to a mathematical model that determines the best combination of long term supply contracts, under the lowest feasible total cost.

In that way, the concerns of unknown supplier quality and cost of switching from one supplier to another constantly [5], are overcome by the proposed methodology through long-term contracts with high quality suppliers, which simultaneously reduces the number of biddings and give time to the buyer to evaluate their actual and candidate suppliers. Thus the DSS is going to support decisions in trade-off problems by means of separating quality and price in two levels. In that way, a simpler solution was accomplished, in opposition to more sophisticated solutions like the ones based on Gittins Allocation Indices [10] and Nash Equilibrium [5]. In situations of incomplete information, the methodology suggests that the buyer should seek for information about the supplier in the market, establish contractual warranties, or demand standardized quality certifications, in search for risk reduction. As said before, the methodology can be summarized into two steps:

- Classify into three tiers each pair supplier/product according to the historical quality of service that the supplier offers in relation to the product. That classification relies on multiple criteria aggregation to fit each pair into a class, and is accomplished by the Supplier Classification Model. This step is related to quality.
- Implement a through-the-Web reverse auction with the selected suppliers. This auction will determine the combination of proposals that minimizes costs. To accomplish this, a multiperiod, multi-product, multi-supplier mathematical model, named the Contract Selection Model, is used. This step is related to cost.

The buyer organization is supposed to have the correct information about each product amount it demands and the resources available for the periods considered in the mathematical model. Quantities can be previously determined by a production planning method, like Materials Requirements Planning (MRP). The solution used is more suitable to strategic materials, and is based on long term contract that specifies a quantity the buyer guarantees to buy throughout the planning period and associated payments, with discrepancies between supply and demand resolved in the spot market. To differentiate from other approaches, like [11], the problem here focused treats not only many suppliers, but also many products, and the goal of obtaining the lowest total cost in many periods – time dimension is important, since industrial purchases are often recurrent, and the planning horizon depends on products' obsolescence.

## **3 Supplier Classification Model**

The criteria selected are the ones proposed by [12], who estates that besides price, there are ten other cost determinants; each one representing a service level provided by the supplier:

- 1 Product Quality: problems of quality, if not detected by the supplier, will incur an increase in costs related to inspection and rejection by the producer.
- 2 Order Fulfillment Lead Time: the smaller the leadtime, the greater the flexibility of the buyer in being able to respond to demand fluctuations.
- 3 Fill Rates: the percentage of the order delivered on the exact time is an important factor in maintaining schedule. Partial deliveries can result in production program synchronization problems.
- 4 On-Time Delivery Performance: the percentage of the order delivered on the exact date is an important factor in maintaining schedule. Delayed deliveries can also result in synchronization problems.
- 5 Responsiveness to Demand: suppliers must be flexible enough to quickly respond to demand changes.
- 6 Technical Support: a good supplier technical support adds expertise to the company's staff and assists the company to become aggressive in product design, ease of assembly, part commonality and cost control.
- 7 Product Warranty: how readily can replacement components be sourced? If the supplier is fast enough for that, the company will not have synchronization problems.
- 8 Freight Enhancements: good logistics lead to lower costs and shorter lead-times.

- 9 Payment Terms: with what ease can better payment terms be negotiated which bring a return for both sides, allowing a reduction in costs?
- 10 Ordering Practices: how far can the supplier facilitate the placing of orders so as to reduce administrative costs and speed up the whole process as, for example, in the use of Electronic Commerce.

Classification for each pair is accomplished through the use of grade aggregation for each criterion. Specialists supported by a database with historical data determine these grades, for instance, from 0 to 9. This method places the ten criteria in three aggregation sets - Quality, Punctuality and Flexibility. These final criteria will originate an overall level of service for each supplier/product pair. Table 1 shows this hierarchical criteria aggregation. Besides the use of the overall level of service for strategic purposes, the three aggregation criteria or even the basic ones can be used to support specific necessities.

Quality	Product Quality: Percentile of the
-	product rejected
	Technical Support: Support to product
	use
	Product Warranty: How fast and in
	which rates rejected products are
	replaced
Punctuality	Fill Rates: Percentile of the orders
	delivered in the right amount
	On Time Delivery Performance:
	Frequency with which the orders are
	received in the right moment
	Order Fulfillment Lead Time: Total
	time for delivery of an order
Flexibility	Responsiveness to Demand: Capacity
	to answer to changes in orders
	Ordering Practices: Use of practices
	that reduce order costs
	Freight Enhancements: Capacity to
	transport small amounts
	Payment Terms: Discounts and
	parceled out payment

Table 1: Criteria Hierarchy

The classification process goes on by evaluating the performance of each pair supplier/product according to each sub-criterion. The next step is to aggregate the grades towards Quality, Punctuality, and Flexibility and then towards the Overall Performance. To aggregate criteria performances, many methods can be used: De Carvalho shows in [14] the use of Fuzzy Logic, Rough Sets Theory and Back Propagation Artificial Neural Networks. Yet other solutions like arithmetic mean and Multi-Criteria Decision Making techniques can also be used, depending on the levels of subjectivity involved in the process and the technical culture of purchasing experts.

The final step is to segment pairs into three classes:

- First Class: the supplier is selected to compete for long and medium term contracts. Also, it can enter ordinary bidding processes for spot necessities, and joint product development programs.
- Second Class: the supplier can compete for spot necessities and may substitute a First Class supplier for the product, if necessary.
- Third Class: the supplier must enter a quality development program to rejoin procurement processes in the future.

## 4 Contract Selection Model

This model seeks to minimize the direct purchasing costs, since the classification process treats the indirect costs. Prices are negotiated in terms of the total amount per product, and each supplier adjusts its offer to its selling multiples and capacity, establishing a final price that considers its own price ranges and logistics costs. Each supplier bids in terms of periods, selling multiples, prices, and payment conditions. Based on the proposals, demand, financial conditions and storage capacity available, the buyer coordinates the creation of different purchasing scenarios through the DSS, according to different parameters like maximum inventory levels. These scenarios can be used to coordinate purchasing with planning, like in the case of earlier and latter MRP dates. Optionally, numerical values obtained in the classification process can be used to adjust price coefficients [14]. The Deterministic Single Objective Model sets of terms are described as follows.

#### **Objective Function:**

(0) Minimize the total direct cost of acquisition: (total of loans – total of invested surplus) + (total inventory cost) + (total spent directly in acquisition). Aims to minimize the direct acquisition costs. When using classification coefficients, indirect costs are also considered. Loans and invested surplus are updated according to interests paid or earned respectively. **Supply Constraints:**  (1) Product Necessity (Demand): (previous period inventory + amount acquired in the current period)  $\geq$  (product necessity in the current period). This set of constraints aims to guarantee the acquisition of the minimum necessary amount.

(2) Inventory Formation: (current period inventory) = (previous period inventory + amount acquired in the current period – consumed amount). Set of constraints that controls inventory formation.

(3) Supply Scheme: (amount acquired in the current period) = (total amount acquired from one selected supplier). Guarantees that one and only one supplier will be selected for each product.

#### **Financial Aspects:**

(4) Financial Inventory Formation: (money "inventory" at the end of the period) = (initial "inventory" available for the period + loans + previous period invested surplus – amount of money spent in the current period – parcel payments relative to loans taken in previous periods). Establishes the relation between orders and the necessity of obtaining financial resources from the market, or, inversely, the formation of financial surplus in a given period. Loans and invested surplus are updated according to interests paid or earned respectively.

(5) Necessary Investment per Period: (amount spent in the period) = (sum of the payments to be realized in the period). Totalizes the amount of money to be invested directly in product acquisition.

#### **Storage Aspects:**

(6) Storage Limits: (total room for products)  $\leq$  (available room for products) or (maximum inventory allowed). Establishes the storage limits for each group of materials. Room is expressed in quantities of products, not in real physical volume.

#### **Tie-in-Sales:**

(7) Tie-in-sale: For the cases where the order of a given product in a given condition is tied to the order of another material.

The algebraic representation of the model is as follows.

#### **MINIMIZE:**

 $\begin{array}{l} (\forall \ t \in T) \land (\forall \ g \in G) \\ \Sigma_{t,g} \left[ ((1+j_g)J_g - d_g D_g) + \Sigma_{m \in M} \left( e_{tm} E_{tm} \right) \right] + C_g r_{mf} \end{array}$ 

### **SUBJECT TO:**

 $\begin{array}{l} (1) \ (\forall \ t \in T) \land (\forall \ m \in M) \\ E_{(t-1)m} + Q_{tm} \geq \ N_{tm} \\ (2) \ (\forall \ t \in T) \land (\forall \ m \in M) \\ E_{tm} \ = \ E_{(t-1)m} + Q_{tm} - \ N_{tm} \\ (3) \ (\forall \ t \in T) \land (\forall \ m \in M) \land (\forall \ f \in F(m)) \\ Q_{tm} = \ \Sigma_f \ Y_{mf} \ P_{tmf} \\ (\forall \ m \in M) \land (\forall \ f \in F(m)) \end{array}$ 

 $\sum_{f} Y_{mf} = 1$ 

(4)  $(\forall t \in T) \land (\forall g \in G)$   $D_g = D^0_g + J_g + d_{g-1}D_{g-1} - C_g - j_{g-1}J_{g-1}$ (5)  $(\forall g \in G) \land (\forall m \in M) \land (\forall f \in E(m))$ 

(5) 
$$(\forall g \in G) \land (\forall m \in M) \land (\forall f \in F(m)))$$
  
 $C_g = \sum_g \sum_m \sum_f p_{gmf} Y_{mf}$ 

 $\begin{array}{l} (6) \ (\forall \ t \in T) \land (\forall \ a \in A) \land (\forall \ m \in M(a)) \\ \Sigma_m S_m E_{tm} \leq C A_{ta} \\ (7) \ Y_{If} = Y_{If} \end{array}$ 

#### WHERE:

T: Set of supply periods

t: T index

M: Set of products

m: M index

F: Set of suppliers

f: F index

G: Set of payment periods

g: G index

F(m): Set of suppliers for a given product  $m \in M$ 

A: Set of warehouses

a: A index

M(a): Set of products stored at warehouse  $a \in A$ 

 $r_{mf}$ : Classification coefficient for pair m/f

Jg: Loan amount in period g

jg: Interest rates for loans in period g

 $D_g$ : Money surplus at the end of period g

dg: Return rates for invested surplus in period g

 $D_{g}^{0}$ : Available money in the beginning of period g

C<sub>g</sub>: Total money spent in period g

E<sub>tm</sub>: Inventory of m in period t

etm: Unitary cost for Etm

 $P_{tmf}$ : Proposed amount of m in period t by supplier f  $p_{tmf}$ : Proposed price for  $P_{tmf}$ 

Q<sub>tm</sub>: Amount ordered of product m in period t

N<sub>tm</sub>: Necessity of product m in period t

 $S_m$ : Approximated space occupied by a unit of m  $CA_{ta}$ : Storage capacity available of warehouse a in period t

i, j: Indexes for tie-in-sales

## **5** DSS General Structure

The DSS must support the classification and contract selection models in a Web based environment. Therefore, it should allow users to: (i) keep a database of historical data that helps quality analysis for each pair supplier/product, (ii) build and solves contract selection problems, and (iii) access all its functionalities through the Web.

To store historical data collected from orders and deliveries transactional databases, a data mart model was developed. This database implements a star schema [13], shown in Fig. 1. This kind of schema is especially useful for analytical databases, in other words, databases that must be optimized for queries. Star schemas are based on a single Fact Table, or a table that holds transactions, and many Dimensions, or tables that hold data associated to the transactions. The Deliveries Fact Table holds data for each delivery transaction. The Time dimension places the facts in time, the dimensions Supplier and Product links the facts to the pairs supplier/product, the Transportation and Agreement dimensions are related to each fact deal characteristics, and finally the dimension Location associates a fact to a geographical reference. De Carvalho [14] provides more details on how each sub-criterion can be evaluated in quantitative terms and how to navigate in the data mart.



Fig.1: Deliveries Data Mart Star Schema

To support the Contract Selection model an object-oriented model was developed. This approach can provide a solid methodological and philosophical basis for both decision making and the development of a DSS [15].



Fig. 2: Class Diagram for the Contract Selection Model

As graphical notation for modeling, the Unified

Modeling Language (UML) was used. Fig. 2 shows a simplified version of the Class Diagram for the mathematical model. Data is easily obtained through the navigation on object relations, much more than if a relational database approach were used.

Besides being Web based, a series of other requirements were defined for the DSS platform, including: fully object oriented, access to both object and relational databases, content management capabilities, embedded workflow engine, and open source. The platform chosen was the open source Z Object Publishing Environment (Zope), which is compliant to all those requirements.

The high-level DSS architecture is shown in Fig. 3. The system relays on a web server that answers to HTTP requests from a browser. Integrated with the web server there is an application server that runs the algorithms related to data collecting and storage, contract selection problems building, and a workflow engine that supports the methodology related tasks. A relational database (MySQL) is used to store analytical data and an Object Oriented Database (ZODB - Zope Object Database) stores transactional data, in order to facilitate algorithm implementation, making data persistence the more transparent possible. ZODB is used store procurement also to process documentation, which is manipulated by predefined workflows. An external solver is used to solve contract selection problems created by the system, which can hold the results obtained for future analysis. In [14] the open source solver LpSolve was used.

According to Holsapple and Whinston classification [16], this DSS is classified as a hybrid one. It is, at the same time database based (classification data mart), solver based, and text based (general documentation storage and retrieval).



Fig. 3: DSS Architecture

### **6** Conclusions

The current implementation of the DSS here presented is a proof of concept that can be adapted for specific purposes, according to the adopting organization. Following this premise, efforts are now divided into: (i) packing the DSS as a module for the open source project ERP5 [17], so it can be freely adopted and customized by any organization that uses this ERP, and (ii) adapting the methodology and DSS to the specific procurement environment found on a major Brazilian oil company, which is going to use it to support purchasing decisions for offshore and onshore materials and services.

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