A DECISION SUPPORT SYSTEM FOR PURCHASING MANAGEMENT OF LARGE PROJECTS

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This paper describes a model based Decision Support System (DSS) for purchasing materials and components for large projects. The DSS may be used under two scenarios. Under the first scenario, we have a project to execute, and we are looking for a good way to manage the purchasing to minimize the expected costs. The decisions under our control are when and from whom to order each item. Under the other scenario, we are bidding for the project, and wish to assess the costs associated with the purchasing decisions which we should consider before making our bid. In both cases, we take into account expected out of pocket costs as well as lateness and/or expediting penalties. The DSS is designed to help choose the best supplier for each item and schedule the placement of the orders—decisions which are very difficult to make well without such a model based DSS.

In the project management environment, we frequently face the need to schedule the purchasing orders of project items (i.e., items which are not stocked regularly), and to choose the appropriate suppliers for each.

Consider the following typical situation: a project manager has to prepare a bid for an assembly project that requires 1000 different purchased items, 600 of which are stocked regularly. The other 400 items are project specific and need to be purchased. The manager may have quotes from different suppliers for each item, and information about the historic lead time distribution for each item-supplier combination. If items arrive ahead of time, the project will be debited for holding costs at a rate of 28% of the item cost per year (according to internal cost accounting). If some of the items arrive late, the project will be delayed, and a contract penalty of 2% per month will be deducted from the project revenues. In addition to the direct penalty, a delay may tie up expensive resources, and cause a loss of goodwill that cannot easily be assigned a monetary value. (Would it be $20,000 or $200,000 per month?)

If a vital item is late, the manager can try to expedite its delivery. This solution has its own penalty because expediting implies incurring certain cost. Furthermore, expediting an order will usually reduce its lateness, but not eliminate it completely.

To minimize the total of holding and lateness costs calls for optimizing the ordering time. Given a purchasing plan, the expected costs can be calculated as a function of the due date, the lateness penalty and/or the expediting penalty. This information can be useful while executing the project and planning the bid. In other words, to assess the expected costs correctly, the manager can and should plan the purchasing orders while still in the bidding stage.

The purchasing decisions that the project or the purchasing manager have to make include placing orders and monitoring their status. The manager has to decide when and from which supplier to purchase each item (or group of items). This is based on price, lead-time distribution, and other information about the supplier's quality and anticipated future deliveries. For example, one supplier may offer a high mean lead-time, but low variance and a medium price, while another might have a shorter mean and a low cost, but a high variance. Note that the supplier's choice decision cannot be separated from the decision when to place the order. Furthermore, the supplier choice may be highly influenced by the due date.

The effectiveness of such a complex decision process

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can be significantly increased when a DSS, such as the one presented here, is used. Before proceeding with our discussion of the DSS, a brief survey of published results in two relevant areas—inventory theory and stochastic project management—is in order.

Inventory management models are usually classified by the type of demand, i.e., deterministic and stochastic models. Deterministic models may be static or dynamic, while stochastic models are similarly divided into stationary and nonstationary. For instance, the well known EOQ model is deterministic and static; the newsboy problem (Hillier and Lieberman 1986, chapter 18) is stochastic and static. A variety of other factors are incorporated in various models. Delivery lags or lead times are discussed by Whybark and Williams (1976), who use simulation to show that time buffers are preferred over safety stocks when the variation is in lead-time (as opposed to demand fluctuations). For a more recent treatment of lead time problems see Karmarkar (1987). Another factor is the number of items stocked. Most of the literature deals with the case of a large number of items under the implicit assumption that they are independent of each other. The items are sorted by the ABC policy to determine which requires more managerial attention (e.g., see McLeavey and Narasimhan 1985).

The stochastic project management literature mainly concerns assessing the probability that an activity will become critical, given the implicit assumption that it is scheduled as early as possible ("early start"). A more detailed discussion can be found in Dodin and Elmaghraby (1985). One notable exception is Britney (1976), where no such assumption is used. Britney's model is concerned with estimation errors in activities durations, when two different penalties are assigned to over- and underestimating. The activities are then scheduled to minimize the expected penalty, an approach close to the one adopted here. However, Britney's results are limited to single activities, and cannot take into account interdependencies.

The rest of the paper is organized as follows: In Section 1, we present the environment and the role of the system. Section 2 presents the model base module that drives the system. Section 3 is devoted to the information requirements and the data base. Section 4 describes an example of how the system is used. In Section 5, we present the dialogue between the user and the system, and the decision making process carried out under different possible scenarios. To do so, a simple prototype DSS built specifically for this purpose is used. Section 6 concludes the discussion and suggests some further research.

1. General Background

The problems that the DSS described here is designed to help solve have structured as well as unstructured components. The structured part is easy to recognize, though difficult to handle without a computer. Items that do not arrive by the time they are needed cause expediting expenses and/or penalties for late delivery are incurred if the whole project is delayed. On the other hand, items that arrive too soon, carry holding costs.

The unstructured part of the decision making process contains qualitative information which the decision maker has and uses frequently. This may include informal information relating to the future behavior of the supplier, the quality of items, the items' performance in the specific project and so on.

Two scenarios of decision making may be supported by the DSS. Under the first scenario, we are bidding for the project and wish to assess the costs associated with the purchasing decisions that should be considered before making the bid. Under the second scenario, we already have a project to execute and are looking for a good way to manage the purchasing so as to minimize the expected cost.

Note that under the first scenario the DSS is used strategically by the top management team, while under the second, it is used tactically by middle management.

Still, whether the project is underway or being bid for, the same type of output is required, namely, the minimal costs associated with purchasing. Usually, the holding costs are known. A problem arises when we have to assess the penalty costs, which include intangible components (loss of goodwill, reputation, etc.). Therefore, using a DSS which enables us to perform sensitivity analysis, especially on intangibles, improves and facilitates the decision process.

Furthermore, if management feels there is a high enough probability that the bid will be successful, it may be a good business decision to take a calculated risk and order some long lead-time/low relative cost items in anticipation of winning the bid for the project. The system can easily support this type of decision.

2. The Model Base

The model underlying our DSS was developed by Ronen and Trietsch (1987). It is a stochastic, stationary inventory model which emphasizes the variability of lead–time. The model is embedded in a PERT environment, which describes the interdependencies among the various items.

We assume that the lead time of each component is a stationary, stochastic variable with a known distribution. In practice, the distribution can be inferred from historic purchasing data. We also assume that the variability of the assembly activities is negligible relative to the lead-time variability. This assumption is quite reasonable in an environment where the standard deviation of lead-time is usually measured in months and the standard deviation of assembly time is measured in hours or days.

To minimize the total expected cost, the manager has to choose a supplier for each item and optimize the scheduling of order placement based on the minimum cost criterion. The procedure we follow for any given supplier is to optimize the order time for each item, and then to choose the supplier whose minimal cost is the global minimum for a specific item.

Consider first the special case where only one item needs to be purchased. Let t^* be the due date for the item based on the project schedule. If the item is on the critical path and arrives after t^*, the whole project will be delayed and a penalty will be incurred. Let T be the actual order date, our decision variable. Figure 1 illustrates the relationship between t^*, T, and the lead-time distribution. Note that the distribution *starts* at T (the item cannot arrive before being ordered), and consequently, the area to the right of t^*, i.e., the penalty probability, increases with T.

Our objective function is

$$\min\{E(\text{Penalty Cost}) + E(\text{Holding Cost})\}. \tag{1}$$

Expanding the target function (1), we may write

$$\min_T \left\{ C \int_T^{t^*} F(t-T)\,dt + P \int_{t^*}^{\infty} [1 - F(t-T)]\,dt \right\} \tag{2}$$

where

$F(t-T)$ is the cumulative distribution function of the lead-time;

C is the holding cost per period;
P is the penalty cost per period.

Note that these costs are assumed to be linear.

By taking the derivatives of (2) it can be shown that

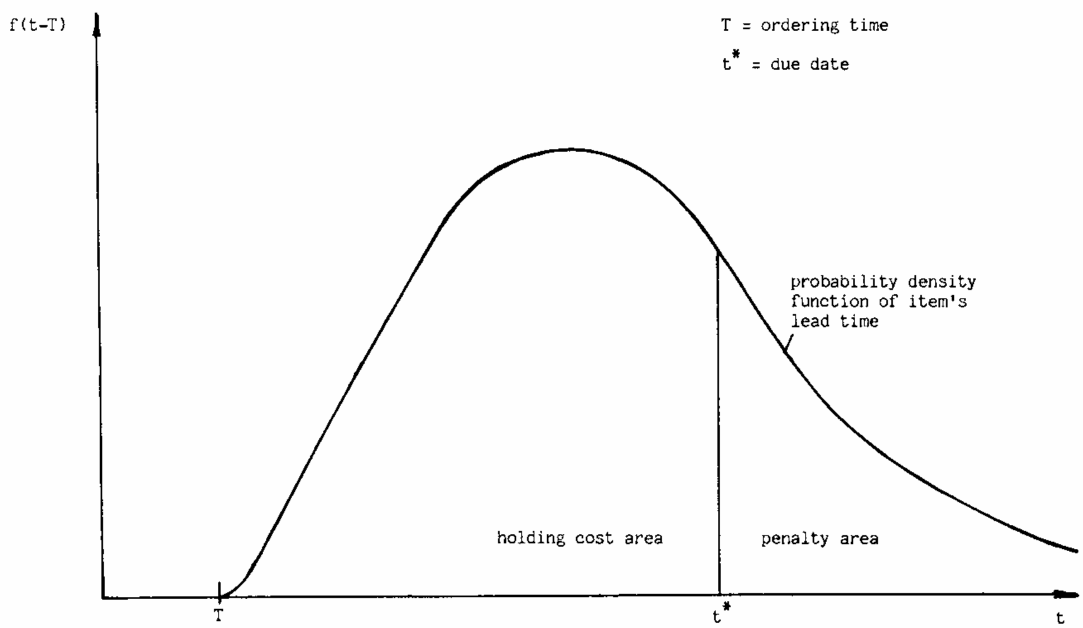

Figure 1. The relationship between t^*, T and the lead time distribution.

the optimal order point, T^*, is that value of T which satisfies

$$F(t^* - T^*) = P/(P + C). \quad (3)$$

If F( ) has an analytic inverse, then

$$T^* = t^* - F^{-1}(1/(1 + C/P)) \quad (4)$$

else, this part of the solution has to be carried out numerically.

If $P \gg C$ (which is very often the case in practice), the model will push T^* far to the left. It may even happen that (4) cannot be satisfied for any nonnegative T, which implies an immediate order. On the other hand, if the variance of the lead time is small enough, we may order "just in time."

Except for the constraint on T^*, the one item model has the same structure as the newsboy problem. Conceptually, there is a major difference in that the newsboy problem deals with the optimal quantity, and our model deals with optimal timing.

The newsboy problem analog, however, fails where several project items need to be purchased and the project depends on the timely arrival of *all* items. If we order n independent items and if delay in one order is sufficient to delay the whole project, we incur the penalty cost P. Moreover, if some orders arrive on time or early, while others are delayed, we also incur holding costs for orders that arrive.

A special case worth noting is when the *only* penalty involved with lateness is expediting cost. In other words, for a cost, we can make sure that all orders will arrive on time. In this case, we assume that the expediting cost will increase with the "would be" lateness. (Otherwise, we could delay all orders until the last minute, and still get them in time for a nominal expediting fee.) If expediting is possible there is no risk of the project being delayed. Therefore, the n item case can be decomposed to n single item cases.

The typical (and real-life) case is more complicated. Let

P = the lateness penalty cost per period.
C_i ($i = 1, \ldots, n$) = the holding cost of item i.
t^* = the project due date.
t_i^* ($i = 1, \ldots, n$) = the time item i is required.
$\Delta t_i = t^* - t_i^*$ (or: $t_i^* = t^* - \Delta t_i$).
$t_i = t - \Delta t_i$ (or: $t = t_i - \Delta t_i$).
$F_i(z)$ = the cumulative distribution function of item i's arrival ($i = 1, \ldots, n$).
T_i^* = the optimal time to order item i.
$F_i^* = F_i(t_i^* - T_i^*)$.
$S = P + \sum_i C_i$.

Then the optimal ordering points satisfy the following (see Ronen and Trietsch):

$$C_i = S \int_{t^*}^{\infty} \frac{dF_i}{d(t_i - T_i^*)} \prod_{j \neq i} F_j(t_j - T_j^*)\, dt; \qquad i = 1, \ldots, n. \quad (5)$$

Relation (5) represents a set of nonlinear equations. Although (5) can be solved numerically, it requires a large computational effort. Fortunately, it is possible to obtain upper and lower bounds on the optimal time. The bounds are quite close to each other in well behaved cases and constitute an efficient heuristic procedure. The first heuristic, which is extremely fast, results in ordering too soon. The second heuristic, slightly slower, has the opposite bias.

To compute a lower bound for the T_i^* values, solve for each item separately, as if it is the only item that needs to be purchased. When doing so, we assume that the lateness penalty for item i is P plus the sum of the holding costs for all other items (defined earlier as $S = P + \sum_i C_i$). The proof that this approach yields a valid lower bound is found by substituting T_i = value of T such that $F_i(t_i^* - T) = 1 - C_i/S$ into (5). Since we order too soon, the penalty cost in this case will be less than the penalty cost in the optimal case, while the holding cost will be more than in the optimal solution. This policy may be attractive to some risk averse managers, who prefer to pay a premium to protect against the project being late. In this sense, it is a "conservative policy."

To find the upper bounds for ordering times, we look for a lower bound on the optimal probability of arrival, F_i^*. The computational effort in determining it is slightly higher now, since the bounds are no longer separable over items. Denote the lower bound by $\underline{F}_i$, then by observation of (5), we obtain

$$F_i^* > 1 - C_i \Big/ \left(S \prod_{j \neq i} F_j^* \right) > 1 - C_i \Big/ \left(S \prod_{j \neq i} \underline{F}_j \right). \quad (6)$$

Therefore, if we solve the following set of equations, subject to all values of $\underline{F}_i$ being feasible (i.e., $T_i \geqslant 0$), we obtain

$$\underline{F}_i = 1 - C_i \Big/ \left(S \prod_{j \neq i} \underline{F}_j \right). \quad (7)$$

Equations 7 are much easier to solve than (6). Furthermore, given the upper and lower bounds we may

Table I
Solution to Two Examples Given the Proposed DSS Model

Example 1
Given:

$$P = \$250$$
$$C_1 = \$200$$
$$C_2 = \$14$$
$$t^* = t_1^* = t_2^* = 12 \text{ months}$$
$$\mu_1 = \mu_2 = 10 \text{ months}$$

Results:
- Optimal solution:
  - order item 1 after 5.2 months
  - order item 2 immediately
- Lower bound for ordering item 1:
  - 3.6 months
- Upper bound for ordering item 1:
  - 7.2 months
- Heuristic result:
  - order after 5.7 months

Example 2
Given:

$$P = \$1000$$
$$C_1 = \$300$$
$$C_2 = \$200$$
$$t^* = t_1^* = t_2^* = 12 \text{ months}$$
$$\mu_1 = \mu_2 = 18 \text{ months}$$

Results:
- Optimal solution:
  - order item 1 after 4 months
  - order item 2 immediately
- Lower bound for ordering item 1:
  - 0.7 months
- Upper bound for ordering item 2:
  - 5.8 months
- Heuristic result:
  - order after 3.9 months

The heuristic result is based on the geometric average of the probabilities.

use a weighted average as the heuristic. Further details about an efficient solution for (7), when it exists, may be found in Ronen and Trietsch.

Preliminary computational results for two items using the exponential distribution function for the lead-time, a case where the exact optimum can be easily computed, look quite encouraging. In cases where the holding costs are low relative to the penalty and there is ample time to order, the bounds are very close to one another. In less well behaved cases, the geometric average of the two bounds seems to perform well. Considering that the objective function in similar problems tends to be quite flat near the optimum, this procedure should be very effective. Table I illustrates some less well behaved instances for which the holding costs are substantial relative to the penalty cost.

Notice that even with the wide gaps between bounds the average heuristic is within a couple of weeks from the optimal solution. In fact, the first example includes the worst result among the values we tried. More often than not, the average was well within a week from the optimum. Readers are referred to Ronen and Trietsch for an additional simple heuristic especially tailored for cases where the bounds are not close.

3. Information Requirements and the Data Base

The data base module requires the following input.
For each item

- List of suppliers.
- Holding cost per item as a fraction of price.

For each item-supplier pair

- Lead time distribution (on-time delivery history).
- Item price.

The module produces the following output.
For each item-supplier pair

- Order date.
- Expected holding cost.
- Expected penalty cost.
- Expected total cost (unit price, holding cost and penalty).
- Price discount required to make a bid competitive (i.e., the difference between the total cost for this supplier and the best competitor for this item).

For each item

- List of suppliers sorted by expected total cost.

For all items

- ABC analysis by expected total cost (Buffa 1983).
- A traditional ABC analysis by item cost.

To support these input and output features the data base requires both external (suppliers' bids) and internal data (past experience with the lead time of items, both in general and for each supplier).

Aggregating the internal and external data, we have the following information for each item-supplier pair.

- Item catalog number (usually the company's number)
- Item part number (usually the manufacturer's number)
- Item price quote
- Item date for the quote
- Mean lead time
- Lead time standard deviation

- Actual net requirement for the item
- Item holding cost
- Alternate suppliers.

An important issue is how to specify the system's defaults where information is not available. This might occur for new items or when dealing with new suppliers.

The use of defaults depends on the nature of the decision to be made as well as on the level of the decision maker. If the decision involves bidding a project, the data accuracy may be relatively low, whereas if it is made during the project execution, more effort may be called for to obtain a good estimate. Default values are entered by the decision makers, according to the best available information, formal and informal.

4. Example

We proceed to show an example of how a decision maker would use the DSS. A prototype was built for this purpose, using a spreadsheet program (LOTUS 123). We use a 20 item project to illustrate the decision process. To simplify the presentation, and since the calculation has no bearing on the description of the interactive process, only the first heuristic is used. Therefore, the results shown are biased in the direction of ordering too soon.

The DSS prototype assumes that each of the 20 items can be purchased from two sources: suppliers A and B. Table II shows the catalog numbers of the items (column 1), the corresponding quantities required (column 2), the supplier's unit price (column 3), and the total price per item (column 4). The percentage of the total cost for all 20 items is shown in column 5. The supplier's lead time is given in months in column 6. For simplicity, we assume that the lead time distribution is exponential with a mean of μ. Thus, the lead time cumulative distribution function will be

$$F(t_i - T_i) = 1 - \exp[-(t_i - T_i)/\mu] \tag{8}$$

where T_i is the ordering time. Substituting in (5) we obtain

$$T_i = \max\{t_i + \mu \ln(C_i/S), 0\} \tag{9}$$

where 0 is used if T_i would otherwise be negative. The results are shown in column 7. Both holding and penalty costs for each item must be computed to obtain the order times shown in column 7. They are computed as follows.

Table II
DSS Prototype, Supplier A

1 Cat. No.	2 Qty. Req.	3 Unit Price ($)	4 Total Price ($)	5 % of Total	6 Lead Time	7 Ordering Time	8 Holding Cost ($)	9 Penalty Cost ($)	10 Total Cost ($)	11 Discount Req. ($)	12 Preferred Supplier
1	12	0.23	3	0	3	0.0	1	20	24	21	B
2	45	78.90	3,551	1	2	6.5	826	6	4,383	0	A
3	5	40.00	200	0	6	0.0	54	2,198	2,452	0	A
4	1,000	12.98	12,980	2	3	1.6	3,772	35	16,786	0	A
5	567	9.70	5,500	1	4	0.0	1,651	198	7,349	0	A
6	8	2,679.00	21,432	4	4	0.0	6,433	198	28,063	14,711	B
7	45	0.23	10	0	12	0.0	2	32,480	32,493	0	A
8	88	1.56	137	0	4	0.0	41	198	377	351	B
9	4	7.00	28	0	6	0.0	8	2,198	2,233	2,212	B
10	435	45.90	19,967	4	2	9.9	3,610	36	23,612	12,968	B
11	1,200	34.98	41,976	8	6	0.0	11,403	2,198	55,577	6,929	B
12	1	100.00	100	0	3	0.0	32	20	152	35	B
13	6	2,348.90	14,093	3	14	0.0	2,647	50,426	67,166	49,972	B
14	789	6.99	5,515	1	22	0.0	777	147,801	154,093	121,618	B
15	500	34.99	17,495	3	9	0.0	4,100	12,507	34,103	12,977	B
16	6	2.99	18	0	3	0.0	6	20	44	28	B
17	65	0.01	1	0	14	0.0	0	50,426	50,427	0	A
18	345	1,140.50	393,473	73	3	11.9	54,223	1,051	448,746	0	A
19	4	500.00	2,000	0	40	0.0	179	439,049	441,228	397,850	B
20	80	6.99	559	0	3	0.0	176	20	755	0	A

Notes: due date = 24 months; holding cost = 18% per year; penalty cost = $240,000 per year; cost of all components plus the penalty (S) = $337,027.

Table III
DSS Prototype, Supplier B

1 Cat. No.	2 Qty. Req.	3 Unit Price ($)	4 Total Price ($)	5 % of Total	6 Lead Time	7 Ordering Time	8 Holding Cost ($)	9 Penalty Cost ($)	10 Total Cost ($)	11 Discount Req. ($)	12 Preferred Supplier
1	12	0	2	0	2	0.0	1	0	3	0	B
2	45	90	4,050	1	3	0.0	1,276	20	5,346	963	A
3	5	30	150	0	7	0.0	39	4,541	4,729	2,277	A
4	1,000	17	17,000	3	2	9.6	3,156	30	20,186	3,400	A
5	567	10	5,670	1	5	0.0	1,619	823	8,112	763	A
6	8	1,280	10,240	2	3	0.9	3,085	27	13,352	0	B
7	45	0	10	0	12	0.0	2	32,480	32,493	0	A
8	88	0	19	0	2	0.0	6	0	26	0	B
9	4	4	16	0	2	0.0	5	0	22	0	B
10	435	22	9,657	2	1	16.2	978	9	10,644	0	B
11	1,200	31	37,200	6	5	0.0	10,625	823	48,648	0	B
12	1	100	100	0	1	11.7	17	0	117	0	B
13	6	1,234	7,407	1	8	0.0	1,822	7,966	17,194	0	B
14	789	8	6,304	1	11	0.0	1,347	24,824	32,475	0	B
15	500	39	19,350	3	1	16.9	1,758	17	21,126	0	B
16	6	2	12	0	2	0.0	4	0	16	0	B
17	65	4	252	0	16	0.0	44	71,402	71,698	21,271	A
18	345	1,350	465,750	80	1	20.1	20,239	415	486,403	37,657	A
19	4	489	1,956	0	13	0.0	383	41,039	43,378	0	B
20	80	8	640	0	4	0.0	192	198	1,030	275	A

Notes: due date = 24 months; holding cost = 18% per year; penalty cost = $240,000 per year; cost of all components plus the penalty (S) = $825,786.

Denoting the expected holding costs for item i by HC_i, and using the first part of (2), we may write

$$HC_i = C_i \int_{T_i}^{t_i^*} (1 - \exp[(T_i^* - z)/\mu])\, dz. \qquad (10)$$

The value of (10) depends on whether T_i is zero or greater than zero:

$$HC_i = \begin{cases} C_i\mu(C_i/S - \ln(C_i/S) - 1) \\ \qquad \text{if } t_i^* \geq -\mu \ln(C_i/S) \\ C_i(\mu \exp(-t_i^*/\mu) - \mu + t_i) \\ \qquad \text{otherwise} \end{cases} \qquad (11)$$

The penalty costs associated with item i, PC_i, are calculated similarly by taking the following integral, as in the second part of (2):

$$PC_i = (S - C_i)\mu \int_{t_i^*}^{\infty} \exp[(T_i - z)/\mu]\, dz. \qquad (12)$$

Note that we assume the penalty is $S - C_i$. In other words, we assume that all the other items will arrive on time. If the order was placed at time $T_i \geq 0$, as per (9), the lateness probability is C_i/S. Using this we obtain the following final result for PC_i

$$PC_i = \begin{cases} (S - C_i)(C_i/S)\mu \\ \qquad \text{if } t_i^* \geq -\mu \ln(C_i/S) \\ \exp(-t_i^* \mu)(S - C_i)\mu \\ \qquad \text{otherwise} \end{cases} \qquad (13)$$

Columns 8 and 9 show the expected holding and penalty costs. For example, the calculation of the penalty for item no. 1 will be as follows: first, we determine S by using $S = P + \sum C_i$. In this case, S = $337,027. Then, the expected penalty is calculated from (13); in this case, $20. Column 10 shows the total cost, which is the sum of the unit price, the holding cost, and the penalty cost. The same calculations are shown in Table III for supplier B.

Column 11 in Table II shows the discount supplier A has to offer to match the total costs of supplier B. The preferred supplier for each item is identified in column 12.

5. Using the DSS for Decision Making

Let us now see how the manager works using this DSS. Under the first scenario, the manager has to bid

Table IV
Total Costs Using 24 and 28 Months

Decision	Total Price ($)	Total Holding ($)	Total Penalty ($)	Grand Total ($)
Case 1: Due Date = 24 Months				
All items ordered from Supplier A	539,037	89,939	741,086	1,370,062
All items ordered from Supplier B	585,786	46,597	184,615	816,998
Items chosen by minimum price criterion	505,842	82,506	298,950	887,298
Items chosen by minimum total cost criterion	508,536	80,735	161,121	750,392
Case 2: Due Date = 28 Months				
All items ordered from Supplier A	539,037	96,033	632,334	1,267,404
All items ordered from Supplier B	585,786	50,202	135,024	771,011
Items chosen by minimum price criterion	505,842	86,855	231,562	824,260
Items chosen by minimum total cost criterion	508,536	84,203	116,146	708,886

for the project. At this stage, the system generates purchasing decisions such as choosing the supplier for each item and calculating the expected holding cost and penalties. The manager can use the system's "What-If" capability to view the results of changing the due date, which is often negotiable at this stage.

Table IV compares the total expected cost for the 24 and 28 months schedules. The first two rows correspond to ordering all items necessary for the project from supplier A or B, respectively. The third row shows the costs incurred when a separate purchase decision is made for each item, but, as often happens in reality, the decision is based solely on the item price, i.e., holding and penalty costs are ignored. For the chosen examples, such a seemingly "rational" decision, is a bad one, as shown by the total costs in column 4. The last row corresponds to the optimal decision. As before, the supplier for each item is chosen independently, but now the decision takes all cost components into account.

Table V
Sensitivity Analysis by Due Date

Due Date	Holding Cost ($)	Penalty Cost ($)	Item Cost ($)	Total Cost ($)
2	4,278	1,367,205	512,556	1,884,038
4	13,871	1,040,495	512,556	1,566,922
6	26,112	823,511	512,556	1,362,179
8	38,900	670,044	508,536	1,217,480
10	52,260	549,029	508,536	1,109,825
12	66,032	454,226	508,536	1,028,794
14	69,167	378,814	508,536	956,517
16	71,579	317,412	508,536	897,527
18	74,006	266,907	508,536	849,449
20	76,382	225,072	508,536	809,990
22	78,779	190,233	508,536	777,548
24	80,735	161,121	508,536	750,392
26	82,464	136,698	508,536	727,698
28	84,203	116,146	508,536	708,886

A full sensitivity analysis for the due date is presented in Table V. The manager can also vary penalty costs to see the consequences. This is of great value because penalty cost is very difficult to assess (Buffa).

Under the second scenario, the project is already underway, and the DSS is used to minimize total expected costs. The system is flexible, and enables the decision maker to change any parameter. The decision variables are as follows.

- The supplier. The system shows the preferred supplier. It also provides support when negotiating with suppliers, since it shows the decision maker the minimal discount the supplier should offer if he is not the low total cost bidder.
- The time to place the order. The system calculates the required order dates for the manager's approval.

The system handles those tasks by using an ABC analysis. This is appropriate because the manager cannot devote enough time to evaluate all the items (often several thousand), even with a good DSS. Our ABC analysis differs from the traditional one in that we order by total expected cost rather than purchase cost. Thus, the manager can perform a sensitivity analysis on the high total cost items, negotiate their lead time with the supplier, decide how much to invest to reduce the lead time of certain items (if at all possible), and so on. Table VI shows this total expected cost analysis.

6. Conclusions

The issue we address is one in operations management. Sophisticated purchasing management offers great profit improvement potential, but by reducing costs and by making on-time deliveries possible. A good DSS that supports both the actual purchasing

Table VI
ABC Analysis by Total Costs

Cat. No.	Qty. Reg.	Price ($)	Holding Cost ($)	Penalty Cost ($)	Total Expected Cost ($)	Preferred Supplier
18	345	393,473	54,223	1,051	448,746	A
17	65	1	0	50,426	50,427	A
11	1,200	37,200	10,625	823	48,648	B
19	4	1,956	383	41,039	43,378	B
7	45	10	2	32,480	32,493	A
14	789	6,304	1,347	24,824	32,475	B
15	500	19,350	1,758	17	21,126	B
13	6	7,407	1,822	7,966	17,194	B
4	1,000	12,980	3,772	35	16,786	A
6	8	10,240	3,085	27	13,352	B
10	435	9,657	978	9	10,644	B
5	567	5,500	1,651	198	7,349	A
2	45	3,551	826	6	4,383	A
3	5	200	54	2,198	2,452	A
20	80	559	176	20	755	A
12	1	100	17	0	117	B
8	88	19	6	0	26	B
9	4	16	5	0	22	B
16	6	12	4	0	16	B
1	12	2	1	0	3	B

Note: the price, holding, penalty, and total expected costs refer to the optimal decision based on the minimum total cost criterion.

decisions and the bidding for projects, which have large purchasing requirements (or are dependent on long lead items), can provide users with an important competitive edge.

The DSS described here uses a model that focuses on lead time management. The data base is quite simple and is usually available. A next natural development is to integrate the DSS within the corporate information base.

For further research we suggest incorporating the subjective probabilities of winning the bid under alternative promised dates (and/or prices). This can enhance the DSS in its role as a strategic negotiation support system. The same concepts can also be used for short-term purchasing decisions.

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