A DECISION SUPPORT SYSTEM
FOR PURCHASING MANAGEMENT OF LARGE PROJECTS

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Abstract

This paper describes a model base Decision Support System (DSS) for purchasing materials and components for large projects. The DSS may be used under two scenarios. Under one scenario, we have a project to execute, and we are looking for a good way to manage the purchasing so as to minimize the expected costs. The decision variable under our control is 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 us 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 base DSS.

1. Introduction

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

For instance, take the following typical situation: a project manager has to prepare a bid for an assembly project. The project requires 1000 different purchased items, 600 of which are stocked regularly. The other 400 items are project oriented, and need to be purchased as part of the project execution. For each such item the manager may have quotes from different suppliers. In addition, information about the historic lead time distribution for each item-supplier is available. If the items will arrive before time, the project will be debited for holding costs at a rate of 28% per year (according to the 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 penalty, a delay causes loss of goodwill which cannot be assigned a monetary value easily. (Would it be $20,000 per month or $200,000?)

In case a vital item is late, the manager may, perhaps, try to expedite its delivery. This solution may be viewed as carrying its own penalty, since expediting is not really free. Furthermore, usually expediting an order will reduce its lateness, but not eliminate it completely.

To avoid these penalties the project manager has to order the items as soon as possible. This, however, will increase the holding costs which the project will have to carry. To avoid large holding costs, then, the manger may be tempted to order "just in time."

Clearly, an optimization is called for.

Given an optimal purchasing plan, the expected costs can be calculated, as a function of the due date and the lateness penalty and/or expediting penalty. This information can be very useful while planning the bid. In other words, in order to assess the expected costs correctly the manager should plan the purchasing orders while still in the bidding stage.

When we have a project under way, the project manager or the purchasing manager has to actually place the orders and to monitor their status. He or she would have to decide when and from which supplier to purchase each item (or, more realistically, each family of items), based on price, lead time distribution, and other information about the suppliers' quality and anticipated future deliveries. Furthermore, the decision <u>when</u> to place the order may be influenced by the choice of the supplier, and cannot be made independently.

For all these tasks, a good Decision Support System (DSS) should be welcome. This paper ventures to propose such a DSS.

The rest of the paper is organized in five sections. In Section 2, we describe the environment and the role of the system in more detail. Section 3 presents the model base module which drives the system. Section 4 is devoted to the data structure and information requirements. Section 5 describes the dialogue between the user and the system, and the decision making process carried out under different scenarios with the DSS. To do so, we actually built and describe a prototype DSS. In section 6 we will conclude our discussion and suggest some further research.

2. General Background

The problems the DSS is designed to help solve, have structured and unstructured components. The structured part is easy to recognize, though difficult to optimize without a computerized system. Items which do not arrive by their due dates cause two types of costs (denoted below as P, or penalty costs): expediting expenses and/or penalties for late delivery incurred by the whole project being subsequently delayed. On the other hand, items which arrive too soon, carry holding costs (denoted below as C).

The unstructured part of the decision 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, quality of items, items' performance at 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 which we should consider before making our bid. Under the second scenario, we already have a project to execute, and we 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 as a "strategic weapon," (from the project manager point of view) while under the second one it is used for tactical decisions. The people using the DSS under the first scenario probably belong to the top management team, while under the second one they typically belong to middle management.

Still, whether the project is underway, or being bid for, the same type of output is required. We need to find 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 good will, reputation, etc.) Therefore, using a DSS which enables us to perform sensitivity analysis, especially on this parameter, improves and facilitates the decision process.

If the project is under way, the decisions are actually implemented, and the value of a good DSS is undisputed. However, the DSS may be even more important during the bidding process. At this stage, the system may arm us with information about the purchasing cost as function of the project due date; the probability that we will miss the due date as a result of problematic items (i.e., items with long lead time and/or has a high variance); and the expected penalty costs. What-If questions can be asked about the implications of various changes. For instance, what will happen if we use a steeper penalty, or negotiate a later due date.

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

As suggested by Ariav and Ginzberg, a DSS consists of five aspects (Ariav and Ginzberg, 1985).

2.1 The Environment

The system's environment is within the project management and purchasing management of large projects. Any project, either in production or in service organization, which requires many purchased items (say, more than a hundred different items) will need such a DSS. One has to take into consideration that this environment is changing very rapidly, and data is sometimes relatively inaccurate (Ronen and Palley, 1986). The proposed DSS may be used by managers in the managerial control level and the strategic planning (Anthony, 1965). The user of the DSS may be (or act on behalf of) one of the following three: (i) the manager in charge of the bid for this project (usually a senior executive); (ii) the project manager, either while preparing the bid, or (after the project is accepted) when choosing suppliers and placing orders; or, (iii) the purchasing manager of the organization, choosing a supplier, or negotiating prices with several vendors.

This environment is very sensitive to lead time management (Goldratt and Fox, 1986), and the penalty for late delivery (especially the intangible one) has grown substantially in the last few years.

2.2 The Role

The role of the system is to aid the decision makers described above to better schedule the purchasing items and to make better bids for new projects.

2.3 The Components

As noted by Sprague and Carlson (Sprague and Carlson, 1982), a DSS consists of a DSS data base, Model base and a user-interface, containing data base management system, model base management system and the dialogue generation management system. Indeed, these are the components of our DSS.

2.4 The Arrangements

There is a linkage between the data base management system and the model base as well as the dialogue management. Most of the data should be taken from the corporate data base. The system we describe can be implemented as a stand-alone system which requires input from the general data base as well as from PERT/CPM data supplied by the project management. At a later stage, such a DSS can be integrated with a PERT/CPM system, thus creating a more complete project management package. At this stage we describe the stand-alone version, since it is the "missing link" today.

2.5 The Resources

The main DSS resources are hardware, software, people and data.

The system described in this paper can be built using any type of hardware -- covering the whole range from microcomputers to mainframes.

The system is classified as a specific DSS (Sprague and Carlson, 1982), and can be written in practically any common programming language.

The people for this DSS include the DSS builders and users.

The data resources include internal and external data, as will be elaborated later.

3. The Model Base

The problem we deal with is very common in practice: There is a project deadline, which, through the PERT planning process, determines the due date for each component. Associated with each item-supplier combination we have a lead time distribution and a price. For instance, 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 high variance.

We have to decide when and with whom to place an order. Obviously, one cannot make the supplier choice decision separately from the decision when to place the order from that supplier. Furthermore, the supplier choice is certainly influenced by the due date.

The model at the base of our DSS is a heuristic introduced by Ronen and Trietsch (Ronen and Trietsch, 1986). The pertinent details which we implement in our DSS, are summarized below.

Our basic premise is that the project manager is responsible for all the costs associated with the purchasing decision. Therefore, it's in the manager's interest and power to minimize the expected total cost of holding the inventory (in case of early delivery) and of the penalty (in case of late delivery; e.g, see Taha, 1982, Ch. 13).

We assume that the lead time of each component is a stationary stochastic variable with a given distribution. In practice, we can produce this distribution from the historic purchasing data in the data base.

Another assumption we make, is that the lateness penalty is linear with the length of the delay. In case of expediting it may be more reasonable to assume that the penalty has two components: a fixed expediting charge, and a component linear with the delay. This more general assumption does not require a substantially different model to handle it. For simplicity, and since the DSS would not be much different in this case, we chose not to include it in this paper.

In order to minimize the expected cost, the manager has to choose a supplier for each item and optimize the scheduling of the orders placement. The procedure we follow is to assume a supplier and optimize the order time. Then, after repeating for all suppliers, we choose the one whose minimal cost is the global minimum for each item.

First, let us discuss a special case, where only one item needs to be purchased. For this case we may offer an optimal solution.

For more components, we extend this result heuristically, later. Our heuristic, which is extremely fast, is biased in such a manner that it drives us to order too soon. Therefore, in a sense it is a conservative solution.

Let t^* be the due date for the item, based on the project PERT/CPM scheduling. That is, if the item arrives after t^*, the whole project will subsequently be delayed, and a penalty will be indicated. Let T be the order date, our decision variable.

Figure 3.1 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, as might be expected.

Place Figure 3.1 about here

Our objective function is:

(3.1) MIN {E(Penalty Cost) + E(Holding Cost)}.

Expanding the target function (3.1), we may write:

$$(3.2)\quad \min_{T} \left\{ C\int_{T}^{t^*} F(t-T)\,dt + P\int_{t^*}^{\infty} [1-F(t-T)]\,dt \right\}$$

Where:

- F() is the CDF 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 derivatives of (3.2) (using the Leibnitz method to differentiate under the integral), it can be shown that the optimal order point, T^*, satisfies

$$(3.3)\quad F(t^* - T^*) = P/(P + C)$$

In other words, T^* satisfies (3.4)

$$(3.4)\quad T^* = \arg\{F(t^* - T^*) = P/(P + C)\}.$$

Assuming that F() has an analytic inverse, we may now obtain T^* directly from it, i.e.

$$(3.5)\quad T^* = t^* - F^{-1}(1/(1 + C/P)).$$

If F() does not have an explicit inverse, this part of the solution has to be carried out numerically.

Obviously, when P >> C (which is very often the case in practice), the model will push T^* as far to the left as possible (i.e., ASAP). It may even happen that (3.5) cannot be satisfied for any non-negative T, which implies an immediate order. In this case, the expected total cost will be larger than "optimal." On the other hand, if the probability that the item will be delivered immediately upon order is high enough, we may order "just in time."

It is interesting to note that the result is not dependent upon the form of distribution, or any of its moments, except for the cumulative probability itself. However, the optimal value of the target function which results, is very dependent upon the distribution, and especially its tails. (In the "more than one item" case, however, the optimal order points are dependent upon the distributions.)

Indeed, in real life, several items need to be purchased. If we have n independent items to order, it is enough that one order will be delayed, to delay the whole project, and thus incur the penalty cost P. Moreover, if at least one of the orders arrives in time while at least one of the others is delayed, we also have to carry the holding cost for the orders which have arrived.

A special case worth noting is when the only penalty involved with lateness is the expediting cost. In other words, for a cost, we can make sure that all orders will arrive on time. In that case it stands to reason that the expediting cost will be a function of the "would be" lateness. (Otherwise, we could perhaps delay all orders until the last minute, and still get them in time for a nominal expediting fee.) To continue, in this case there is no risk of the project being delayed. Therefore, the n items case can be decomposed to n single item cases. The regular case (and real life) is more complicated, however.

- Let C_i $(i = 1,\ldots,n)$ be the holding cost of item i.
- Let t_i $(i = 1,\ldots,n)$ be the time item i is required.
- Let $F_i = F_i(t_i - T_i)$ denote the probabilities that the respective orders will arrive before t, given that they were ordered at T_i (regardless of what happens to the other items).
- Let P be the lateness penalty cost per period.
- Let T_i^* be the optimal time to order item i.
- Let $F_i^* = F_i(t_i - T_i^*)$.
- Let $S = P + \sum_i C_i$

Then the optimal ordering points satisfy (3.6) (See Ronen, Trietsch, 1986)

$$(3.6) \quad C_i = S \int_{t^*}^{\infty} \frac{\partial F_i}{\partial (t - T_i)} \prod_{j \neq i} F_j(t_j - T_j)\,dt \quad ; \quad i = 1, \ldots, n.$$

(3.6) is a set of nonlinear equations, which can be handled numerically. This requires much computational effort, however.

Fortunately, it is very easy to compute a lower bound for the T_i^* values. In effect what we do is solve for each item separately, as if it was the only item which needs to be purchased, with very little modification. When doing so we assume the lateness penalty for item i is P plus the sum of the holding costs for all the other items. For a proof that this yields a valid lower bound, refer to Ronen, Trietsch 1986. Our formula is:

(3.7) $T_i = \arg\{F_i(t_i - T_i) = 1 - C_i/S\}$,

and can be calculated for each item independently.

Using (3.7) instead of (3.6) we order too soon, since it yields a lower bound for the optimal ordering time. In other words, the penalty cost will be less then optimal, while the holding cost will be more than optimal. This policy may be attractive to risk averse managers, who prefer to pay some "insurance," against the project being late. In this sense, this is a "conservative policy." The heuristic is recommended because it is a lot easier to compute than (3.6). As a matter of fact, by looking at (3.6) the readers may appreciate that the optimal solution for this case requires a substantial computation effort, which may not be justified. Actually, if we have many orders to place it may be practically <u>impossible</u> to compute the optimal solution with a reasonable degree of accuracy, while the heuristic is extremely fast. The fact that most managers are risk averse, is an additional reason to recommend the heuristic.

The module requires the following input:

For each item:

- List of suppliers

- Holding cost per item as a fraction of price. (We can assess one typical holding cost as a percentage of the purchase cost for each family of items.)

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.
- Discount required to make competitive.

For each item:

- List of suppliers sorted by expected total cost.

For all items:

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

4. The Data Base

The data Base for the DSS includes external and internal data. The external data are the suppliers' bids. The internal recorded data consists of the past experience with the items lead time, in general and as related to 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 quote
- Item date for the quote
- Lead time mean
- 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 with new items or when dealing with new suppliers.

The use of defaults depends on the nature of decision to be made, or the level of the decision maker. If the decision is made for bidding a project, by some senior executive, the data accuracy may be relatively low (Ahituv and Neumann, Ch. 5). When the DSS is used by a lower echelon manager during the project execution, more effort may be called for to obtain good estimates. Be that as it may, the Default values should be entered by the decision makers, according to their best information, formal or informal, and based on their needs.

5. The Decision Making Process

We will now show an example of how a decision maker may use the DSS. A DSS prototype was built for this purpose, using a spreadsheet program (LOTUS 123). We will use a 20 item demo project to illustrate the decision process.

The DSS prototype assumes that each of the 20 items can be purchased from two sources: Supplier A and Supplier B. Exhibit A shows in Column 1 the catalog numbers of the items, and the corresponding quantities (Column 2). Column 4 shows the Supplier's unit price. Multiplying Columns 2 and 4 gives the total price per item (Column 5). The relative price of each item can be read in Column 6.

An important data is, of course, the supplier's Lead Time, given in months in Column 7. For simplicity, we assume that the lead time distribution is exponential with a mean of μ. Thus, the lead time CDF will be

(5.1) $F(t_i - T_i) = 1 - \mathrm{EXP}[-(t_i - T_i)/\mu]$

and substituting in (3.7) we obtain

(5.2) $T_i = \arg\{1 - \mathrm{EXP}[-(t_i - T_i)/\mu] = 1 - C_i/S\}$.

Note that (5.2) is not guaranteed to yield a non-negative result. Therefore, we have to stipulate this, i.e.,

(5.3) $T_i = \mathrm{Max}\{t_i + \mu \ln(C_i/S),\ 0\}$.

Denoting the expected holding costs for item i by HC_i, and using the first part of (3.2), we may write for it

$$(5.4) \qquad HC_i = C_i \int_{T_i}^{t_i} (1-\exp[T_i-z)/\mu])\,dz$$

The value of (5.4) depends on whether or not (5.2) yields a non-negative result, and is as follows:

$$(5.5) \qquad HC_i = \begin{cases} C_i\mu(C_i/S - \ln(C_i/S) - 1) & ; \quad t_i >= -\mu\ln(C_i/S) \\ C_i(\mu EXP(-t_i/\mu) - \mu + t_i) & ; \quad t_i < -\mu\ln(C_i/S). \end{cases}$$

The penalty costs associated with item i, PC_i, are calculated similarly by taking the following integral, as per the second part of (3.2):

$$(5.6) \qquad PC_i = (S - C_i)\int_{t_i}^{\infty} \exp[(T_i - z)/\mu]dz$$

Note that we assume the penalty is $S - C_i$. In other words, we assume that all the other items arrived, as per our heuristic. Another interesting point is, that since the exponential distribution does not have a memory, we can also write for PC_i,

$$(5.7) \qquad PC_i = \Pr\{\text{item will be late}\}(S-C_i)\mu.$$

Assuming that the order was placed at time $T_i > 0$, as per (5.3), the lateness probability is C_i/S. Using this we obtain the following final result for PC_i:

$$(5.8)\qquad PC_i = \begin{cases} (S - C_i)(C_i/S)^{\mu} & ;\ t_i >= -\mu\ln(C_i/S) \\ EXP(-t_i/\mu)(S - C_i)^{\mu} & ;\ t_i < -\mu\ln(C_i/S). \end{cases}$$

Using (5.2) to calculate the order timing if we choose Supplier A, we obtain Column 8. We have used an annual holding cost (C_h) of 18% and t_i of 24 months, for all the items. As noted above, the time we place the orders cannot be negative. Thus, Column 9 transforms the negative values of Column 8 into zeros. In other words, Column 9 gives the result of (5.3).

In Columns 10 and 11 we calculate the expected holding costs and penalty costs. Column 11 contains the real total costs: The unit price, the holding cost and the penalty cost. The same calculations are done by the system for the quotations of Supplier B (see Exhibit 2). Column 13 of Exhibit A shows the discount Supplier A has to offer in order to match the total costs of Supplier B. The preferred supplier for each item is identified in Column 3.

In Exhibit C the system chooses the best supplier for each item by two criteria: the minimal unit price and the expected minimal total price. The right criteria should be, of course, the total costs approach. However, sometimes managers are interested to know how much they are spending "out of pocket."

Let us now see how the manager works using this DSS.
Under the first scenario, the manager has to bid for the project. At this stage the system generates the 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. Exhibit C shows the total costs expected if we bid for 24 as compared to 28 months. A full sensitivity analysis for the due date is presented in Exhibit D. The manager can also try different penalty costs and see the consequences. This is of much value, as the penalty cost is very difficult to assess (Buffa, 1983), and the "What-If" feature might be of great help.

Exhibit D also shows that the cost is monotone decreasing with the due date. This is to be expected under a good policy. If we always order as soon as possible, however, the holding cost component may increase faster than the penalty decreases. In this case, postponing the due date is not always advantageous, unless the client is willing to pay upon delivery even if it is too soon.

Be that as it may, we simply cannot postpone the due date too much, because our competitors may then win the bid. The DSS can be very instrumental as a negotiating support system for this parameter as well. For this purpose it can be enhanced by the manager's subjective probability distribution of winning the bid as a function of the promised date. Given such a distribution, it is possible to maximize the expected net revenues. The details of enhancement are outside the scope of this paper, however.

Under the second scenario, the project is under way already, and the DSS is used to minimize the total expected costs. The system is flexible, and enables the decision maker to change any parameter that might be needed: holding cost, penalty cost, lead times, etc. The decision variables are as follows:

- The supplier - from which supplier to purchase. The system shows the preferred supplier. The system serves also as a negotiation support system (while negotiating with suppliers), and shows the decision maker the minimal discount a certain supplier should offer if the better offer is to be matched. We have to remember that the decision maker has more information than is stored in the system. Thus, the decision is not an automatic one.
- The time to place the order. The system calculates the required order dates, for the manager's approval.

The way the system handles those tasks is by using an ABC analysis. This is certainly called for, since the manager cannot devote enough time for all the items (sometimes, more than thousands at a time), even with a good DSS. Our ABC analysis is different than the traditional one. Usually, the Pareto analysis is carried out for the monetary costs only (Buffa, 1983). According to our approach, however, the manager should only deal with the items which have <u>High Total Expected Cost</u>, and our Pareto analysis does this. Thus the manager can perform a sensitivity analysis on these items, negotiate their lead time with the supplier, decide how much to invest in reducing the lead time of certain items (if this is possible at all), and so on. Exhibit E shows the traditional ABC analysis, and Exhibit F shows the total expected cost Pareto analysis.

6. Conclusions

The issue we address may be one of the most important problems in operations management today. Sophisticated purchasing management has a lot of profit improvement potential, both by reducing costs and by making possible on-time deliveries.

The proposed DSS uses a model that focuses on correct lead time management. The data base is quite simple, and data is available in every plant. The system as described is a stand alone system. Later in its life cycle, the system should be incorporated with the main manufacturing information system of the company.

We feel that it is a challenge to every manufacturing company to adopt this approach. A good DSS supporting both the actual purchasing decisions and the bidding for projects which have large purchasing requirements (or are dependent on long lead items), may provide the users with an important competitive edge.

For further research we suggest to work on the human interface of this DSS. As mentioned above, incorporating subjective probabilities of winning the bid under alternative promised dates (and or prices) can enhance the DSS a lot in its role as a strategic negotiation support system. The same concepts can also be utilized for tactical decisions. Note that by doing this we can introduce some of the unstructured elements into the structured component of the DSS. Another interesting issue, also in the realm of the human interface, is to develop a

GDSS (Group Decision Support System) using the concepts described in this paper.

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PURCHASING FROM SUPPLIER A

DSS PROTOTYPE
================

S= $337,027

t* (DUE DATE) 24 month
Ch (HOLDING C. 18.00% per year

THE PENALTY = $240,000 per year

1 CATAL NO.	2 QTY REQ.	3 PREFERRED SUPPLIER	4 SUPP. A U/P	5 SUPP. A TOTAL PRICE	6 %OF TOTAL	7 SUPP. A L. TIME	8 SUPP. A TIMING	9 SUPP. A ACT. TI	10 SUPP. A HOLDING CO	11 SUPP. A PENALTY	12 SUPP. A TOTAL	13 SUPP. A DISCOUNT R
1	12	A	$0.23	$3	0%	3	-23.7	0.0	$1	$20	$24	$21
2	45	B	$78.90	$3,551	1%	2	6.5	6.5	$826	$6	$4,383	$0
3	5	B	$40.00	$200	0%	6	-45.8	0.0	$54	$2,198	$2,452	$0
4	1,000	B	$12.98	$12,980	2%	3	1.6	1.6	$3,772	$35	$16,786	$0
5	567	B	$9.70	$5,500	1%	4	-9.3	0.0	$1,651	$198	$7,349	$0
6	8	A	$2,679.00	$21,432	4%	4	-3.8	0.0	$6,433	$198	$28,063	$14,711
7	45	B	$0.23	$10	0%	12	-151.1	0.0	$2	$32,480	$32,493	$0
8	88	A	$1.56	$137	0%	4	-24.0	0.0	$41	$198	$377	$351
9	4	A	$7.00	$28	0%	6	-57.6	0.0	$8	$2,198	$2,233	$2,212
10	435	A	$45.90	$19,967	4%	2	9.9	9.9	$3,610	$36	$23,612	$12,968
11	1,200	A	$34.98	$41,976	8%	6	-13.7	0.0	$11,403	$2,198	$55,577	$6,929
12	1	A	$100.00	$100	0%	3	-13.0	0.0	$32	$20	$152	$35
13	6	A	$2,348.90	$14,093	3%	14	-79.2	0.0	$2,647	$50,426	$67,166	$49,972
14	789	A	$6.99	$5,515	1%	22	-158.9	0.0	$777	$147,801	$154,093	$121,618
15	500	A	$34.99	$17,495	3%	9	-40.4	0.0	$4,100	$12,507	$34,103	$12,977
16	6	A	$2.99	$18	0%	3	-18.1	0.0	$6	$20	$44	$28
17	65	B	$0.01	$1	0%	14	-219.0	0.0	$0	$50,426	$50,427	$0
18	345	B	$1,140.50	$393,473	73%	3	11.9	11.9	$54,223	$1,051	$448,746	$0
19	4	A	$500.00	$2,000	0%	40	-349.1	0.0	$179	$439,049	$441,228	$397,850
20	80	B	$6.99	$559	0%	3	-7.8	0.0	$176	$20	$755	$0

Exhibit A: DSS Prototype, Supplier A

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DSS PROTO
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t* (DUE DATE)        24
Ch (HOLDING C.   18.00%

THE PENALTY = $240,000


CATAL¦QTY    ¦PREFERREDSUPP. B    ¦SUPP. B    ¦SUPP. B¦SUPP. B ¦SUPP. B  ¦SUPP. B  ¦SUPP. B  ¦SUPP. B  ¦SUPP. B    ¦PRICE OF
NO.  ¦REQ.   ¦SUPPLIER U/P        ¦TOTAL PRICE¦L. TIME¦TIMING  ¦ACT. TIME¦HOLDING C¦PENALTY  ¦TOTAL    ¦DISCOUNT RE¦BEST PRICE
-----¦-------¦--------------------¦-----------¦-------¦--------¦---------¦---------¦---------¦---------¦-----------¦----------
   1 ¦    12 ¦A                $0 ¦        $2 ¦     2 ¦   -8.4 ¦     0.0 ¦      $1 ¦      $0 ¦      $3 ¦        $0 ¦        $2
   2 ¦    45 ¦B               $90 ¦    $4,050 ¦     3 ¦   -1.9 ¦     0.0 ¦  $1,276 ¦     $20 ¦  $5,346 ¦      $963 ¦    $3,551
   3 ¦     5 ¦B               $30 ¦      $150 ¦     7 ¦  -59.4 ¦     0.0 ¦     $39 ¦  $4,541 ¦  $4,729 ¦    $2,277 ¦      $150
   4 ¦ 1,000 ¦B               $17 ¦   $17,000 ¦     2 ¦    9.6 ¦     9.6 ¦  $3,156 ¦     $30 ¦ $20,186 ¦    $3,400 ¦   $12,980
   5 ¦   567 ¦B               $10 ¦    $5,670 ¦     5 ¦  -17.4 ¦     0.0 ¦  $1,619 ¦    $823 ¦  $8,112 ¦      $763 ¦    $5,500
   6 ¦     8 ¦A            $1,280 ¦   $10,240 ¦     3 ¦    0.9 ¦     0.9 ¦  $3,085 ¦     $27 ¦ $13,352 ¦        $0 ¦   $10,240
   7 ¦    45 ¦B                $0 ¦       $10 ¦    12 ¦ -151.1 ¦     0.0 ¦      $2 ¦ $32,480 ¦ $32,493 ¦        $0 ¦       $10
   8 ¦    88 ¦A                $0 ¦       $19 ¦     2 ¦   -3.9 ¦     0.0 ¦      $6 ¦      $0 ¦     $26 ¦        $0 ¦       $19
   9 ¦     4 ¦A                $4 ¦       $16 ¦     2 ¦   -4.3 ¦     0.0 ¦      $5 ¦      $0 ¦     $22 ¦        $0 ¦       $16
  10 ¦   435 ¦A               $22 ¦    $9,657 ¦     1 ¦   16.2 ¦    16.2 ¦    $978 ¦      $9 ¦ $10,644 ¦        $0 ¦    $9,657
  11 ¦ 1,200 ¦A               $31 ¦   $37,200 ¦     5 ¦   -6.0 ¦     0.0 ¦ $10,625 ¦    $823 ¦ $48,648 ¦        $0 ¦   $37,200
  12 ¦     1 ¦A              $100 ¦      $100 ¦     1 ¦   11.7 ¦    11.7 ¦     $17 ¦      $0 ¦    $117 ¦        $0 ¦      $100
  13 ¦     6 ¦A            $1,234 ¦    $7,407 ¦     8 ¦  -40.1 ¦     0.0 ¦  $1,822 ¦  $7,966 ¦ $17,194 ¦        $0 ¦    $7,407
  14 ¦   789 ¦A                $8 ¦    $6,304 ¦    11 ¦  -66.0 ¦     0.0 ¦  $1,347 ¦ $24,824 ¦ $32,475 ¦        $0 ¦    $5,515
  15 ¦   500 ¦A               $39 ¦   $19,350 ¦     1 ¦   16.9 ¦    16.9 ¦  $1,758 ¦     $17 ¦ $21,126 ¦        $0 ¦   $17,495
  16 ¦     6 ¦A                $2 ¦       $12 ¦     2 ¦   -4.9 ¦     0.0 ¦      $4 ¦      $0 ¦     $16 ¦        $0 ¦       $12
  17 ¦    65 ¦B                $4 ¦      $252 ¦    16 ¦ -158.4 ¦     0.0 ¦     $44 ¦ $71,402 ¦ $71,698 ¦   $21,271 ¦        $1
  18 ¦   345 ¦B            $1,350 ¦  $465,750 ¦     1 ¦   20.1 ¦    20.1 ¦ $20,239 ¦    $415 ¦$486,403 ¦   $37,657 ¦  $393,473
  19 ¦     4 ¦A              $489 ¦    $1,956 ¦    13 ¦  -97.5 ¦     0.0 ¦    $383 ¦ $41,039 ¦ $43,378 ¦        $0 ¦    $1,956
  20 ¦    80 ¦B                $8 ¦      $640 ¦     4 ¦  -17.9 ¦     0.0 ¦    $192 ¦    $198 ¦  $1,030 ¦      $275 ¦      $559
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Exhibit B: DSS Prototype, Supplier B

SUMMARY

	TOTAL PRICE	TOTAL HOLDING	TOTAL PENALTY	GRAND TOTAL
SUPPLIER A	$539,037	$89,939	$741,086	$1,370,062
SUPPLIER B	$585,786	$46,597	$184,615	$816,998
BEST PRICE	$505,842	$82,506	$298,950	$887,298
BEST TOTAL	$508,536	$80,735	$161,121	$750,392

t* = 24 months

SUMMARY

	TOTAL PRICE	TOTAL HOLDING	TOTAL PENALTY	GRAND TOTAL
SUPPLIER A	$539,037	$96,033	$632,334	$1,267,404
SUPPLIER B	$585,786	$50,202	$135,024	$771,011
BEST PRICE	$505,842	$86,855	$231,562	$824,260
BEST TOTAL	$508,536	$84,203	$116,146	$708,886

t* = 28 months

Exhibit C: Total Costs Using Due Dates of 24 & 28 Months

SENSITIVITY ANALYSIS (BY BEST TOTAL)

DUE DATE	HOLDING COST +BO11	PENALTY COST +BQ11	ITEMS COST +BM11	TOTAL COST +BS11
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

Exhibit D: Sensitivity Analysis

ABC ANALYSIS PER TOTAL COSTS

CATAL NO.	QTY REQ.	PREFERRED SUPPLIER	PRICE OF BEST TOTAL	HOLDING OF BEST TOTAL	PENALTY OF BEST TOTAL	BEST TOTAL
18	345	B	$393,473	$54,223	$1,051	$448,746
17	65	B	$1	$0	$50,426	$50,427
11	1,200	A	$37,200	$10,625	$823	$48,648
19	4	A	$1,956	$383	$41,039	$43,378
7	45	B	$10	$2	$32,480	$32,493
14	789	A	$6,304	$1,347	$24,824	$32,475
15	500	A	$19,350	$1,758	$17	$21,126
13	6	A	$7,407	$1,822	$7,966	$17,194
4	1,000	B	$12,980	$3,772	$35	$16,786
6	8	A	$10,240	$3,085	$27	$13,352
10	435	A	$9,657	$978	$9	$10,644
5	567	B	$5,500	$1,651	$198	$7,349
2	45	B	$3,551	$826	$6	$4,383
3	5	B	$200	$54	$2,198	$2,452
20	80	B	$559	$176	$20	$755
12	1	A	$100	$17	$0	$117
8	88	A	$19	$6	$0	$26
9	4	A	$16	$5	$0	$22
16	6	A	$12	$4	$0	$16
1	12	A	$2	$1	$0	$3

Exhibit F: ABC Analysis in Total Costs

ABC ANALYSIS PER TOTAL COSTS

CATAL NO.	QTY REQ.	PREFERRED SUPPLIER	PRICE OF BEST TOTAL	HOLDING OF BEST TOTAL	PENALTY OF BEST TOTAL	BEST TOTAL
18	345	B	$393,473	$54,223	$1,051	$448,746
17	65	B	$1	$0	$50,426	$50,427
11	1,200	A	$37,200	$10,625	$823	$48,648
19	4	A	$1,956	$383	$41,039	$43,378
7	45	B	$10	$2	$32,480	$32,493
14	789	A	$6,304	$1,347	$24,824	$32,475
15	500	A	$19,350	$1,758	$17	$21,126
13	6	A	$7,407	$1,822	$7,965	$17,194
4	1,000	B	$12,980	$3,772	$35	$16,786
6	8	A	$10,240	$3,085	$27	$13,352
10	435	A	$9,657	$978	$9	$10,644
5	567	B	$5,500	$1,651	$198	$7,349
2	45	B	$3,551	$826	$6	$4,383
3	5	B	$200	$54	$2,198	$2,452
20	80	B	$559	$176	$20	$755
12	1	A	$100	$17	$0	$117
8	88	A	$19	$6	$0	$26
9	4	A	$16	$5	$0	$22
16	6	A	$12	$4	$0	$16
1	12	A	$2	$1	$0	$3

Exhibit F: ABC Analysis in Total Costs

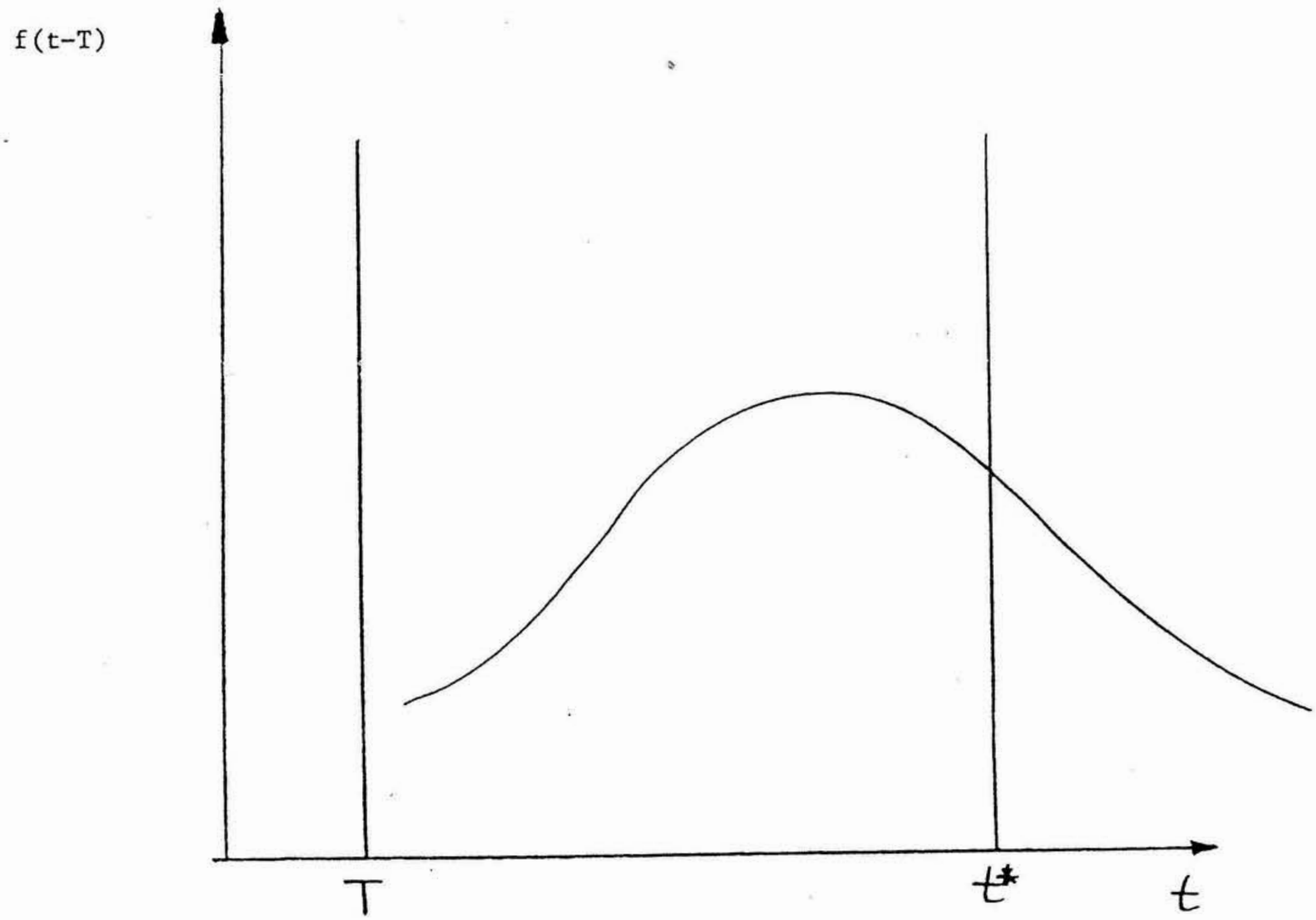

Figure 3.1 The relationship between t*, T and the lead time distribution.