OPTIMIZATION OF MULTIPLE INVESTMENTS WITH RISK ANALYSIS

by

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I. INTRODUCTION

Accurate and realistic economic evaluations are becoming increasingly important in the chemical industry as the initial capital investments are rising for the larger scale of new chemical plants. The need to build a very large plant to obtain the necessary economies of scale creates difficult investment decisions just to maintain capacity for a firm's projected sales growth. Similarly, a large plant for a new market venture can easily develop into a big loss. The use of a consistent and realistic economic evaluation criterion, such as present worth, has become a must. Economic evaluations more closely model reality when risk analysis is used to account for uncertainty in the input parameters. The more sophisticated techniques of evaluating economic models have led to the use of the digital computer in the application of statistical and optimization techniques. An economic model including features of: an accurate and flexible determination of present value, a Monte Carlo risk analysis, and a reliable optimization technique can easily use hours of computer time.

The purpose of this investigation was to develop a general economic evaluation model compromising some flexibility for large savings in computer time. This general model includes: 1) An accurate present value determination,

2) The option of building either one large plant now or building one plant now and another plant later, 3) Monte Carlo risk analysis for all of the important uncertain parameters, and 4) A reliable optimization scheme to select the most profitable decisions. The model is tested and illustrated with an example case of an ethylene market venture. No marketing considerations are included in the model. Management needs the answers to many questions to decide in favor of a particular venture. Given an expected sales curve for the firm, what size plant should the firm build now? If a second plant is built, when should it be built and how large should it be? And what are the profit and risk associated with the decisions? These are the questions which the economic model of this investigation attempts to answer.

II. LITERATURE REVIEW

This section contains a review of the published methods of: estimation of input parameters, investment analysis criteria, risk analysis, and existing evaluation procedures.

Estimation of Input Parameters

The accuracy of an economic evaluation will be dependent on the accuracy of the input parameters. The various concepts and methods for estimating the input parameters were obtained from the literature.

Learning curve. The capacity of a chemical plant will usually increase with time. By improving operating conditions and general equipment debottlenecking, the capacity of a plant is substantially increased. Hirschmann[11] has documented this concept and shown that it should be used in economic evaluations. Another work using a three per cent learning curve has shown it to be a significant factor in economic evaluations.[36]

Product sales. Predicting an accurate curve for new sales for the firm is very difficult, particularly if the new sales are large enough to affect the total market. The main problem is in predicting the reaction of the competitors to a firm's entry into a new market. Several theoretical approaches to this problem have been devised, but few practical, quantitative applications of these approaches have been published. For the limiting cases of perfect competition and perfect duopoly some quantitative work has been done, but these are only applicable to a few industries.[6,13] The efforts on the middle region of imperfect competition and oligopoly have remained theoretical. Shubik[31] gives a clear and convincing discussion on the use of game theory. His work shows the theoretical and conceptual use of game theory, but a direct quantitative application appears unlikely. One conclusion from a conference on modeling markets was "that game theory is not very relevant to competitive behavior in any practical sense."[24]

For a firm entering a market in the chemical industry, the non-price competition will most likely be the main determinant of the firm's sales curve. An example is the entry of Northern Petrochemical into the ethylene market. Their ethylene sales curve was established through forward integration by acquiring several polyethylene fabricators and developing a marketing network for the resale of ethylene glycol.[17,19,21,20,22,23] For the first few years after a firm enters a market, the firm's sales might be expected to grow at a faster rate than the industry wide demand growth.[15] The firm would be increasing its market share through mainly non-price competition. Once the firm has become settled in the market, the firm's share of the total industry demand would remain nearly constant. Then the firm's sales would grow at a rate comparable to the total industry demand growth rate.

Investment Analysis Criteria

The present value criterion for investment appraisal is an accurate and consistent technique which takes into account the time value of money. All cash flows are discounted to time zero at an interest rate which is the cost of capital for the firm. The discounted cash flows are summed, the investment is subtracted from the sum, and the remainder is the net present value. This appraisal technique is well suited for optimization; for in a deterministic investment evaluation, a firm will seek to maximize the net present value of a venture.[1,3]

Another criterion similar to present value, called venture worth, was used by Happel and Kapfer.[7] Venture worth evaluations include a minimum acceptable rate of return in addition to the cost of capital for the firm.

$$W = PV - \frac{(1+c)^n - 1}{(1+c)^n \, c} \, (i_m - c) \, (I + I_W) \qquad (1)$$

where: W = venture worth, dollars

PV = present value, dollars

c = cost of capital, fraction/year

i_m = minimum acceptable rate of return, fraction/year

I = initial capital investment, dollars

I_W = working capital, dollars

The venture worth criterion requires that some minimum acceptable rate of return be established for a firm. It may be difficult to determine what this minimum rate should be. The minimum acceptable rate of return could be set low for a low-risk venture and set high for a high-risk venture. This would be one crude method of allowing for risk in an investment evaluation.

Risk Analysis

Net present value and other similar investment evaluation techniques are accurate and informative for deterministic economic evaluations. But for an investment decision, the consideration of and allowances for risk overshadow the consistency gained by good investment evaluation techniques. Methods of risk analysis to be reviewed include: sensitivity analysis, time pattern of cash flows, a simplified statistical approach, and a Monte Carlo method.

Sensitivity analysis. There are two different concepts included under the title of sensitivity analysis. Both are simple and straightforward risk analysis methods. For the first concept a separate economic evaluation is made for the optimistic, pessimistic, and most likely values of each of the main variables.[29] For consideration of three main variables, twenty-seven economic evaluations would be required. This method is cumbersome and impractical for a complicated, interrelated economic evaluation.

The second type of sensitivity analysis requires evaluation of the partial derivatives of the investment criterion with respect to each of the main input parameters.[9] The derivatives may be evaluated analytically or numerically, but they are accurate only for the one set of input parameters. If any of the input parameters are changed, the derivatives may need to be reevaluated. Still, both of these types of sensitivity analysis can give only an indication of the importance of deviations in the main variables.

Time pattern of cash flows. This is an extension beyond square case economics. A more realistic economic evaluation can be obtained by allowing the items included in the cash flow to vary with time. The possibility of adverse, unforseen future events can be considered by selecting time patterns which result in a rapidly declining series of cash flows.[8] This is a very crude method of allowing for uncertainty and does not even allow for favorable, unforseen future events.

Simplified statistical approach. Thorngren[35] has presented a simplified statistical approach to risk analysis. The approach is an extension of the concept presented by Reynard.[29] A probability distribution must be defined for each of the main variables. Using a correction factor, each distribution is made to approximate a "pseudo" normal distribution. The economic evaluation is made using the mean values of the new distributions where:

$$R = f(Z_1, Z_2, Z_3 \ldots) \quad (2)$$

with: R = investment criterion

Z_i = independent variables

The mean value of the investment criterion is given by:

$$m(R) = f(m(Z_1), m(Z_2), m(Z_3) \ldots) \quad (3)$$

And the variance of the investment criterion is given by:

$$\gamma(R) = \left(\frac{\partial R}{\partial Z_1}\right)^2 \gamma(Z_1) + \left(\frac{\partial R}{\partial Z_2}\right)^2 \gamma(Z_2) + \left(\frac{\partial R}{\partial Z_3}\right)^2 \gamma(Z_3) \ldots \quad (4)$$

where: $\gamma(R)$ = variance of R

$\gamma(Z_1)$ = variance of Z_1

The assumptions and main weaknesses of this approach are: 1) For the partial derivatives to be valid, R must be linear over the range of variation of the main variables, Z_i, and 2) Every main variable must be stochastically independent. For many cases this approach may be sufficiently accurate and flexible with a relatively short computer running time.

Monte Carlo method. Work by Hess and Quigley(10) and by Hertz(9) has resulted in the development of a comprehensive Monte Carlo technique for risk analysis. The method avoids the assumptions in the approach by Thorngren discussed above. Probability distributions around each of the main input parameters must be estimated. The means and variances are not combined by a complicated analytical approach but rather by an analytically simple, though repetitious, Monte Carlo approach. With the probability distributions defined, the main input variables are chosen at random according to the chances each has of occurring. The economic evaluation is then made. By repeating this process many times, a probability distribution around the economic criterion is produced. This distribution, of say the net present value, gives the expected present value and the full ranges of risk involved. The number of economic evaluations may be from 200 to 2000, thus requiring the use of a digital computer. Considerable computer time can be consumed in the evaluations of the profitability criterion. This leads to the necessity of simple computation techniques.

Computation technique for present value. One type of cash flow pattern can be discounted by a very direct technique. One example of this technique is presented in an article by W.W. Twaddle and J.B. Malloy.[36] If the cash flows change at some constant rate over a given time period, the discounted cash flow may be computed directly by:

$$DCF = \int_{t_1}^{t_2} CF_1 \ EXP(at) \ EXP(-ct) \ dt \qquad (5)$$

where: DCF = discounted cash flow, dollars

CF_1 = cash flow at time, t_1, in dollars

a = rate of change of cash flow, fraction/year

t = time, year

c = cost of capital, fraction/year

And the cash flow at any time between t_1 and t_2 is given by:

$$CF = CF_1 \ EXP(at) \qquad (6)$$

Many of the terms which make up the cash flow can be expected to change at constant rates, thus can be evaluated by this technique. For cash flow terms which are not of this type, a simple Gaussian integration technique can be used for discounting. These discounting techniques will give the present value with only a few computations. This is a necessity for the many present value evaluations needed in the Monte Carlo risk analysis. In a recent article by J.B. Malloy,[15] the Monte Carlo risk analysis is incorporated with the simplified discounting techniques for present value computations of a single plant case. The probability distributions about each of the input parameters are defined in terms of the beta distribution. This distribution is flexible in reproducing normal and unsymmetrical probability distributions. Also, only two parameters, the range and degree of asymmetry, are needed to specify the normalized beta distribution.

Evaluation Procedures

Considerable effort has been made to improve the quantitative input to investment decisions. Much of this work has been devoted to the development of evaluation procedures employing the new analysis techniques.

Saletan and Caselli[30] studied a single plant investment decision using Monte Carlo risk analysis. The probabilistic terms included plant capacity, sales level, and sales growth. Combining the probability distributions of capacity for each of the process units resulted in an overall plant capacity probability distribution with an expected value considerably lower than the lowest mean value of the single process units. The present value (actually present cash equivalent) evaluations were analytically simplified using Laplace transform functions. The Monte Carlo procedure was developed using an analog computer. From conclusions of the investigation:

> At this point, the present analysis indicates the effect of uncertainty on plant sizing becomes quite moderate, and primary attention can be focussed on growth rate per se and on concatenation in fixing the target capacity for design purposes. (30)

In a subsequent study by Coleman and York[2] provisions are made for multiple plant expansions in a growing market. The forecasted firm's demand curve consisted of an exponentially increasing section and a constant ultimate demand section. A simplified equation for the present value of the total costs was derived analytically. By setting the partial derivatives of present value (with respect to each expansion capacity) equal to zero, the minimum cost combination was obtained for the number of capacity expansions specified. For simple cash flow combinations with deterministic evaluations, the procedure is convenient and accurate. For more realistic evaluations "the largest question centers in accuracy of the demand parameters." The risk analysis presented was based on the minimax principle using a pessimistic, optimistic, and expected value for the ultimate demand level. The analysis revealed that by sacrificing some of the economies of scale, a firm could hedge against a pessimistic demand level and still be in a good position for the optimistic and expected demand outcomes.

Generoso and Hitchcock[5] investigated optimizing plant expansions considering a single-step expansion and several expansions in time for a growing market. The economic interrelationships of the various process units within the plant were handled with some detail. Dynamic programming was used to optimize the expansion of the process units, thus necessitating a computer model. Risk analysis was not included in the study.

In a recent article by J.B. Malloy[15] and in a thesis by S.J. Katz[12], an over-all venture evaluation was made using Monte Carlo risk analysis for a single plant investment. In Malloy's computer model, considerable flexibility was allowed for all of the important variables. Each main variable could be defined in probabilistic terms. The investment criterion evaluation technique was discussed above (page 10). Comparisons with actual plant investments of Standard Oil Co. (Ind.) showed that the predictions of Malloy's risk analysis closely match actual experience. However, by considering only a single plant, no advantage was allowed for hedging on the first plant and deciding later on the size of the second plant. The economic model in this thesis considers a two-plant possibility with the advantage of hedging but with some sacrificing of the flexibility in Malloy's economic model.

III. DEVELOPMENT

This section contains the reason for the investigation with a definition of the system and a detailed description of the computer program including the sources of data.

Definition of System

The value of an economic evaluation is reflected in the way it will model the economics of an actual investment. Both the profitability criterion and the evaluation technique must be accurate and consistent. For an economic analysis procedure to be useful, it should be convenient to use and computationally feasible.

In this work a general economic analysis technique was developed. The technique is illustrated and verified by an example of an ethylene venture. The example chosen is that of a petroleum company or large chemical company which is considering going into the ethylene business. The petroleum company would own the main raw material, ethane, and would be considering forward integration into ethylene and the possible final products, polyethylene, glycol, vinyl chloride, and styrene. The chemical company would be presently marketing some of the final products and would be considering backward integration into the intermediate, ethylene. Entry into the ethylene market would be difficult if not impossible by price competition alone. Non-price competition such as trade agreements and acquisition of product outlet firms would be necessary. A significant initial level of sales would be established before the plant is built. The sales curve would increase rapidly for the first few years as the company is still aggressive in non-price competition. Then the sales growth would tend to level out to the total industry demand growth.

In the literature there are two types of techniques available to analyze the economics of this type of venture. The approaches of Malloy[15] and Katz[12] do not allow for the option of building two plants, and the approaches of Generoso[5], Coleman[2], and Saletan[30] do not include comprehensive risk analysis. The computer model presented here is expected to eliminate the two shortcomings above, thus more accurately reflect the economics of an actual venture investment. Also the technique is convenient and can be executed with a short computer running time.

General Description of Computer Program

The features of the computer program for the economic model will be described in the order in which they are used in the program. The sources of data will be discussed along with each of the features. A complete print-out of the computer program is included in the Appendix (page 96). Frequent references to statement numbers in the program will be made to facilitate the understanding of the program. Complete flow diagrams of the computer programs are included in the Development (pages 23 to 27) and in the Appendix (pages 91 to 95). The profitability criterion used is net present value, and the evaluations are made by the direct integration technique used by Twaddle and Malloy.(36) The independent variables included in the optimization are: (1) first plant size, X(1), (2) second plant size, X(2), and (3) timing factor, TM, for second plant. The timing factor is a ratio of the capacity to sales.

$$TM = \frac{\text{capacity of first plant}}{\text{sales at time second plant is built}} \qquad (7)$$

The value of TM can be less than one for a firm marketing another company's production. Sum-of-years-digits depreciation is used with an eleven year depreciation life. The Federal income tax rate is 48 per cent, and the cost of capital to the firm is set at ten per cent after tax.

Monte Carlo risk analysis. The Monte Carlo risk analysis is used with probability distributions around fourteen main variables. For a list of the main variables and the probability distributions see Table I, page 17 and Figure 1, page 18. This Monte Carlo risk analysis includes two random variable selections for each present value evaluation. After the first plant is built, the main variables are chosen from the input probability distributions around each of the variables (PRO 1670 to PRO 1800). This sets

TABLE I

Input Probability Distributions

for Random Variable Factors

RANDOM VARIABLE		Z1	Z2	Z3	Z4	Z5	Z6
1	Sales (1)	0.60	0.96	1.16	1.20	0.30	0.80
2	Capacity	0.70	0.94	1.10	1.20	0.30	0.70
3	Cap. cost	0.90	0.94	1.02	1.24	0.20	0.80
4	Price	0.01	0.68	1.40	1.80	0.30	0.70
5	By-prod	0.70	0.94	1.10	1.20	0.30	0.70
6	Var. cost	0.70	0.94	1.10	1.20	0.30	0.70
7	Raw material	0.70	0.94	1.10	1.20	0.30	0.70
8	SARE-sales, admin. and research	0.70	0.94	1.10	1.20	0.30	0.70
9	Fixed cost	0.70	0.90	1.10	1.30	0.30	0.70
10	TSD-time, sales decline	0.70	0.94	1.10	1.20	0.30	0.70
11	Sales (2)	0.70	0.94	1.10	1.20	0.30	0.70
12	Project life	1.00	1.00	1.00	1.00	0.30	0.70
13	Initial sales	0.80	0.90	1.10	1.20	0.30	0.70
14	Initial capacity	0.90	0.95	1.05	1.10	0.10	0.90

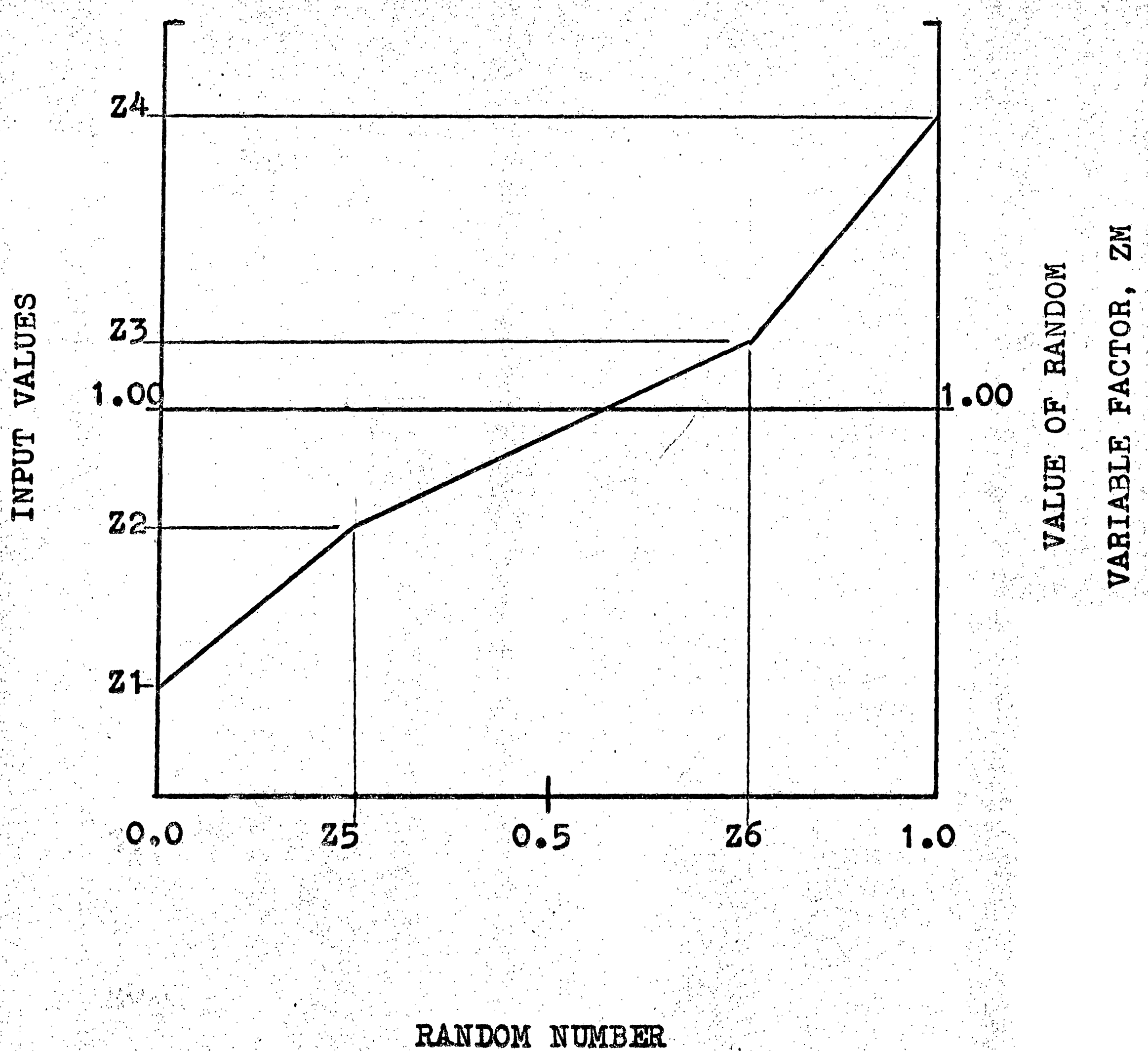


FIGURE 1: GENERAL FORM FOR INPUT PROBABILITY DISTRIBUTIONS

the economic outcome from time zero until the second random variable selection. The second random variable selection occurs after the second plant is built (PRO 3180 to PRO 3440). This sets the economic outcome from the start of production of the second plant until the end of the project life, PRL. The random variables which are re-set after the second plant is built are growth variables. Although the derivatives are not continuous at this point, the functions remain continuous. The values of the variables at the time of the second random selection become the base values for the new random selected growth rates. If the growth for the first period is high, the resulting base value for the second period will be high. A range of 500 to 1000 iterations were used with the Monte Carlo analysis. The outcomes are tabulated at the end of the economic subroutine (PRO 5060 to PRO 5410). The results include: (1) the mean, standard deviation, and cumulative distribution function, CDF, for the present value, (2) the number of iterations in which the second plant was not built, NT2PNB, (3) the mean, standard deviation, and cumulative distribution function of the second plant size, X(2), for the times when the second plant is actually built, and (4) the mean, standard deviation, and cumulative distribution function of the timing factor, TM, for the times when the second plant is actually built. (The timing factor is a ratio of capacity to sales. It can be less than one by the firm marketing another company's production.) Sample outputs of the above tabulations are in the Appendix (see page 145). The second, third, and fourth tabulations are generated through the use of a suboptimization technique for the second plant size and timing factor. (For details see Development, page 46 and Results, page 50). For the output distributions which are normal distributions, the standard deviation is a convenient and accurate measure of variability. If a distribution is not normal, the cumulative distribution function is used to measure and display the variability.

Single plant case. As a first step in the procedure of the economic model, a Monte Carlo risk analysis for a single plant case is made. The deterministic optimum first plant size is used as the starting point. Several values of the first plant size (around and including the starting point value) are used for single plant case Monte Carlo analyses. The results of these analyses would indicate the optimum first plant size with no regard to the possibility of building a second plant. This shortcoming of previous investigators[12,15] is overcome in this work by the two-plant case.

Two-plant case. The Monte Carlo risk analysis becomes considerably more complex when considering the two-plant case. There are three independent variables to be optimized: (1) the first plant size, X(1), (2) the second plant size, X(2), and (3) the timing factor, TM, for building the second plant. The theoretically ideal approach would be to optimize the three independent variables for each of the 500 to 1000 iterations of the Monte Carlo analysis. This approach, although accurate, would consume an unreasonable amount of computer time. An alternative is to choose the two most important random variables and assume that the effect of the other random variables on the optimum plant sizes and timing is small. The two main variables chosen were the sales curve growth rate, GI(1), and the selling price decay rate, GI(4). The validity of this assumption is discussed in the Results (see page 51). For each first plant size being considered, subroutine DPOPT computes value-grids covering the probability distribution ranges of the two main random variables. The values in the grids for each first plant size include the optimum second plant size, timing factor, and present value. The grids are presented and explained in the Results (see page 50).

The first plant is built, then the random variables are generated which set the economic outcome until the second plant is built. If the economic outcome of the first random variable generation is favorable, the second plant is built with the optimum size and timing. This optimum second plant size and timing is obtained by interpolation of the value-grids. After the decision on the second plant is made, a new set of random numbers is generated to establish the values of the random variables for the rest of the project life. The cash flow and present value calculations for the single and two-plant cases are similar.

Description of the Main Program

The operation of the economic model is controlled in the main program (see flow chart, Figures 2, 3, 4, 5, and 6, pages 23 to 27). First the input data are read in and some often used terms are calculated. Then the initial sales level is chosen (MAI 2920). A pattern search is made (MAI 3000) to find the deterministic optimum values of the first plant size, second plant size, and timing for the second plant. The deterministic optimum first plant size will not necessarily be the stochastic optimum first plant size. The stochastic optimum, taking into account the probability distributions, usually indicates a smaller first plant than the deterministic optimum. Several values of the first plant size are chosen (MAI 3070) around the deterministic optimum for consideration in the Monte Carlo risk analysis. A range of 100 per cent about the deterministic optimum first plant size is usually chosen. After the first plant is built, the random variables are generated, and the economic outcome is set. The optimum combination of second plant size and timing for any possible economic outcome is calculated (MAI 3490) or read in (MAI 3400) on cards.

At this point all of the necessary input data are

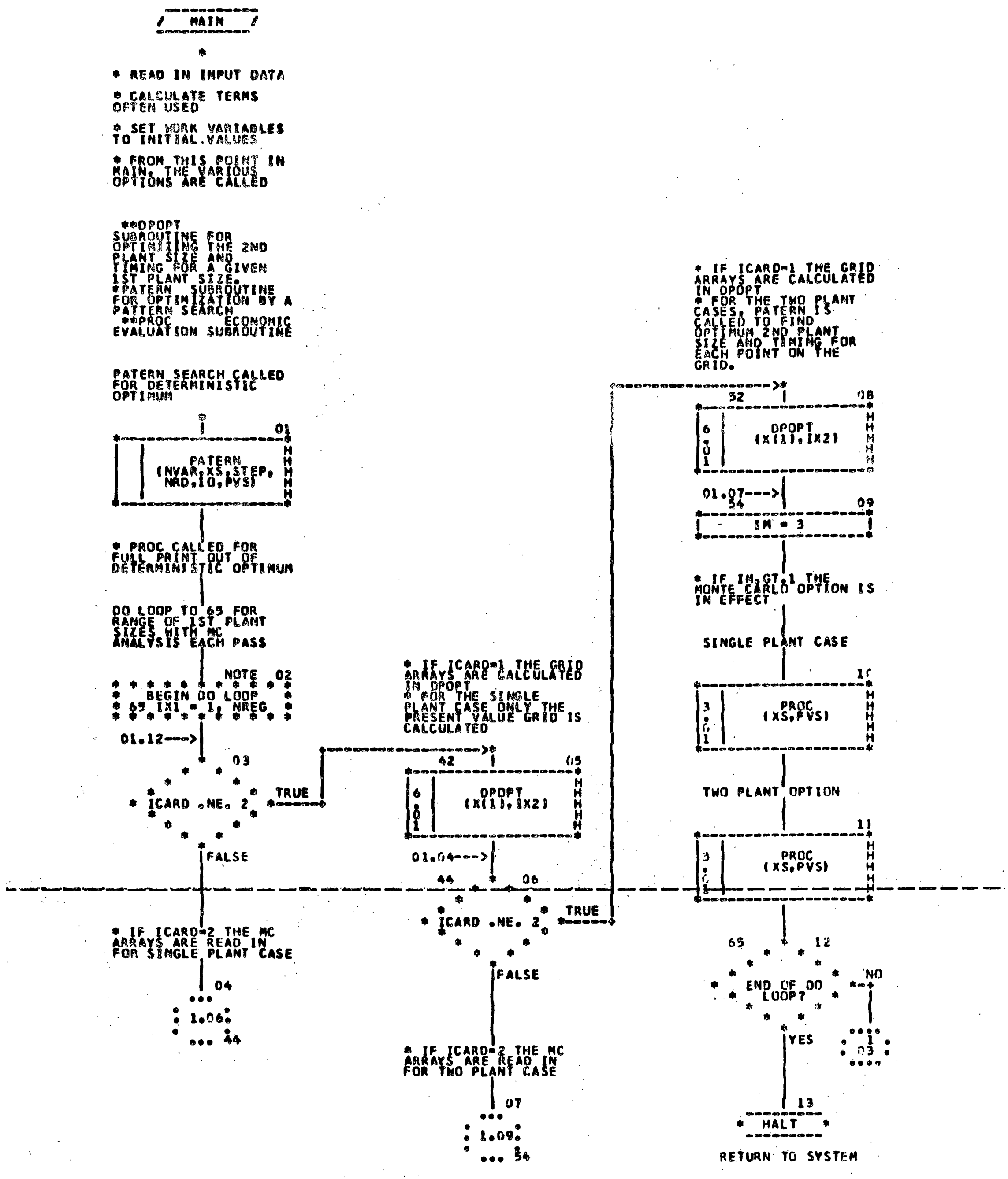


Figure 2. Basic Flow Diagram for MAIN Program and for Solution Technique.

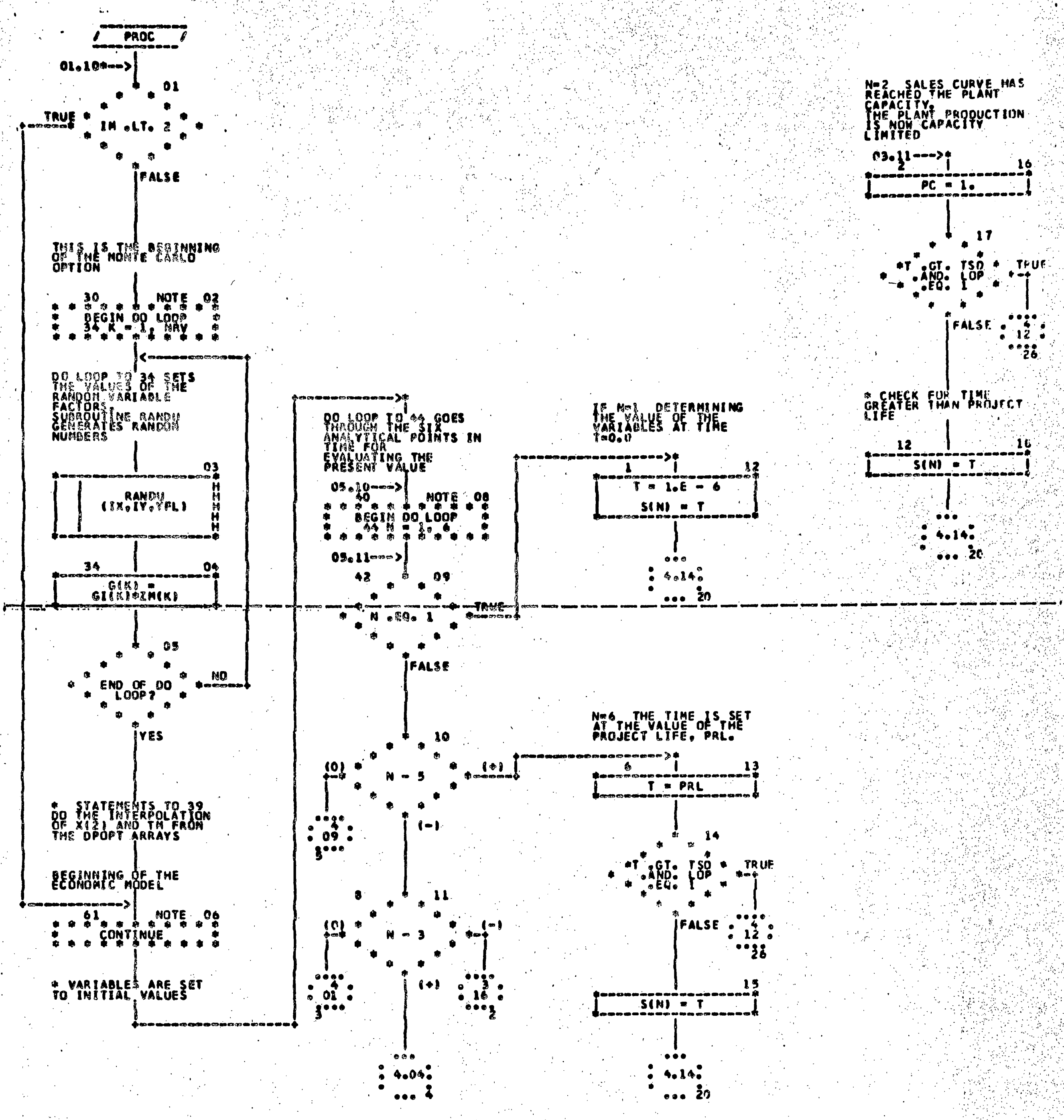


Figure 3. Flow Diagram for Economic Evaluation Subroutine (first part of three)

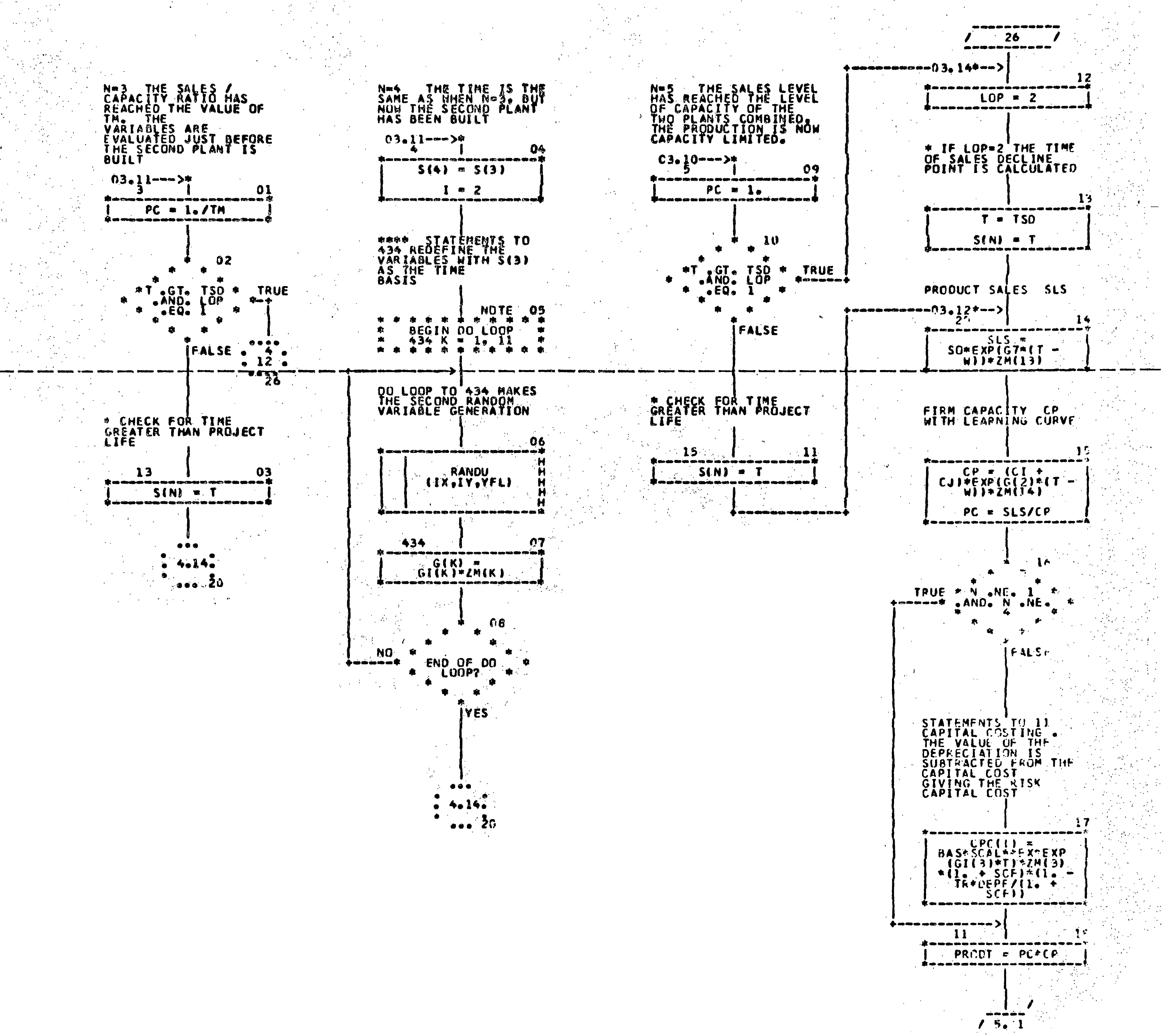


Figure 4. Flow Diagram for Economic Evaluation Subroutine (second part of three)

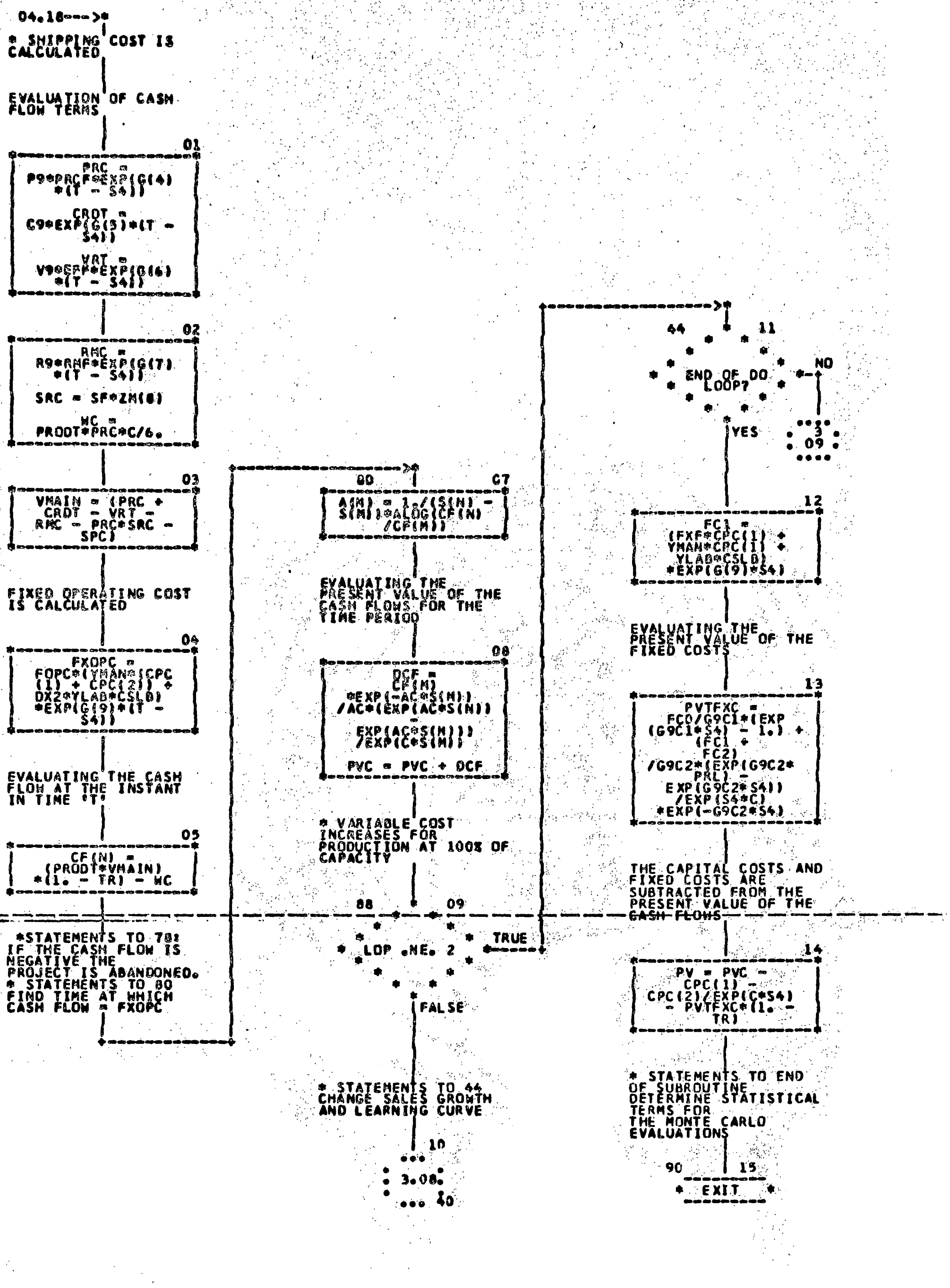


Figure 5. Flow Diagram for Economic Evaluation Subroutine (third part of three)

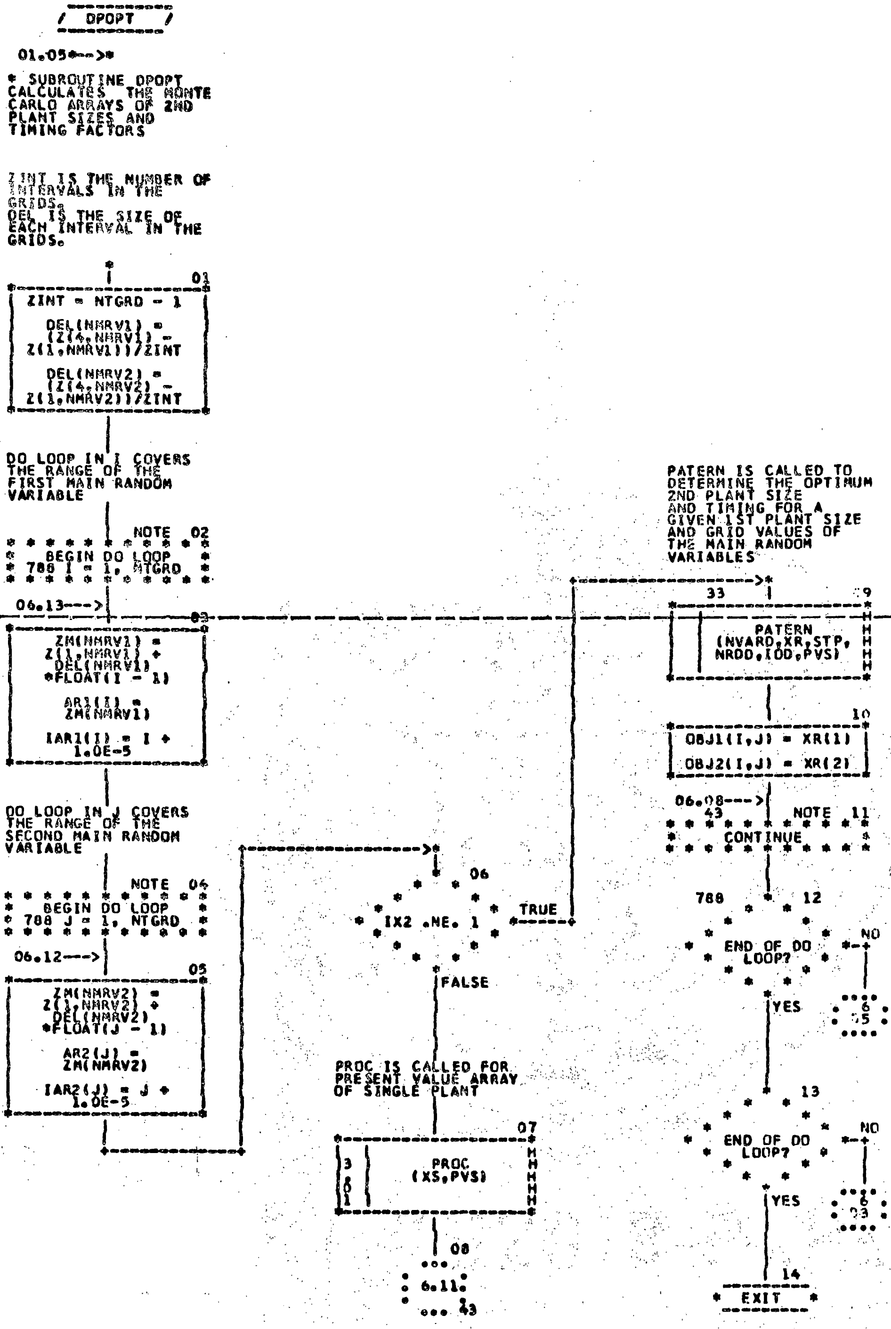


Figure 6. Flow Diagram for Subroutine DPOPT

available. With the Monte Carlo option in effect, the economic evaluation subroutine is called (MAI 3550). This is a single plant case. The standard output from the analysis will include the mean, standard deviation, and cumulative distribution function of the present value. The results of the single plant case are used as a basis for comparison with the results of the two-plant case. With the Monte Carlo analysis still in effect, the economic evaluation routine is called with the second plant option (MAI 3580). The standard output from the two-plant case analysis includes: (1) the mean, standard deviation, and cumulative distribution function of the present value, (2) the number of times the second plant is not built, NT2PNB, (3) the mean, standard, deviation and cumulative distribution function of second plant size for the times that the second plant is built, and (4) the mean, standard deviation, and cumulative distribution function of the timing factor for the second plant. The above procedure is repeated for several values of initial sales and for the several values of the first plant size chosen for each level of initial sales.

Description of the Economic Evaluation Subroutine

In subroutine PROC the economic evaluations of the net present value are made. The cash flows are discounted by the simplified evaluation technique. Each of the main variables must be defined by a function with a constant rate of change. This eliminates the need for any approximate computations such as a Gaussian integration.[36]

Cash flow evaluations. The cash flow evaluations are made at nine distinct points (see Table II, page 30 and Figure 7, page 31). Some of the points may occur at the same time. The first point corresponds to the time at which the first plant begins production (PRO 2750). The second point corresponds to the time at which the sales level equals the plant capacity (PRO 2790). The third point is the same time as point two, but the variable costs have increased because production is at 100 per cent of capacity (PRO 4680). The fourth point occurs at the time of the sales growth rate decline (PRO 3640). For the first few years the sales growth has been high. From this point on the sales growth will remain at this final rate. The fifth point corresponds to the time at which the second plant will begin production (PRO 2930). The second plant has not been started up yet. The sixth point occurs at the same time as point five, but now the second plant has begun production (PRO 3100). The seventh point corresponds to the time at which the sales level equals the combined capacity of the two plants (PRO 3450). The eighth point occurs at the same time as point seven, but the variable costs have increased because production is at 100 per cent of capacity (PRO 4680). The ninth point occurs at the end of the project evaluation life (PRO 3590). From these nine point-values of the cash

TABLE II

Typical Point Values for Cash Flow Evaluations

POINT NO.	TIME	CASH FLOW ($MM/YR)	SALES (MM LB/YR)	CAPACITY (MM LB/YR)	VMAIN ¢/LB	PRICE ¢/LB
1	0.00	3.74	600	1300	1.30	3.00
2	5.51	8.67	1530	1530	1.19	2.84
3	5.51	8.51	1530	1530	1.17	2.84
4	6.00	8.56	1660	1550	1.16	2.83
5	8.41	8.47	2070	1610	1.10	2.76
6	8.41	11.1	2070	2830	1.12	2.76
7	12.60	14.8	3020	3020	1.03	2.64
8	12.60	14.5	3020	3020	1.01	2.64
9	25.00	13.3	9200	3630	0.78	2.34

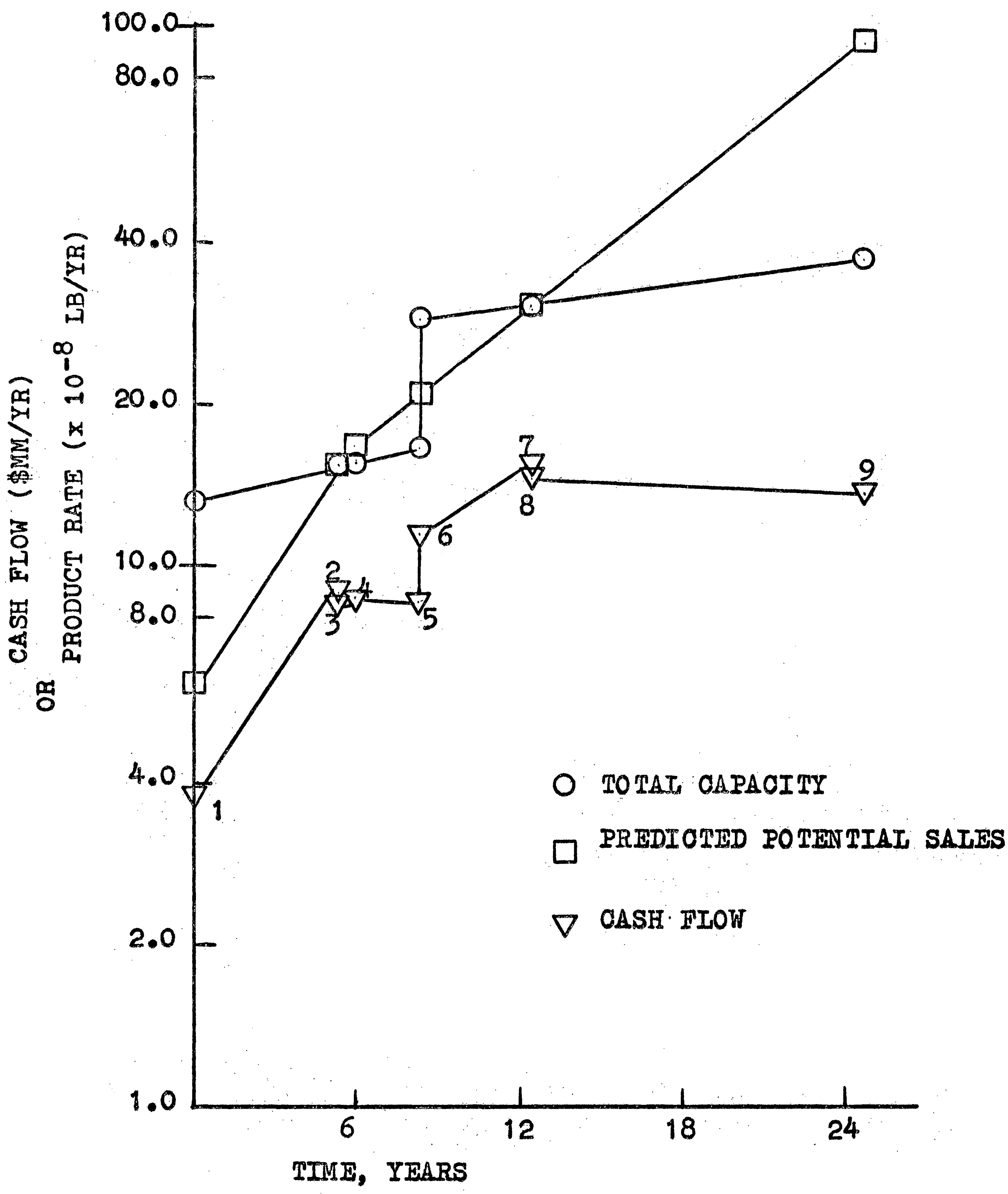


FIGURE 7: EVALUATION POINTS OF DETERMINISTIC OPTIMUM FOR INITIAL SALES OF 600 MM LB/YR

flow, the discounted cash flow of the five intervals is computed (PRO 4630).

The first interval corresponds to the period in which the cash flow is sales curve limited. The second interval corresponds to the period in which the cash flow is capacity limited with only one plant. The third interval corresponds to the period when the cash flow is again sales curve limited. The fourth period corresponds to when the cash flow is capacity limited with the two plants (the second plant size can be zero). The fifth interval is caused by point four. Whenever the time of the sales growth rate decline occurs, a new interval is begun. It is important to note that for computational convenience certain terms normally associated with cash flow are not included. The terms are depreciation and fixed costs, and are included separately in the present value calculations (see page 43 for details). The equation for the cash flow at any time is (PRO 4040):

$$CF(N) = PRODT\ (PRC+CRDT-VRT-RMC-PRC*SRC-SPC)\ (1-TR)\ -\ WC \qquad (8)$$

where: CF(N) = cash flow at point N, dollars/year

PRODT = production rate, pounds/year

PRC = product selling price, dollars/pound

CRDT = by-product credit, dollars/pound of product

VRT = variable costs, dollars/pound of product

RMC = raw material cost, dollars/pound of product

SRC = SARE cost, fraction of price

SPC = shipping cost, dollars/pound of product

TR = tax rate, fraction

WC = cost of working capital at 10% interest rate, dollars

The discounted cash flow is evaluated by the simple technique of Twaddle and Malloy[36]:

$$DCF = \int_{t_1}^{t_2} CF_1 \ EXP(at) \ EXP(-ct) \ dt \qquad (9)$$

See Eq. 5 page 10 for details. Upon integration the discounted cash flow for one interval becomes (PRO 3360): (See appendix, Page 167 for details of the integration).

$$PVCF = \frac{CF(n-1)}{AC} \ \frac{EXP(-AC \ t(n-1))}{EXP(t(n-1) \ c)} \left(EXP(t(n)AC) - EXP(t(n-1)AC) \right) \qquad (10)$$

$$AC = a(n-1) - C$$

where: PVCF = present value of cash flows for interval, dollars

a(n) = rate of change of cash flow at point n, fraction/year

c = cost of capital, fraction/year

t(n) = time at point n, years

The variables which determine the cash flow will be reviewed in the order of occurrence in the economic subroutine. A listing of the input data (page 135) is presented in Table III (see page 35) and Figure 8 (page 36). Table IV (page 37) is a manufacturing cost sheet for a typical one billion pounds per year ethylene plant.

Product sales. The product sales, SLS, for the firm is defined by several inputs (PRO 3700): SI, ZM(13), GI(1), TSDI, and GI(11). SI is the initial sales level. Significant values of initial sales were chosen (200, 300, 400, 500, 600 and 700 million pounds per year).[27] ZM(13) is the random variable associated with the uncertainty of the initial sales level. GI(1) is the initial rate of sales growth and was set for this example at 17 per cent per year reflecting aggressive non-price competition. The time of sales rate decline, TSDI, was set at six years. The final sales growth rate, GI(11), continuing from TSDI until the end of the project, was set at nine per cent per year.[4] This is comparable to the expected market demand growth rate for ethylene. For this work the firm's sales was a hypothetical, although reasonable, prediction. In actual practice the firm's sales prediction would be based on possible market penetration, the effectiveness of the firm's marketing effort through both price and non-price competition, and the over-all company objectives.

Production capacity. The production capacity, CP, of

TABLE III

INPUT DATA FOR ECONOMIC ANALYSIS OF ETHYLENE FACILITY

initial sales	600	MM LB/YR
initial capacity	1000	MM LB/YR
product selling price	0.03000	$/LB prod
by-product credit	0.00274	$/LB prod
variable cost	0.00513	$/LB prod
raw material cost	0.01200	$/LB prod
sales, admin. and research cost	0.05	fraction of selling price
indirect costs	0.030	fraction of capital cost
maintenance cost	0.035	fraction of capital cost
labor cost	60,000	$/man-year
number of men	10	
time of sales decline	6	year
start-up cost factor	.10	fraction of capital cost
depreciation life	11	years
project life	25	years

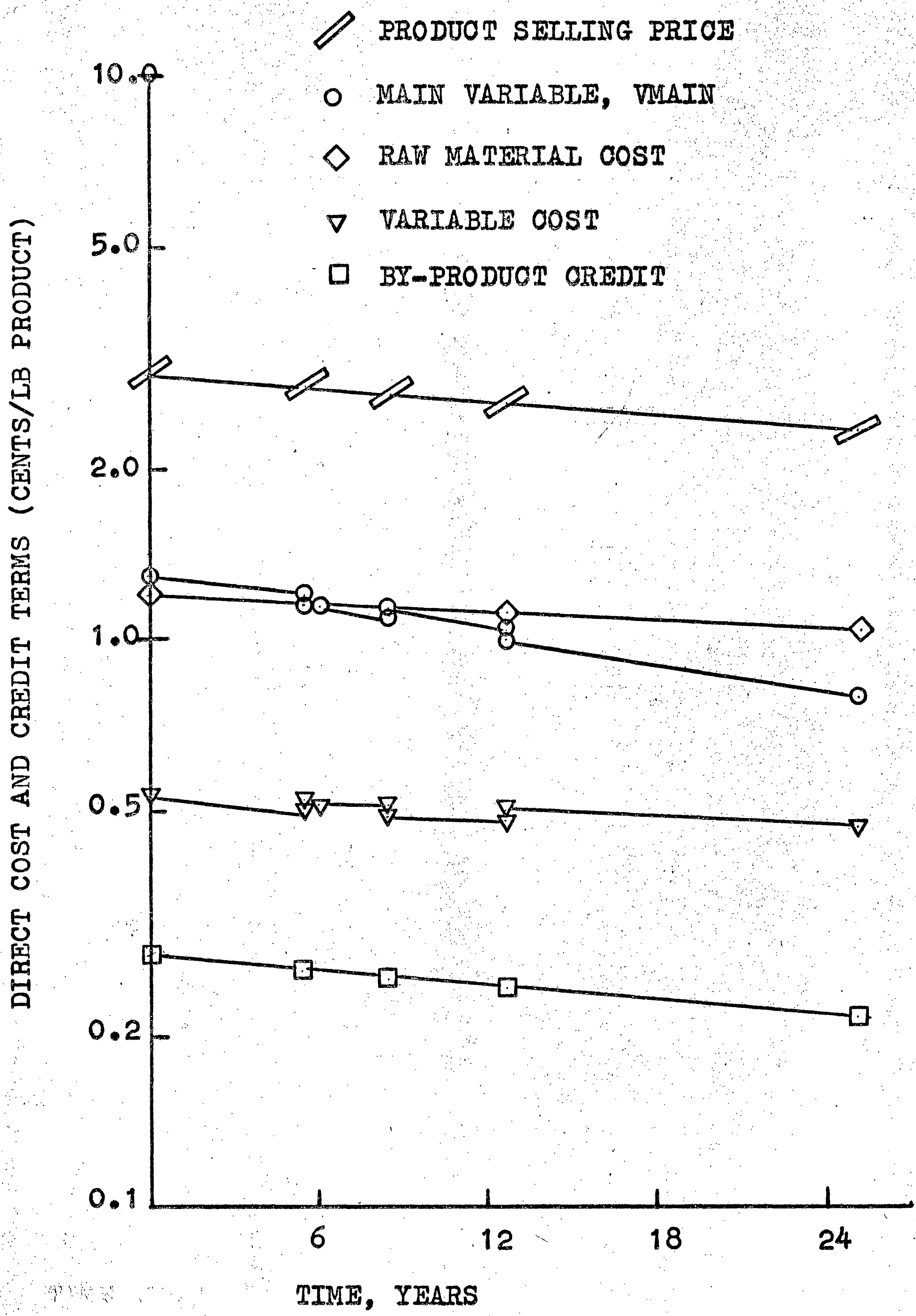


FIGURE 8: TIME DEPENDENT CHANGES IN DIRECT COST AND CREDIT TERMS OF DETERMINISTIC OPTIMUM FOR INITIAL SALES OF 600 MM LB/YR

TABLE IV

Ethylene Manufacturing Costs for
One Billion Pounds Per Year Plant[a]

Feedstock	Ethane
Capital investment	23.700 million dollars
DIRECT COSTS	
Feedstock	12.000
Utilities (Inc. fuel gas)	4.500
Catalysts and chemicals	0.631
Shipping	1.012
Working capital	0.500
Sales, admin., and research (5% of price)	1.500
	20.143
INDIRECT COSTS	
Depreciation	2.370
General overhead (2% investment)	0.474
Taxes and insurance	0.237
Labor and supervision	0.572
Maintenance ($3\frac{1}{4}$% investment)	0.770
	4.423
TOTAL COSTS	24.566
CREDITS	
Residue gas	1.140
Propylene	0.625
B-B	0.585
C_{5}+	0.389
TOTAL CREDITS	2.739
NET COST	21.827
NET COST ¢/LB ethylene	2.18

(a) Peters, E.H.: Ethylene, organic chemical building block, Chemical Engineering Progress, 62, No.6, 87-92 (1966).

the firm is defined by several inputs (PRO 3720): CI, CJ, ZM(14), GI(2), and GI(14). CI and CJ are the first and second plant capacities. CJ remains equal to zero until the second plant is actually built. ZM(14) is the random variable associated with the uncertainty of the production capacity of the new plants. GI(2) is the value of the learning curve set at three per cent per year.[11] For a project life of twenty-five years, a continued three per cent learning curve applied to the first plant is unreasonable. Therefore, after the time of the sales decline, the learning curve reduces to the value GI(14) chosen as 1.5 per cent per year. The firm's actual production, PROD, may be sales or capacity limited (PRO 3850 and PRO 3860).

<u>Selling price</u>. The product selling price, PRC, is determined by the present selling price, PR9, the price-volume factor, PRCF, and the rate of change of the price, GI(4), (PRO 3910). The present selling price of ethylene has been estimated at three cents per pound.[25] The price-volume factor allows for a price decline due to industry-wide overcapacity. Accurate predictions of industry demand and capacity growth rates and their effects on price are needed for this term. The price-volume factor, PRCF, was not used in this analysis. The predicted rate of change of the selling price is a decrease of one per cent per year.[33]

<u>By-product credit</u>. The by-product credit, CRDT, is determined by the present sales value of the by-products,

CR9, and by the averaged rate of change of the selling prices of the by-products, GI(5), (PRO 3920). The value of the by-product credits depends on the raw material used, the process units included in the plant, and the end use of the by-products. For this example ethane is the raw material and the by-products are fuel gas, propylene, butadiene-butylene, and C_5+. The plant does include facilities for polymer grade propylene but does not include facilities for extracting butadiene or hydrogenation of the aromatic distillate and aromatic extraction.(25) The present sales value of the by-product credits is0.274 cents per pound of ethylene.(25) The predicted average rate of change of the selling prices of the by-products is a decrease of one per cent per year.

Variable costs. The variable costs, VRT, are determined by the present variable costs, VR9, the efficiency factor, EFFI, and the rate of change of the variable costs, GI(6), (PRO 3930). The variable costs include utilities and catalysts which at present, for ethylene, add up to 0.513 cents per pound.(25) The efficiency factor reflects a decrease in operating efficiency when the plant is producing at 100 per cent of capacity. A four per cent increase in the variable costs is used to reflect this decrease in operating efficiency (PRO 4710). The predicted rate of change of the variable costs is a decrease of 0.5 per cent per year.

Raw material costs. The raw material costs, RMC, are determined by the present purchase price of the raw materials, RM9, the conversion factor, RMF, and the average rate of change of the raw material purchase prices, GI(7), (PRO 3940). The raw material or feedstock considered in this investigation was ethane at a present purchase price of one cent per pound.[25] The conversion factor is 1.2 pounds of ethane per pound of ethylene. The predicted rate of change of the ethane price is a decrease of 0.5 per cent per year.

Sales, administration, and research costs, SARE. The sales, administration, and research costs, SRC, are expressed as a fraction of the product selling price (PRO 3950). The input value for the SARE costs is five per cent of the selling price.[33] ZM(8) is the random variable associated with the uncertainty of the SARE cost fraction.

Shipping costs. The average shipping costs, SPC, are determined by the base cost, SHC, and the increased cost factor, SHD, (PRO 3890 and PRO 3900). The shipping cost computations allow for considerable flexibility although in this work the shipping cost schedule was hypothetical. The actual shipping cost is an average cost per pound for all of the production. One-half to two-thirds of the ethylene produced is used within this firm's complex. For low volumes of sales the shipping costs (per pound) are high due to small shipping quantities. As the production volume increases the product is shipped at lower bulk rates. Above a certain production level, VL, the average shipping cost will begin to increase. Although the cheaper bulk rates still apply, the average shipping distance is increasing. This will take into account the situation of a very large plant on the Gulf coast shipping the product to New York, Chicago, or California. The equations for the shipping costs are: For production below the level, VL

$$SPC = SHC + SHD(1 - PRODT/VL) \tag{11}$$

For production greater than the level, VL

$$SPC = SHC + 0.1SHD(PRODT/VL - 1) \tag{12}$$

where: (the input values are in parentheses)

SPC = average shipping cost, dollars per pound

VL = level of production at which the shipping costs begin to rise, pounds per year (800 million)

SHC = base average shipping rate, dollars per pound (0.001)

SHD = shipping cost factor, no units (0.0005)

PRODT = production level, pounds per year

The shipping cost in dollars per pound will go through a minimum at a production level equal to VL.

Working capital. The working capital is an initial capital expense which will be returned at the end of production. One computational method to account for working capital is to set the cost for working capital, WC, at the interest charge on the value of two months production.[25]

Capital costing and depreciation. The capital costing and depreciation write-off are combined in the term, risk capital. The risk capital is that portion of the capital investment which could actually be lost. If a firm remains profitable after a plant is shut down, a tax savings is still available through depreciation allowances of the shut down plant.[16] With a sum-of-years-digits depreciation, an eleven year depreciation life, a 48 per cent income tax rate, and a ten per cent cost of capital compounded continuously, only 72 per cent of the actual capital investment is risk capital. The use of risk capital is convenient for the type discounted cash flow evaluations employed in this computer model (PRO 3820).

The capital costing is obtained through a flexible exponential scale-up technique with a variable exponent, EXP, (PRO 3740 to PRO 3830). For small-to-moderate size plants, the scale-up exponent is fixed at AS, usually 0.7. As the plant size becomes very large, the exponent begins to increase, corresponding with certain process units reaching a maximum size, with the result that equipment duplication becomes necessary. The capital costing parameters for ethylene are given in Table V (see page 44 and Figure 9 page 45).[37] Off-site facilities are included in the capital costing. Once the actual capital cost is estimated, a start-up cost, SCF, is added, and the risk capital, CPC, is evaluated (PRO 3820). ZM(3) is the random variable associated with the uncertainty in the capital costing. The predicted rate of change of the capital costing, GI(3), was estimated as an increase of 1.5 per cent per year.

Fixed costs. For convenience and accuracy in evaluating the discounted cash flow, the fixed costs are evaluated separately. The fixed costs for one plant are given by (PRO 4870 to PRO 4920):

$$FC = FXF*CPC + YMAN*CPC + YLAB*CSLB \qquad (13)$$

where: (the input values are in parentheses)

FC = fixed costs of plant at beginning of production, dollars per year

FXF = fixed cost factor, fraction of capital cost (0.03)[25]

CPC = capital cost, dollars

YMAN = maintenance cost, fraction of capital cost (0.035)[25]

YLAB = number of full-time employees for plant (10)

CSLB = cost of labor, dollars per year per full-time man (60,000)

TABLE V

Input Values for Capital

Costing of Ethylene Facility

PARAMETER NAME	COMPUTER NAME	
Base capacity	CPBS	600 MM LB/YR
Base capital cost	BAS	15 $MM
Low value of scale-up exponent	AS	0.70
Upper value of scale-up exponent	BS	0.88
Multiples of base capacity at which exponent begins to increase	CS	2
Multiples of base capacity at which exponent ends increase	DS	3
Capital cost growth rate	GI(3)	1.5% per yr.
Start-up cost factor	SCF	10.0% of capital cost

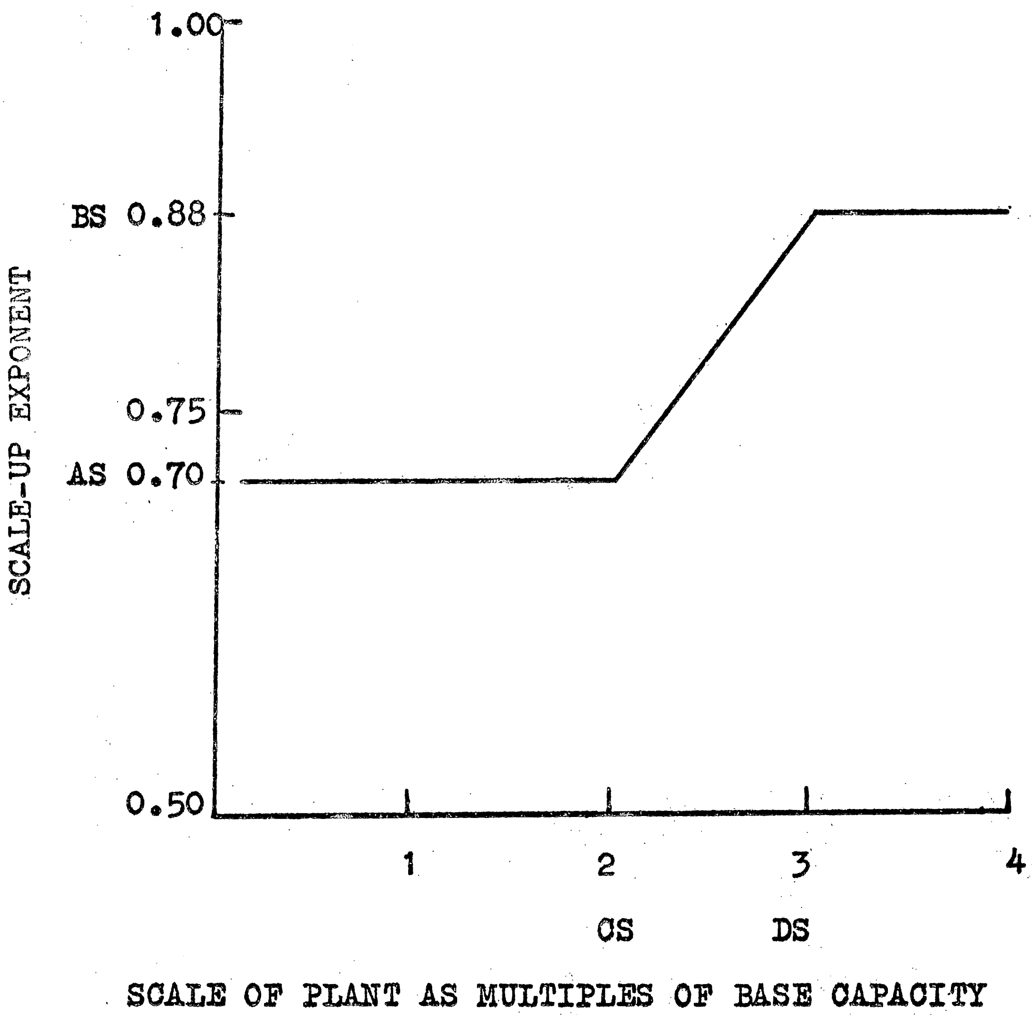


FIGURE 9: CAPITAL COSTING BY SCALE-UP WITH VARIABLE EXPONENT

The fixed cost growth rate, GI(9), was set at two per cent per year. The present value of the fixed cost cash flows, PVTFXC, is evaluated by the same technique as the other cash flows (PRO 4940). The present value of the project is the present value of the other cash flows, PVC, minus the discounted capital costs, and minus the present value of the fixed costs, PVTFXC, (PRO 4960).

Abnormal project termination. The input project life, PRLI, is twenty-five years. If at any time during one evaluation, the cash flow becomes less than the fixed operating costs, FXOPC, (PRO 4000), the project is terminated (PRO 4130 to PRO 4300). The actual time of the project termination is determined within 0.05 years (PRO 4320 to PRO 4570).

Description of Subroutine DPOPT

Within subroutine DPOPT the value-grids are generated. See Figure 6, page 27, for a flow diagram of this subroutine. For a computer print-out of DPOPT and another copy of the flow diagram, see Appendix page 125 and page 95. Typical value-grids are presented in results Figures 10, 11, 12 and 13, pages 52 to 55.

General features. The value-grids of DPOPT cover the full range of possible values for the two main random variables. The two main random variables used in this analysis were the product selling price, PRC, and the initial sales growth rate, GI(1). The total number of levels in each direction on the grids is an input parameter, NTGRD, which was set at seven. For seven grid levels, 49 point values are needed for each grid. The interval size between each point value is determined within the subroutine by dividing the full range of each main variable into equal sections. Thus, for a skewed input distribution the mid-point of the grid would not be the mean or even the most likely value of the distribution. The probabilities of occurrence could be superimposed on each grid, but they would be different for each different input distribution. In general, though, the values corresponding to the center region of each grid have the highest probability of occurring.

For each time subroutine DPOPT is called the first plant size is fixed. Then the single plant case value-grid (grid 1) of present values is determined, PVALO (DPO 580). The present value is evaluated for each of the grid point combinations of the two main variables. Each evaluation is deterministic. Then the three two-plant case value-grids are determined (DPO 660). These grids include: (grid 2) the maximum present value, PVAL, (grid 3) optimum second plant size, OBJ1, and (grid 4) the optimum timing factor, OBJ2. The optimization of the second plant size and timing, given the first plant size and the grid values of the two main variables, is accomplished by a pattern search, subroutine PATERN.[18] In the optimization, present value is the dependent variable and the second plant size and timing factor are the independent variables.

Selection of optimum second plant size and timing. With each iteration of the Monte Carlo analysis for the two-plant case, the optimum second plant size and timing must be selected. After the first selection of the random variables, the optimum second plant size and timing is chosen (PRO 1830 to PRO 2170). This optimum is determined by interpolation of the four value-grids generated in DPOPT. With the values of the two main random variables set (by first random number generation), the second plant size and timing are interpolated from grids 3 and 4 (Figures 12 and 13, pages 54 and 55). Then the single plant present value and two-plant present value are found by interpolation of grids 1 and 2 (Figures 10 and 11, pages 52 and 53) and are compared. If the single plant present value is greater than the two plant present value, no second plant is built (PRO 2160). But if the present value of the two-plant case is greater than the single plant case, the interpolated values of the second plant size and timing factor are used for that Monte Carlo iteration. Two situations make this comparison technique necessary. For interpolations resulting in relatively small second plants, it is often more economical not to build the second plant at all. Also, occasionally, the optimum two-plant case occurs with a large second plant, but this local optimum has a present value less than the single plant case. Therefore, the second plant will not be built.

The use of this optimization technique has two apparent shortcomings. One, only two random variables are used for the grids to predict the economic outcome whereas all of the random variables should be used. If the variations in one or two of the main random variables account for most of the variations in the present value, then this shortcoming should be minor. The second shortcoming is that the optimum second plant size and timing are chosen deterministically for each point on the grids. That is, no attempt is made to account for the second selection of the random variables in determining the second plant size and timing factor. For each present value iteration the second plant size and timing are chosen deterministically from the first randomly generated economic outcome. If the variations due to the second selection of the random variables are significant, one would expect an economic advantage to hedge on the second plant size. The effect of this shortcoming on the present value should be minor, if the second plant is built sufficiently far in the future and the variations of the second random variables generation are sufficiently small. The possible effect of these shortcomings is presented in the Results (see page 51).

IV. RESULTS AND DISCUSSION OF RESULTS

The goal of this investigation was to develop an improved economic evaluation technique. This technique employs a digital computer in evaluating the economic model. In this section the results are presented for the example case of an ethylene market venture. First the value-grids generated in subroutine DPOPT are displayed. Then, the sensitivity analysis for the fourteen random variables is presented. The results of the Monte Carlo analyses are given and finally the recommendations for further investigations are stated. The computer used was an IBM 360, 65. The computer execution time was about six minutes for each level of initial sales. The ethylene example chosen was hypothetical, but the results should be reasonable and somewhat in line with present industry practices.

Value-Grids from Subroutine DPOPT

The value-grids from subroutine DPOPT are an integral part of the economic evaluation technique developed here. The addition of the two-plant case is an improvement over other evaluation techniques. The interpolation of the value-grids allows for rapid optimization of the second plant size and timing factor. Again, the two main variables for the value-grids are the sales growth and the selling price. All four grids cover identical ranges of the two main variables thus can be compared by superimposing the grid plots. Figure 10 (page 52) is a typical value-grid for the present value of a single plant case. The initial sales level is 600 million pounds per year with a first plant size of 1297 million pounds per year. Figures 11, 12, and 13 (pages 53 to 55) are the value-grids for the two-plant case with initial sales of 600 million pounds per year and first plant size of 1297 million. Figure 11 is the value-grid for the maximum present value. For present values less than the XXX line the single plant case has a higher present value. For present values greater than that line, the two-plant case is preferred. Figure 12 is the value-grid for the optimum second plant size. The second plant is actually built only for capacities greater than the XXX line. This build/no-build line is obtained by comparing the present value grids for the one- and two-plant cases and by building the second plant only when it will increase the net present value of the venture. The value-grid for the optimum timing factor, Figure 13, also has the XXX line for the build/no-build decision. The data points for these four grids are given in the Appendix within the sample computer output (see pages 157 to 160).

Sensitivity Analysis for Random Variables

The use of the value-grids assumes that the two main variables can satisfactorily predict the economic outcome

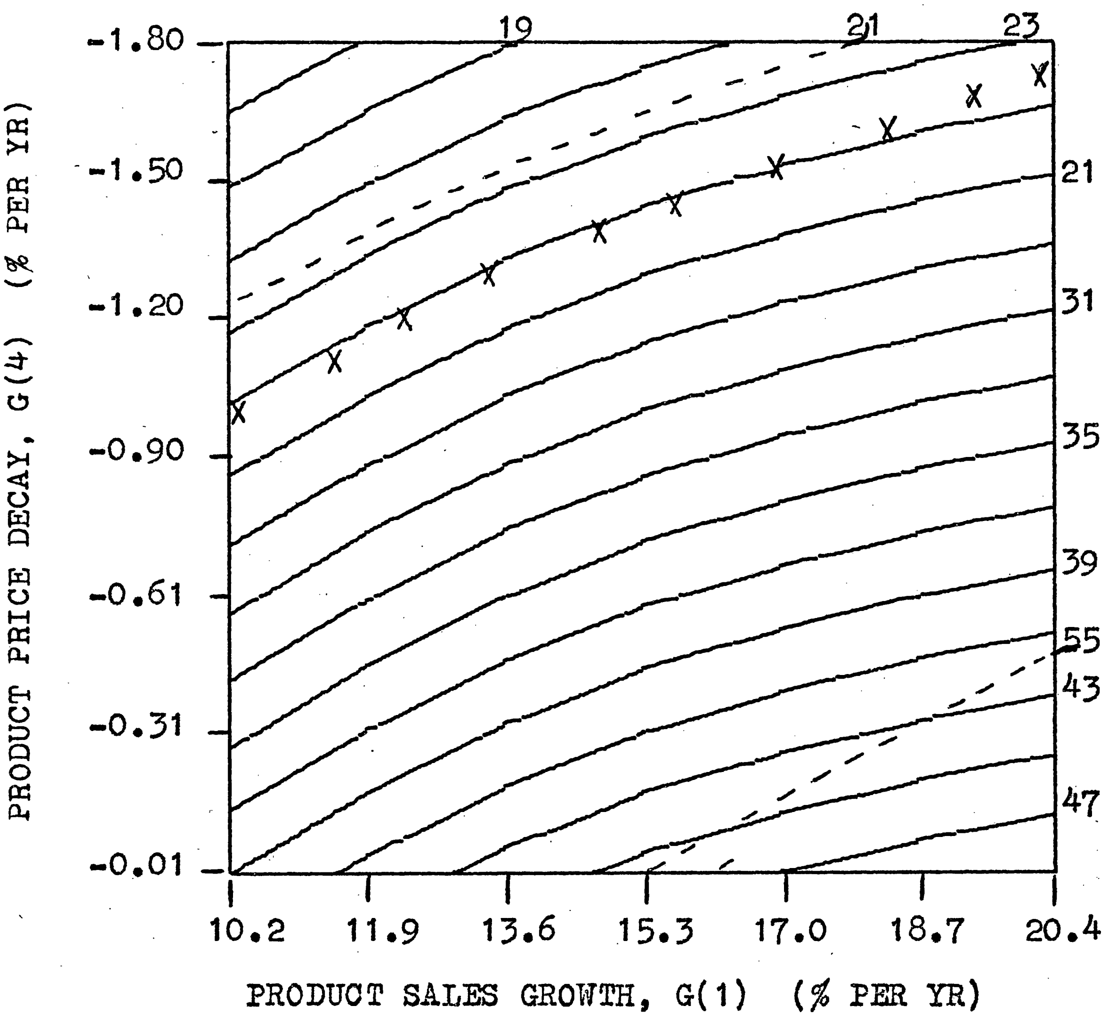


FIGURE 10: VALUE-GRID OF PRESENT VALUES FOR SINGLE PLANT CASE FOR RANGES OF PRICE DECAY AND INITIAL SALES GROWTH.
(INITIAL SALES OF 600 MM LB/YR, FIRST PLANT SIZE OF 1297 MM LB/YR)

NOTE: DASHED LINES ARE 2-PLANT CASE. FOR PRESENT VALUES LESS THAN $25 MM, THE SINGLE PLANT CASE IS PREFERRED.

* CONTOURS LABELED IN $MM

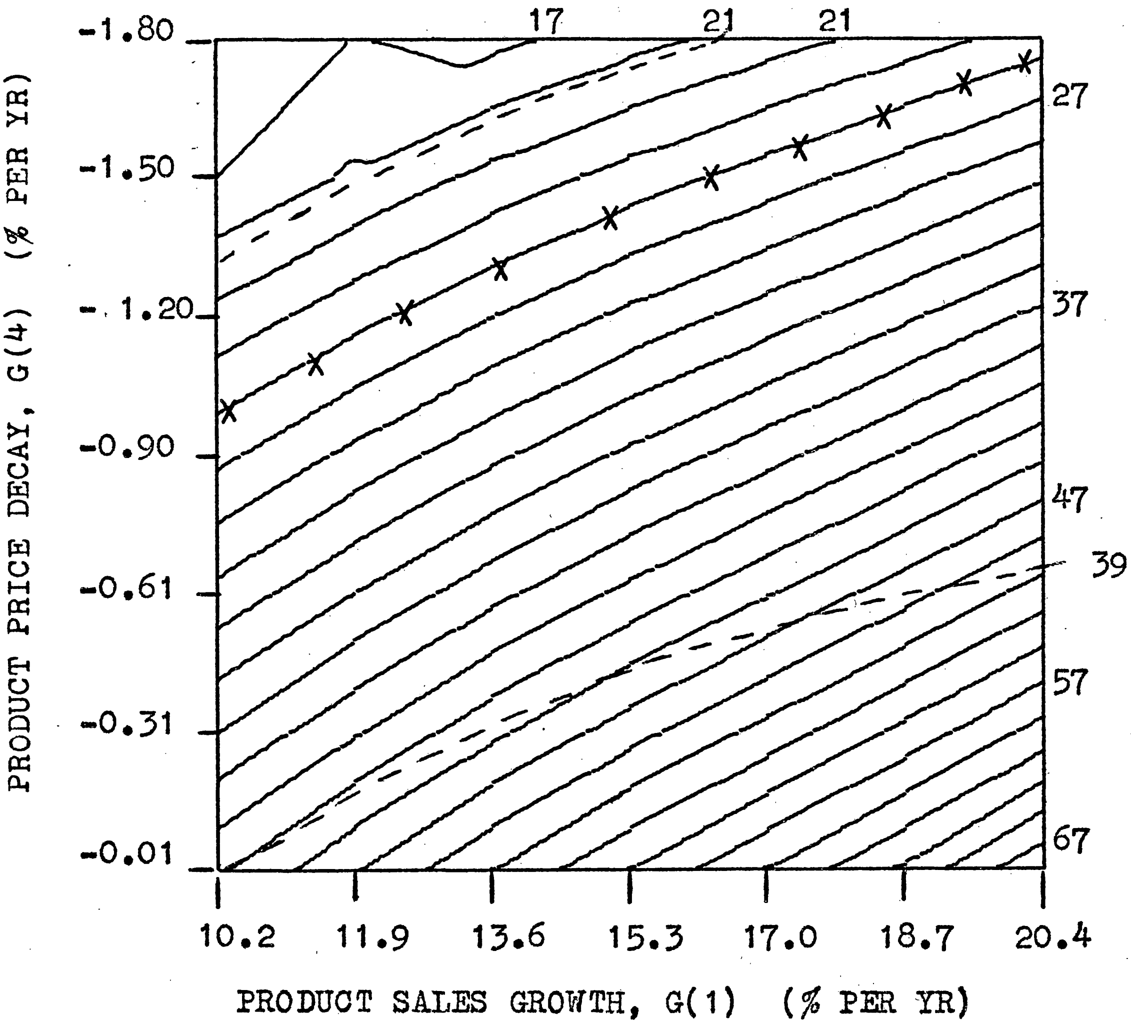


FIGURE 11: VALUE-GRID OF PRESENT VALUES FOR TWO-PLANT CASE FOR RANGES OF PRICE DECAY AND INITIAL SALES GROWTH (INITIAL SALES OF 600 MM LB/YR, FIRST PLANT SIZE OF 1297 MM LB/YR)

NOTE: DASHED LINES ARE SINGLE PLANT CASE. FOR PRESENT VALUES GREATER THAN $25 MM THE TWO-PLANT CASE IS PREFERRED.

* CONTOURS LABELED IN $MM

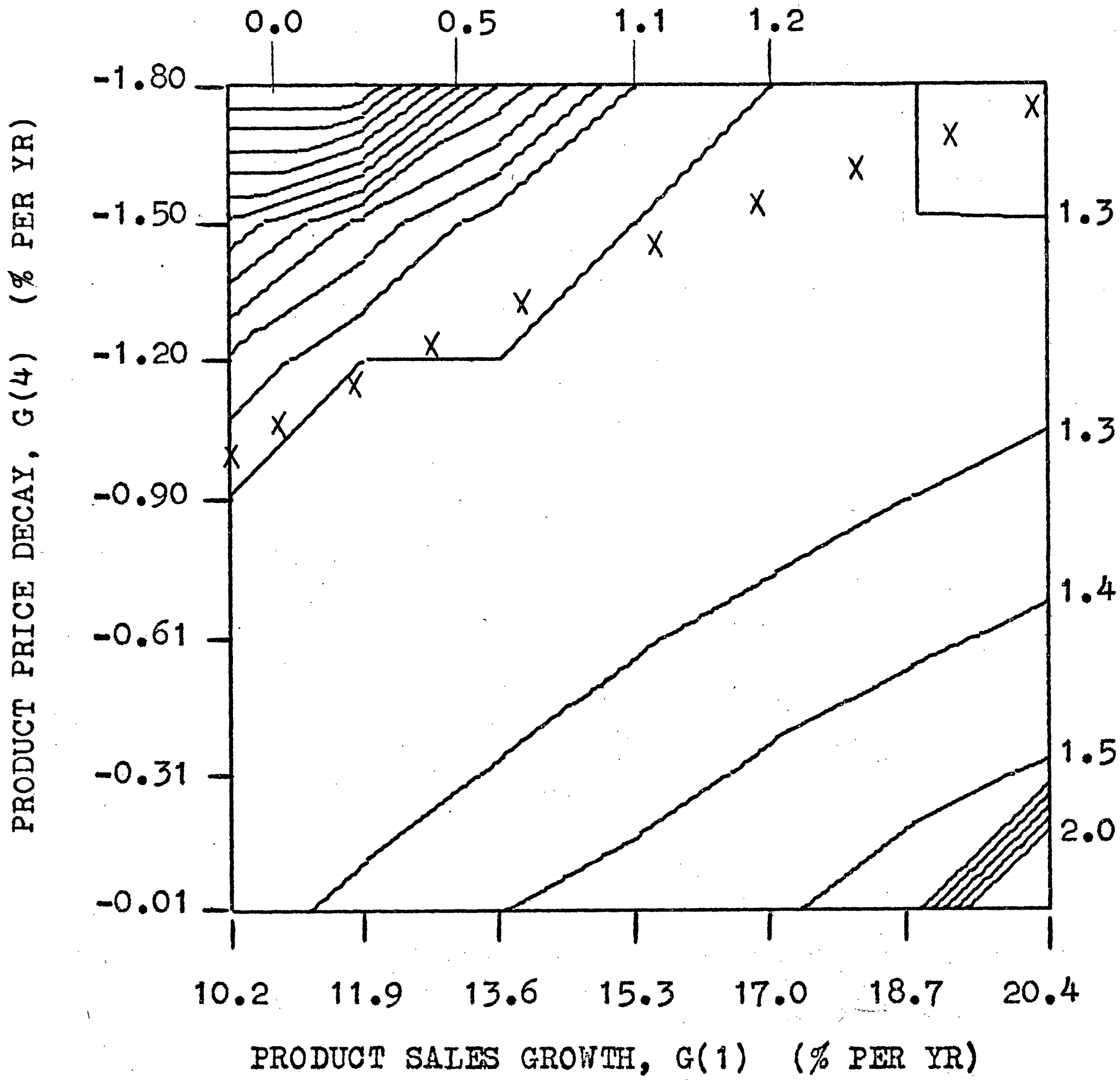


FIGURE 12: VALUE-GRID OF SECOND PLANT SIZE FOR RANGES OF PRICE DECAY AND INITIAL SALES GROWTH (INITIAL SALES OF 600 MM LB/YR, FIRST PLANT SIZE OF 1297 MM LB/YR)

NOTE: FOR CAPACITIES LESS THAN THE XXX LINE, THE SECOND PLANT IS NOT BUILT.

* CONTOURS LABELED IN CAPACITY MMM LB/YR

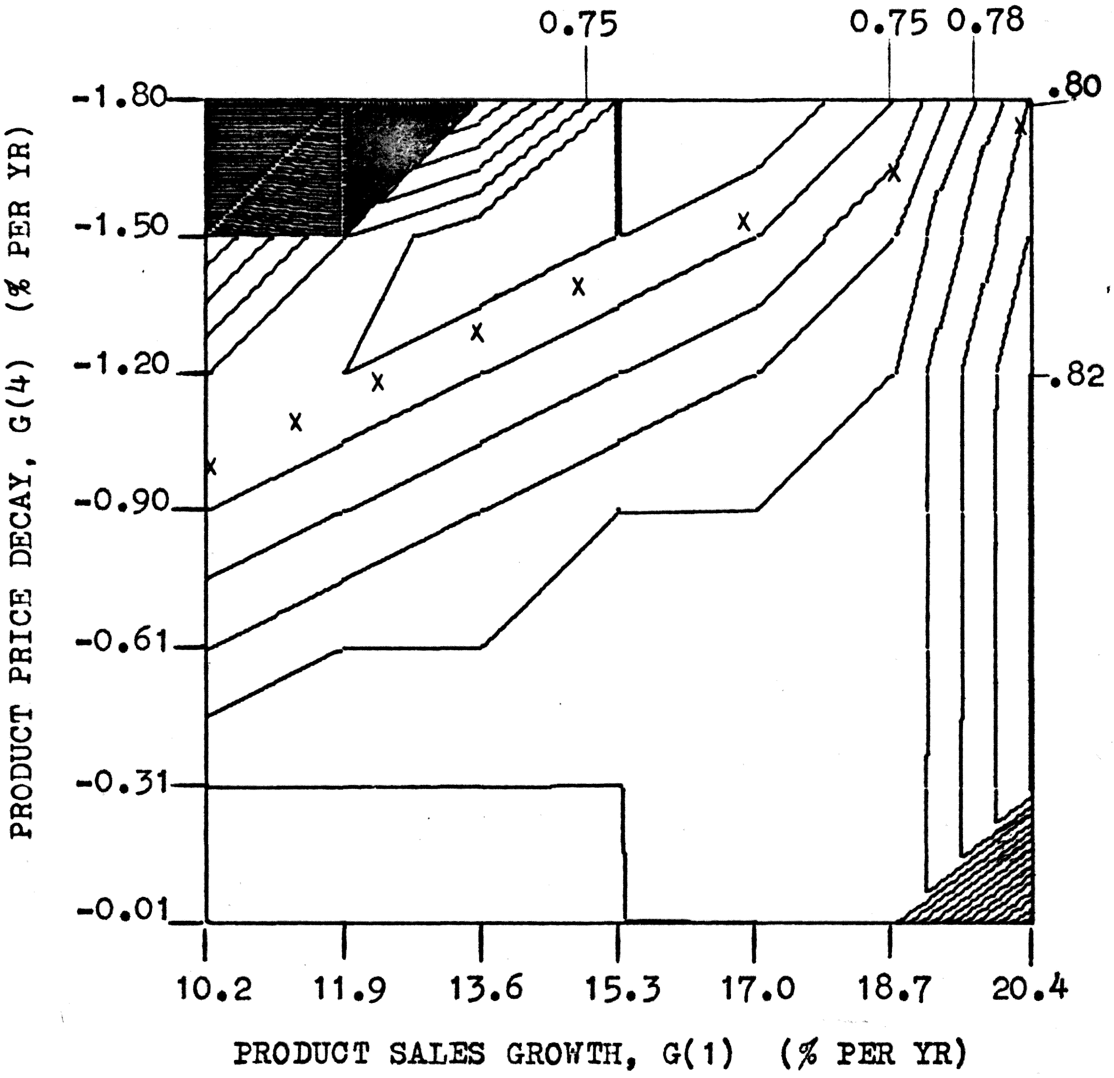


FIGURE 13: VALUE-GRID OF TIMING FACTOR FOR SECOND PLANT FOR RANGES OF PRICE DECAY AND INITIAL SALES GROWTH (INITIAL SALES OF 600 MM LB/YR, FIRST PLANT SIZE OF1 297 MM LB/YR)

of each random variable generation. The validity of this assumption is revealed by a sensitivity analysis for the fourteen main random variables. The Monte Carlo analysis for a two-plant case was made fifteen times with each of the random variable factors in turn being held constant (factor equal to 1.0). The fifteenth analysis, with none of the variables held equal to one, is used as the base case. By taking the difference in the variance between the base case and each analysis, the effect of each of the random variables can be determined. The results show that the selling price, the initial sales level, and the initial sales growth rate are the three most important random variables, accounting for 90 per cent of the total variance (see Table VI, page 57). This is not a general sensitivity analysis but rather takes into account the input probability distributions given to each of the random variables. Also, the use of the variance indicates the assumption of normal distributions. The output distributions around the present value are not necessarily normal distributions, but the differences are not enough to significantly affect the results in Table VI. The two variables used in subroutine DPOPT as the two main random variables were the selling price and the initial sales growth rate. The selling price accounts for 52.3 per cent of the total variance, and the initial sales growth rate accounts for 15.5 per cent of the total variance. The initial sales level accounts for 22.2

TABLE VI

Variance Due to Each of the Random

Variables for Two-Plant Case

initial sales	600MM LB/YR	timing factor	0.779
first plant size	1222MM LB/YR	mean present value	35.6 $MM
second plant size	1297MM LB/YR	number iterations	1000

Random Variable (held=1.0)	Variable Name (held=1.0)	Variance on Present Value ($MM)	% of total Variance
	initial sales		
1	Sales (1) growth rate	100.4	15.5
2	Capacity growth rate	118.6	-
3	Capital cost	113.9	4.0
4	Price	57.0	52.3
5	By-product credit	118.6	-
6	Variable costs	118.6	-
7	Raw material	118.6	-
8	Sales, admin., and research	116.9	1.4
9	Fixed costs	118.6	-
10	Time of sales decline	116.0	2.1
11	Sales (2) final growth rate for sales	118.6	-
12	Project life	118.6	-
13	Initial sales	92.5	22.2
14	Initial capacity	115.6	2.5
15(base)	None	118.6	-
			100.0

per cent of the total variance. It may have been better to use this variable in the DPOPT value-grids rather than the initial sales growth although the difference would probably be small. The economic model could be improved by combining these two sales variables into a single variable. Possibly an inverse relationship between initial sales and initial growth rate for sales could be used. For this computer model the sales curve for each of the two sales periods must be changing at a constant rate.

Monte Carlo Risk Analysis

A complete Monte Carlo risk analysis was made for six levels of initial sales (2, 3, 4, 5, 6, and 7 x 10^8 pounds per year). Each analysis included 500 iterations of present value. In Tables VII-XII (see Appendix, pages 79 to 84) and Figures 14-19 (pages 59 to 64) the main results are shown. The results can best be discussed in two groups: (1) low initial sales (2, 3, 4 x 10^8) and (2) high initial sales (5, 6, 7 x 10^8).

Low initial sales levels. The results for the low initial sales of 2, 3, 4 x 10^8 pounds per year are displayed in Figures 14, 15, and 16. The present values for a single plant case are used for comparison with the two-plant case. For values of the first plant size which are considerably lower than the deterministic optimum first plant size, the

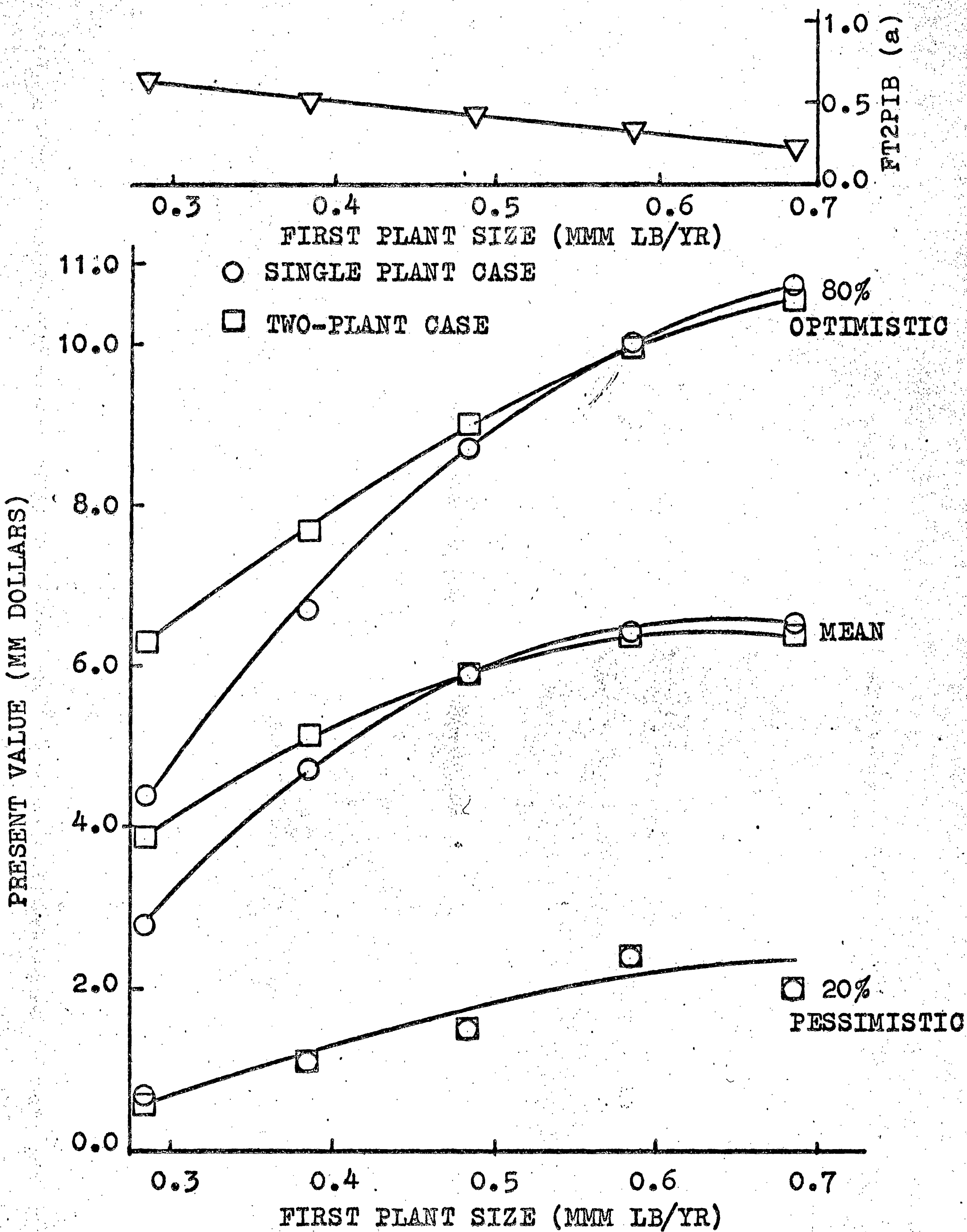


FIGURE 14: PRESENT VALUE DISTRIBUTIONS FOR SINGLE AND TWO-PLANT CASES FOR INITIAL SALES OF 200 MM LB/YR

(a) FRACTION OF TIMES SECOND PLANT IS BUILT

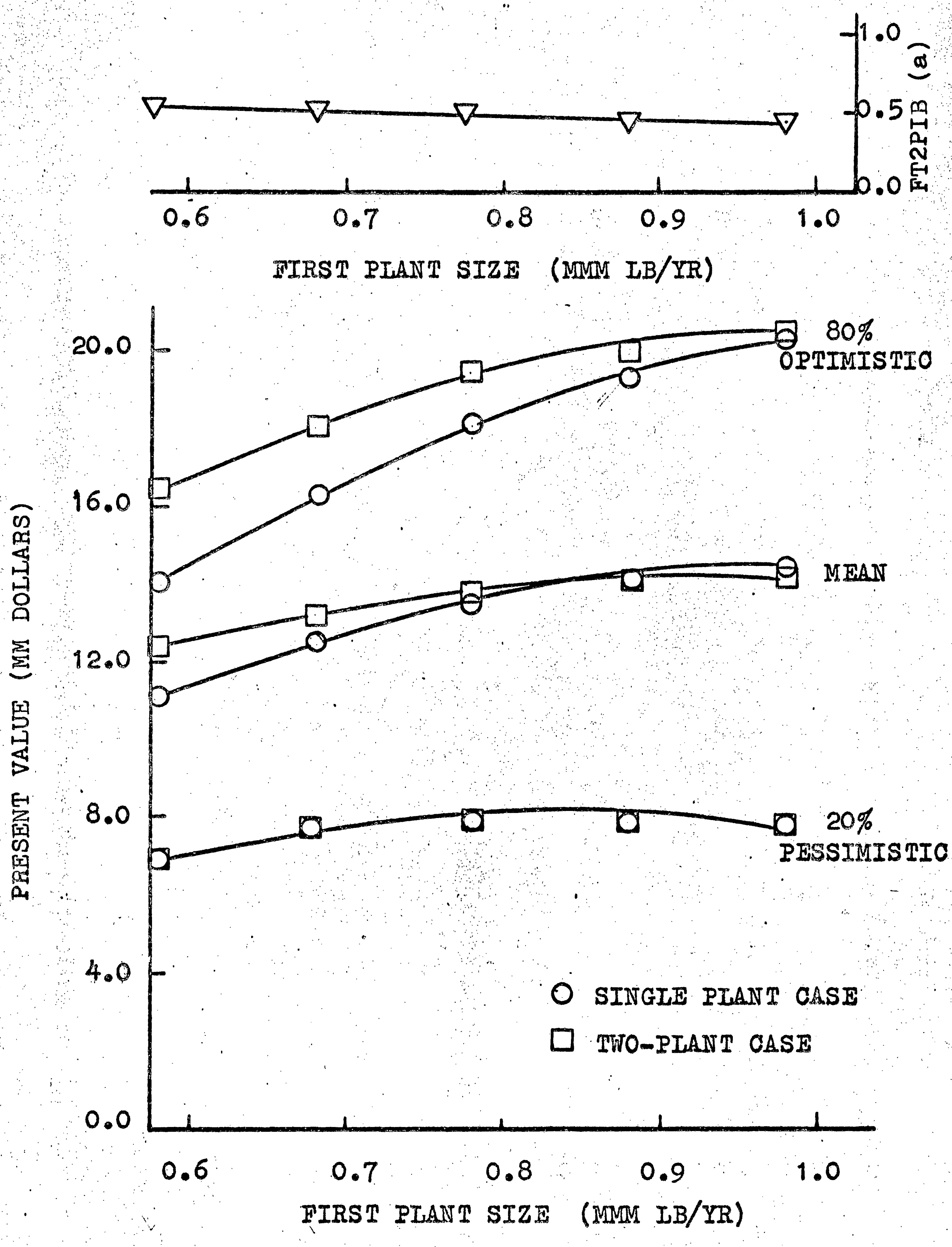


FIGURE 15: PRESENT VALUE DISTRIBUTIONS FOR SINGLE AND TWO-PLANT CASES FOR INITIAL SALES OF 300 MM LB/YR

(a) FRACTION OF TIMES SECOND PLANT IS BUILT

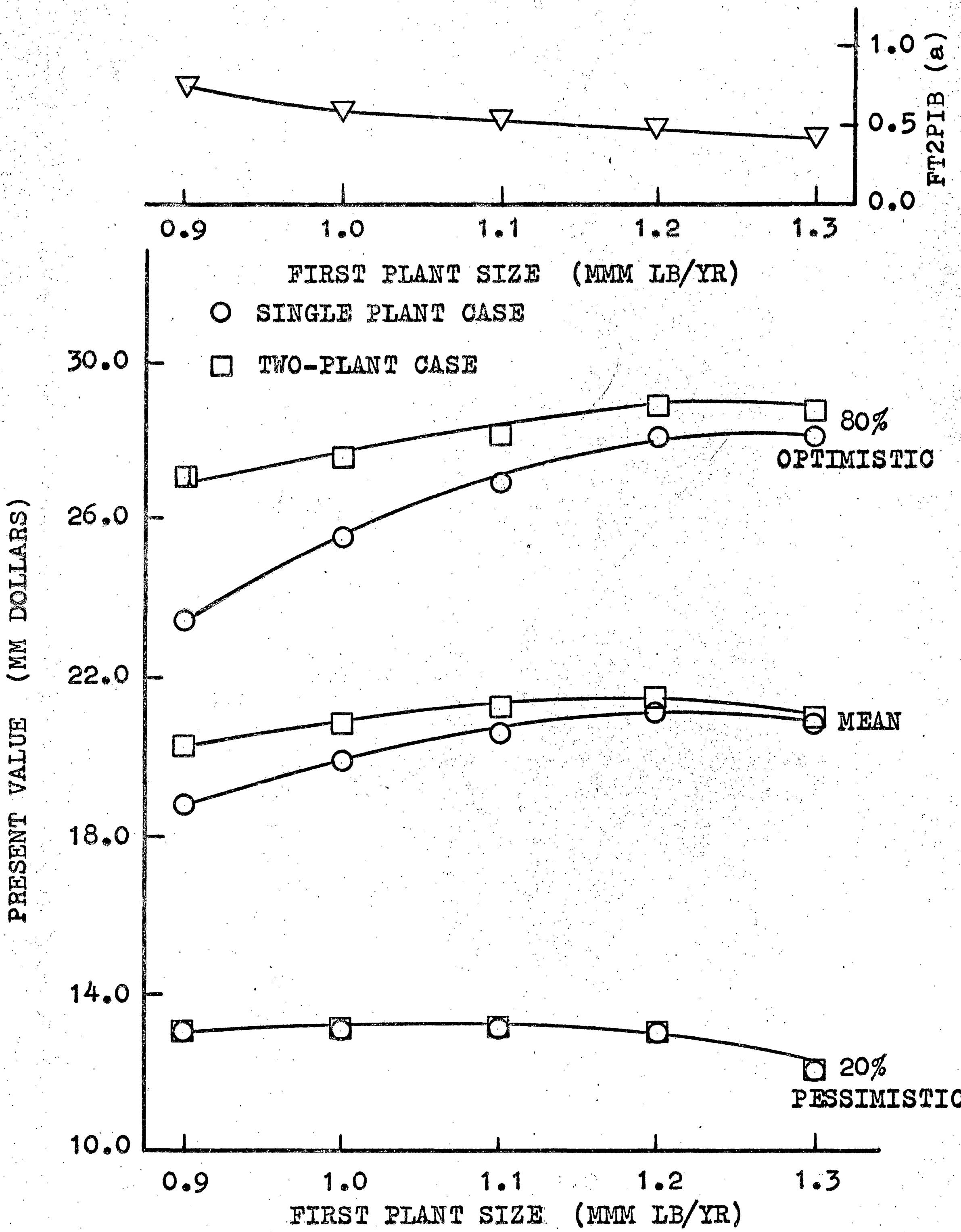


FIGURE 16: PRESENT VALUE DISTRIBUTIONS FOR SINGLE AND TWO-PLANT CASES FOR INITIAL SALES OF 400 MM LB/YR

(a) FRACTION OF TIMES SECOND PLANT IS BUILT

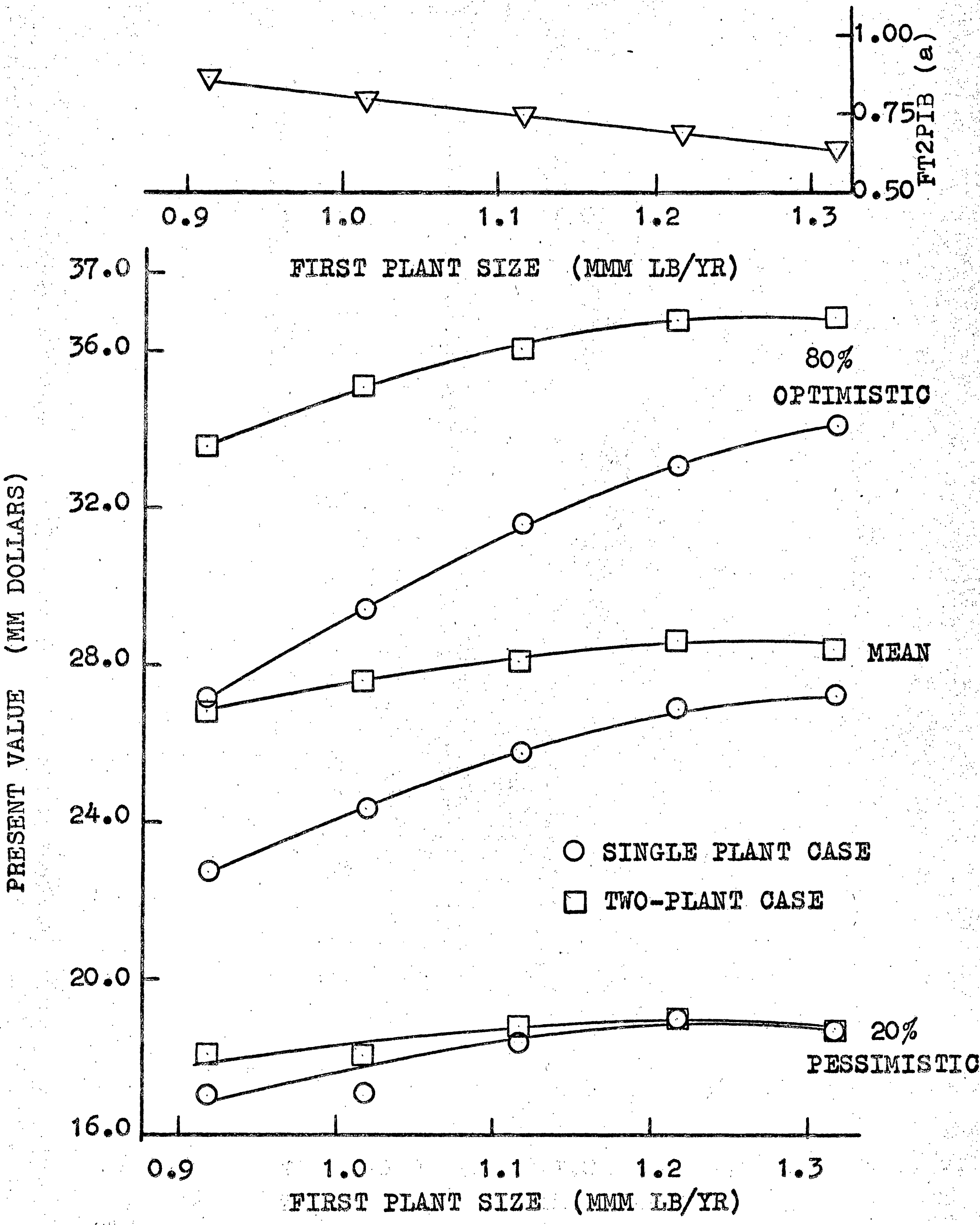
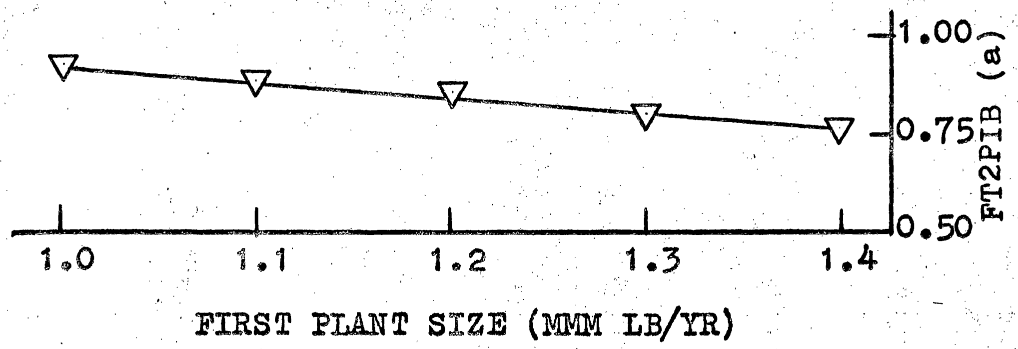


FIGURE 17: PRESENT VALUE DISTRIBUTIONS FOR SINGLE AND TWO-PLANT CASES FOR INITIAL SALES OF 500 MM LB/YR

(a) FRACTION OF TIMES SECOND PLANT IS BUILT



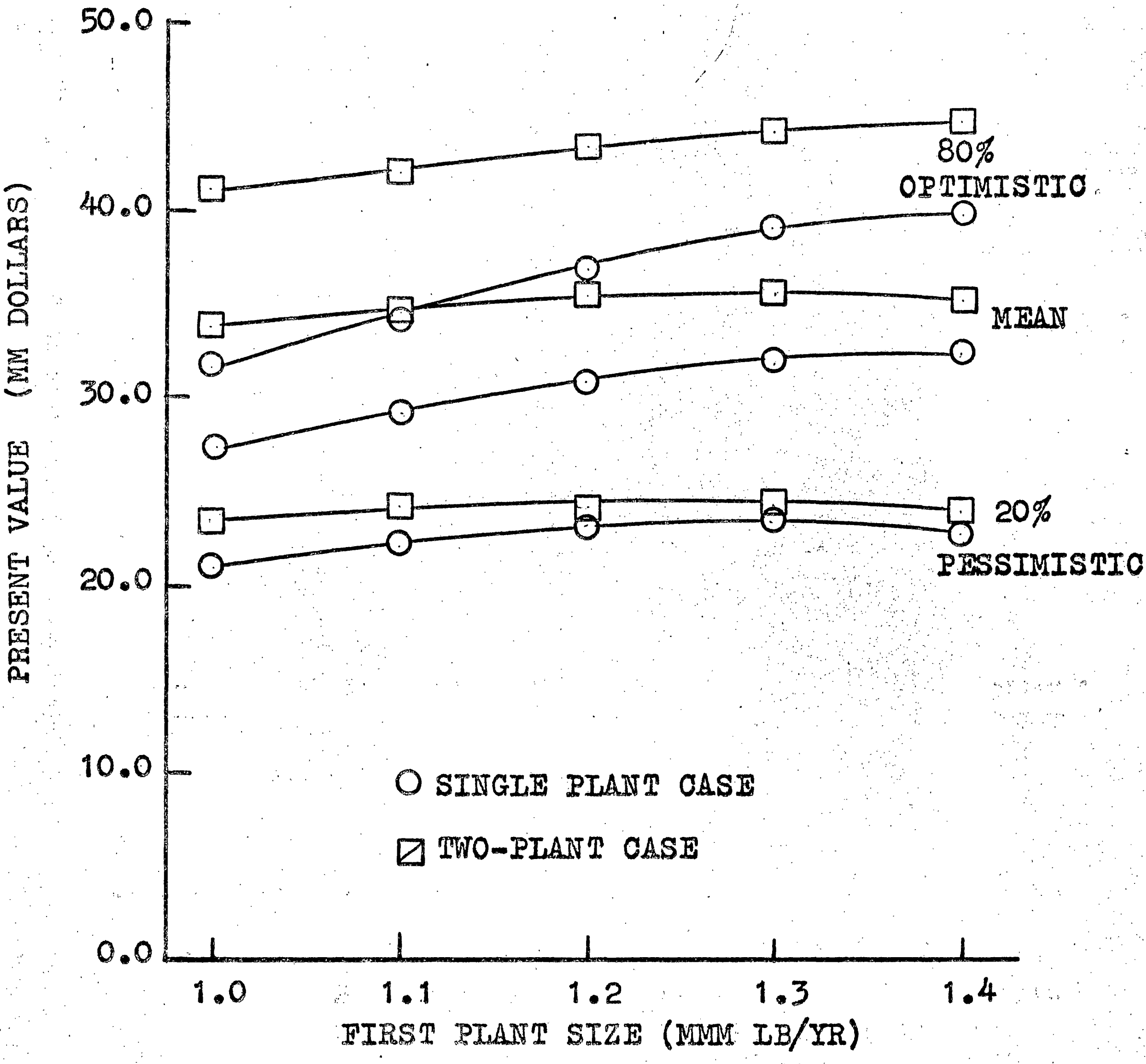


FIGURE 18: PRESENT VALUE DISTRIBUTIONS FOR SINGLE AND TWO-PLANT CASES FOR INITIAL SALES OF 600 MM LB/YR

(a) FRACTION OF TIMES SECOND PLANT IS BUILT

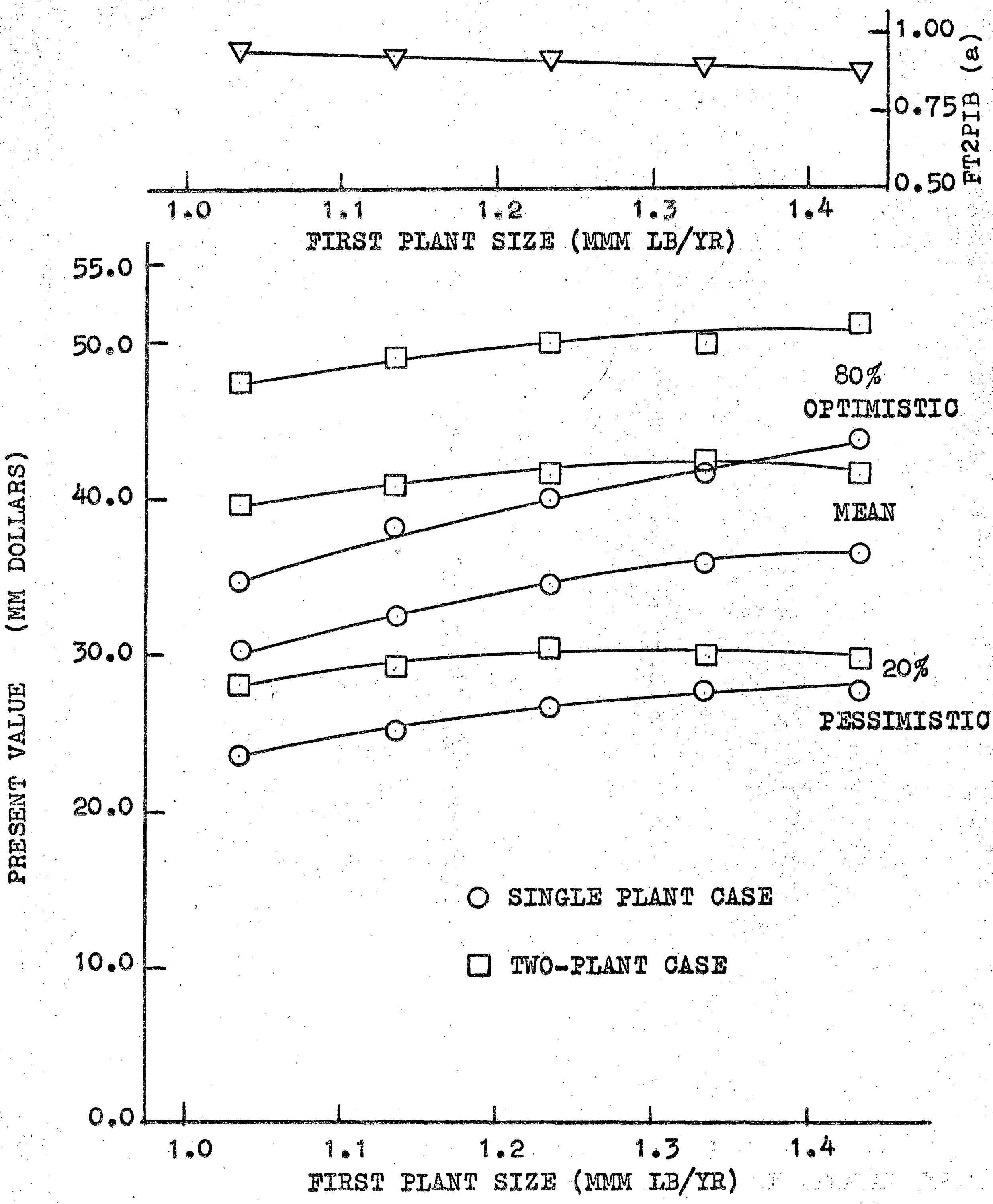


FIGURE 19: PRESENT VALUE DISTRIBUTIONS FOR SINGLE AND TWO-PLANT CASES FOR INITIAL SALES OF 700 MM LB/YR

(a) FRACTION OF TIMES SECOND PLANT IS BUILT

two-plant case returns a significantly higher mean present value. Also, the second plant is built in most of the iterations (see fraction of the time second plant is built, FT2PIB). For larger values of the first plant size both cases return about the same mean present value. And for the two-plant case many times the second plant is not built. The mean second plant size and timing factor for the times that the second plant is built are also included in the tables. These two terms show what the firm might expect to do in the future with each first plant size decision. The standard deviations for each term are included, but they serve only as a general indication of the variability in each term, for the distributions are not necessarily normal. For the low values of initial sales, the use of the two-plant case gives only a moderate improvement in the present value over the single plant case. One reason for this is the size of the plants involved. All plants below 1.2 billion pounds per year show a 0.7 capital costing scale-up factor. (See Capital Costing, page 42 for details). The optimum plants sizes for the low initial sales were below this 1.2 billion level. The analyses showed that the one- and two-plant cases were comparable. For the higher initial sales the two-plant cases were preferred.

<u>High initial sales levels.</u> The high initial sales levels were 5, 6, and 7 x 10^8 pounds per year. The results from these analyses are given in Tables X, XI, and XII (see

Appendix, pages 82 to 84) and are displayed in Figures 17, 18, and 19. The two-plant case exhibits a marked improvement over the single plant case. The second plant is now built most cases. For the low initial sales levels, the optimum first plant size increased significantly with each increase in initial sales. This trend does not continue for the higher levels of initial sales (see Figure 20, page 67). Although the mean present value increases nearly linearly with increasing initial sales, the optimum first plant size levels off below 1.4 billion pounds per year. A major cause for this is the loss of economies of scale for plant sizes above 1.2 billion. For large initial sales, the two-plant case considerably improves the economic analysis.

The value of the two-plant case analysis is further illustrated by the 20 and 80 per cent cumulative probability levels (see Figures 14-19). Although the present value probabilities may be nearly normal distributions, the differences from the normal are significant in comparing the one and two-plant case analyses. For the pessimistic 20 per cent cumulative probability level, the two analyses give comparable results. For the pessimistic economic outcomes, the second plant is not usually built, and the two analyses become comparable. For the eighty per cent cumulative probability level the economic outcome is optimistic. The single plant case is bound to one plant and cannot take full advantage of the good fortune. For the two-plant ana-

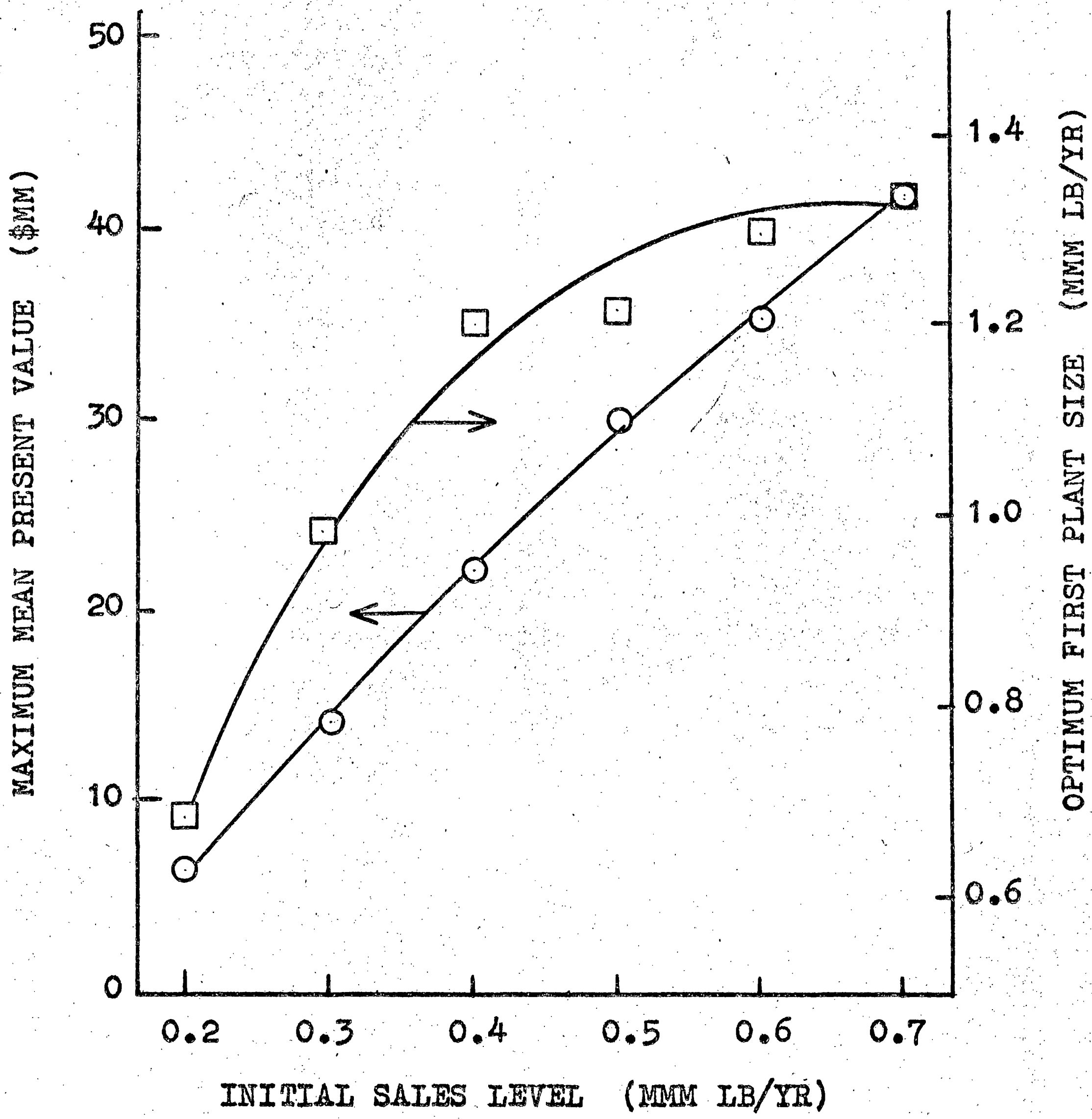


FIGURE 20: MAXIMUM PRESENT VALUE AND OPTIMUM FIRST PLANT SIZE FOR EACH LEVEL OF INITIAL SALES

lysis the second plant is built and the present value for that iteration of the Monte Carlo is relatively high. The optimistic economic outcomes with the two-plant analysis result in a mean present value which is higher than that of the single plant analysis. Thus, the two-plant case analysis will more closely model reality giving a more useful and realistic economic analysis technique.

Hedging on the size of the first plant. Another aspect of the analysis technique which Figures 14-19 (pages 59 to 64) reveal is the economic effect of hedging on the size of the first plant. For a firm with a linear utility function, the first plant size decision will be made to maximize the expected present value of the venture. For small investments, the utility functions for most firms will be linear. But for investments of the amount needed in the ethylene venture, most firms will show risk aversion (resulting in a conservatively curved utility function). This risk aversion would result in building a first plant smaller than the size corresponding to the maximum present value, that is, hedging. Hedging at low values of initial sales reveals some of the advantage of the two-plant case. See Figure 14, page 59. For the 200 million pounds per year initial sales, the first plant size of 600 million pounds per year yields the maximum mean present value (about 6.5 million dollars) for both the one- and two-plant analyses. Hedging on the first plant size to 300 million pounds per year reduces the expected present value of the single plant case to 3.2 million dollars while reducing the two-plant case to 4.1 million dollars. Even at low initial sales the two-plant case shows a significant advantage when the possibility of hedging on the first plant size is taken into account.

Now consider hedging with the large initial sales displayed in Figure 19, page 64. The maximum mean present value occurs for the single plant case at 36.6 million dollars with a first plant size of 1,425 million pounds per year. The maximum for the two-plant case occurs at 41.6 million dollars with a first plant size of 1,335 million pounds per year. If a manager were to choose the risk aversion decision of building a 1,035 million pounds per year plant, the mean present value for a two-plant case drops only to 39.4 million dollars, whereas the single plant analysis shows a reduction to 30.1 million dollars. Thus, for low initial sales and even moreso for high initial sales, the two-plant case technique is a significant improvement over other economic analyses when considering risk aversion by hedging on the size of the initial plant.

Recommendations for Further Investigations

Several recommendations can be made for furthering the investigation of economic analysis with this technique.

Improving suboptimization technique. The suboptimization technique would be improved if the two main variables were to more closely indicate the economic outcome of the first random number generation (see Table VI, page 57). The price variable could be replaced by a price margin term. This could be accomplished by using VMAIN as a main variable, thus including the selling price, by-product credit, variable costs, raw material cost, and SARE cost. Although the improvement for this case would not be significant (from 52.3 per cent of total variance to 53.7), for some cases the improvement could be very significant. For example, if the feed were naphtha, rather than ethane, for the ethylene plant, the value of the by-product credits would become quite important. A second and more important improvement would be to use one variable to define the sales curve outcome, thus combining the initial sales level and the initial sales growth rate.

The optimum second plant size, chosen from the DPOPT value-grids, is a deterministic optimum for each point on the grids. The stochastic optimum would probably indicate that hedging on the second plant size would increase the present value. The analysis technique of this work shows the value of hedging on the first plant size. This information could be used as a guideline for hedging on the second plant size.

Other example cases. Only one example case, an ethylene market venture, was considered in this work. With the flexibility of this analysis technique, a wide range of example cases could be considered. For cases with plant sizes at upper limits of economies of scale and rapidly growing markets, the two-plant analysis would show a significant improvement over the single plant analysis. And when risk aversion, through hedging on the size of the first plant, is being considered, the two-plant analysis should give significantly more meaningful results than the single plant analysis.

V. CONCLUSIONS

The following conclusions were reached:

(1) The economic analysis technique developed here is flexible and realistic. The manager is given the choice of building a single plant or building one plant now and delaying the decision on the second plant.

(2) The technique can evaluate investment risk using the Monte Carlo risk analysis allowing for variations in fourteen main variables.

(3) The technique considers the future economic environment by including the capability for time-dependent changes in the main variables.

(4) The technique can be executed in relatively short computer running times.

VI. SUMMARY

The increasing amounts of initial capital investments in the chemical and petroleum industry are making accurate and realistic economic analyses a necessity. Reliable optimization of economic decisions can significantly increase the value of a venture. Moreover, the possibility of competitors using improved optimization techniques forces each firm to improve its own investment appraisal techniques. The purpose of this investigation was to develop a general economic evaluation model which is an improvement over previous analysis techniques.

This model will indicate the optimum decisions for multiple investments with a comprehensive risk analysis. Significant features of the analysis technique include: (1) a general and flexible computer model which can easily be applied to a wide range of capital investment decisions, (2) the use of present value for a consistent and realistic economic evaluation criterion, (3) consideration of the future economic environment through the capability of predicting the time-dependent changes of the main variables, (4) Monte Carlo risk analysis to determine the effect of uncertainty in the 14 main variables, and (5) two-plant analysis with the advantage of a delayed decision on the second plant. The new aspect of this model is its capability of analyzing the two-plant case with a comprehensive risk analysis and with a short computer running time. Most firms are risk adverse in decisions on large capital investments. Hedging on the size of the initial plant will reduce the amount of the investment and can reduce the risk involved. The complete two-plant analysis can accurately predict the outcome of the risk adverse decision of hedging on the size of the first plant.

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VIII. APPENDIX

The Appendix includes: PAGE

TABLE VII

Results from Monte Carlo Analyses for Initial

Sales of 200 Million Pounds Per Year

Deterministic optimum:		
	first plant	586 MM LB/YR
	second plant	612 MM LB/YR
	timing factor	.656
	present value	5.28 $MM

FIRST PLANT SIZE MM LB/YR	MEAN PRESENT VALUE, ONE-PLANT ($MM)	MEAN PRESENT VALUE, TWO-PLANT ($MM)	MEAN SECOND PLANT SIZE MM LB/YR	MEAN TIMING FACTOR
286	2.86	3.91	840	.500
STD DEV	1.86	3.19	135	.017
386	4.71	5.11	891	.564
STD DEV	2.58	3.29	141	.019
486	5.84	5.85	934	.611
STD DEV	3.36	3.35	125	.021
586	6.42	6.28	947	.647
STD DEV	4.15	4.07	114	.016
686	6.49	6.32	954	.683
STD DEV	4.86	4.68	87	.015

TABLE VIII

Results from Monte Carlo Analyses for Initial

Sales of 300 Million Pounds Per Year

Deterministic optimum:	first plant	881 MM LB/YR
	second plant	953 MM LB/YR
	timing factor	.693
	present value	13.2 $MM

FIRST PLANT SIZE MM LB/YR	MEAN PRESENT VALUE, ONE-PLANT ($MM)	MEAN PRESENT VALUE, TWO-PLANT ($MM)	MEAN SECOND PLANT SIZE MM LB/YR	MEAN TIMING FACTOR
581	11.06	12.44	1131	.624
STD DEV	3.75	5.33	95	.018
681	12.45	13.20	1150	.654
STD DEV	4.57	5.60	77	.021
781	13.37	13.72	1157	.686
STD DEV	5.37	6.00	77	.021
881	13.95	13.99	1166	.711
STD DEV	6.15	6.34	79	.021
981	14.24	14.10	1155	.734
STD DEV	6.88	6.88	91	.019

TABLE IX

Results from Monte Carlo Analyses for Initial

Sales of 400 Million Pounds Per Year

Deterministic optimum:		
	first plant	1200 MM LB/YR
	second plant	1200 MM LB/YR
	timing factor	.733
	present value	21.66 $MM

FIRST PLANT SIZE MM LB/YR	MEAN PRESENT VALUE, ONE-PLANT ($MM)	MEAN PRESENT VALUE, TWO-PLANT ($MM)	MEAN SECOND PLANT SIZE MM LB/YR	MEAN TIMING FACTOR
900	19.42	20.93	1222	.710
STD DEV	5.96	7.52	55	.017
1000	20.52	21.46	1222	.731
STD DEV	6.77	7.89	53	.018
1100	21.38	21.93	1223	.750
STD DEV	7.56	8.27	48	.017
1200	21.98	22.21	1219	.765
STD DEV	8.32	8.75	49	.017
1300	21.77	21.84	1219	.779
STD DEV	9.04	9.25	51	.015

TABLE X

Results from Monte Carlo Analyses for Initial

Sales of 500 Million Pounds Per Year

Deterministic optimum:		
	first plant	1217 MM LB/YR
	second plant	1200 MM LB/YR
	timing factor	.758
	present value	29.40 $MM

FIRST PLANT SIZE MM LB/YR	MEAN PRESENT VALUE, ONE-PLANT ($MM)	MEAN PRESENT VALUE, TWO-PLANT ($MM)	MEAN SECOND PLANT SIZE MM LB/YR	MEAN TIMING FACTOR
917	22.65	26.78	1252	.730
STD DEV	5.81	9.09	79	.026
1017	24.32	27.53	1259	.740
STD DEV	6.61	9.42	79	.020
1117	25.72	28.04	1257	.755
STD DEV	7.40	9.71	76	.021
1217	26.79	28.46	1264	.764
STD DEV	8.18	10.10	81	.014
1317	27.08	28.26	1266	.779
STD DEV	8.96	10.48	80	.014

TABLE XI

Results from Monte Carlo Analyses for Initial Sales of 600 Million Pounds Per Year

Deterministic optimum:		
	first plant	1297 MM LB/YR
	second plant	1222 MM LB/YR
	timing factor	.779
	present value	36.17 $MM

FIRST PLANT SIZE MM LB/YR	MEAN PRESENT VALUE, ONE-PLANT ($MM)	MEAN PRESENT VALUE, TWO-PLANT ($MM)	MEAN SECOND PLANT SIZE MM LB/YR	MEAN TIMING FACTOR
997	27.01	33.48	1347	.754
STD DEV	6.13	10.27	220	.026
1097	29.04	34.32	1321	.768
STD DEV	6.93	10.60	184	.027
1197	30.81	35.09	1306	.776
STD DEV	7.72	10.95	144	.024
1297	31.77	35.24	1311	.781
STD DEV	8.52	11.38	148	.019
1397	32.29	35.06	1315	.786
STD DEV	9.32	11.78	154	.014

TABLE XII

Results from Monte Carlo Analyses for Initial

Sales of 700 Million Pounds Per Year

Deterministic Optimum:	first plant	1335 MM LB/YR
	second plant	1294 MM LB/YR
	timing factor	.784
	present value	42.65 $MM

FIRST PLANT SIZE MM LB/YR	MEAN PRESENT VALUE, ONE-PLANT ($MM)	MEAN PRESENT VALUE, TWO-PLANT ($MM)	MEAN SECOND PLANT SIZE MM LB/YR	MEAN TIMING FACTOR
1035	30.06	39.43	1516	.752
STD DEV	6.12	11.47	407	.038
1135	32.51	40.60	1505	.766
STD DEV	6.91	11.71	407	.038
1235	34.51	41.50	1493	.777
STD DEV	7.70	12.00	410	.038
1335	35.78	41.60	1430	.788
STD DEV	8.51	12.36	319	.027
1435	36.62	41.50	1412	.798
STD DEV	9.32	12.80	318	.029

TABLE XIII

Present Value

Distributions for One- and Two-Plant

Cases for Initial Sales of 200 MM LB/YR

1st Plant Size (MM LB/YR)	Fraction Times 2nd Plant Built	Plant Case	Mean Present Value ($MM)	20% Present Value Level ($MM)	80% Present Value Level ($MM)
286	0.66	1	2.86	0.7	4.4
		2	3.91	0.6	6.3
386	0.54	1	4.71	1.1	6.7
		2	5.11	1.1	7.7
486	0.41	1	5.84	1.5	8.7
		2	5.86	1.5	9.0
586	0.33	1	6.43	2.4	10.0
		2	6.28	2.4	9.9
686	0.22	1	6.50	2.0	10.7
		2	6.32	2.0	10.5

TABLE XIV

Present Value

Distributions for One- and Two-Plant

Cases for Initial Sales of 300 MM LB/YR

1st Plant Size (MM LB/YR)	Fraction Times 2nd Plant Built	Plant Case	Mean Present Value ($MM)	20% Present Value Level ($MM)	80% Present Value Level ($MM)
581	.690	1	11.06	6.9	14.0
		2	12.44	6.9	16.4
681	.620	1	12.40	7.7	16.2
		2	13.20	7.7	18.0
781	.530	1	13.37	7.9	18.0
		2	13.73	7.9	19.4
881	.450	1	13.96	7.8	19.2
		2	13.99	7.8	19.8
981	.400	1	14.24	7.7	20.2
		2	14.11	7.7	20.3

TABLE XV

Present Value

Distributions for One- and Two-Plant

Cases for Initial Sales of 400 MM LB/YR

1st Plant Size (MM LB/YR)	Fraction Times 2nd Plant Built	Plant Case	Mean Present Value ($MM)	20% Present Value Level ($MM)	80% Present Value Level ($MM)
900	.750	1	18.7	13.0	23.4
		2	20.2	13.0	27.0
1000	.596	1	19.76	13.0	25.4
		2	20.75	13.0	27.5
1100	.554	1	20.51	13.1	26.8
		2	21.15	13.1	28.0
1200	.500	1	21.03	13.0	28.0
		2	21.39	13.0	28.8
1300	.436	1	20.74	12.0	28.0
		2	20.93	12.0	28.6

TABLE XVI

Present Value

Distributions for One- and Two-Plant

Cases for Initial Sales of 500 MM LB/YR

1st Plant Size (MM LB/YR)	Fraction Times 2nd Plant Built	Plant Case	Mean Present Value ($MM)	20% Present Value Level ($MM)	80% Present Value Level ($MM)
917	.862	1	22.66	17.0	27.0
		2	26.79	18.0	33.5
1017	.796	1	24.32	17.0	29.4
		2	27.53	18.0	35.0
1117	.748	1	25.72	18.4	31.5
		2	28.05	18.8	36.0
1217	.694	1	26.79	19.0	33.0
		2	28.46	19.0	36.7
1317	.632	1	27.08	18.7	34.0
		2	28.26	18.7	36.7

TABLE XVII

Present Value

Distributions for One- and Two-Plant

Cases for Initial Sales of 600 MM LB/YR

1st Plant Size (MM LB/YR)	Fraction Times 2nd Plant Built	Plant Case	Mean Present Value ($MM)	20% Present Value Level ($MM)	80% Present Value Level ($MM)
997	.930	1	27.01	20.8	31.5
		2	33.48	23.3	41.0
1097	.904	1	29.04	22.0	34.0
		2	34.32	24.0	42.0
1197	.868	1	30.82	23.0	36.8
		2	35.09	24.0	43.3
1297	.826	1	31.77	23.2	38.7
		2	35.24	24.0	44.0
1397	.774	1	32.30	23.0	39.5
		2	35.06	23.8	44.5

TABLE XVIII

Present Value

Distributions for One- and Two-Plant

Cases for Initial Sales of 700 MM LB/YR

1st Plant Size (MM LB/YR)	Fraction Times 2nd Plant Built	Plant Case	Mean Present Value ($MM)	20% Present Value Level ($MM)	80% Present Value Level ($MM)
1035	.956	1	30.1	23.5	34.5
		2	39.4	28.0	47.5
1135	.946	1	32.5	25.0	38.0
		2	40.6	29.0	49.0
1235	.939	1	34.5	26.5	40.0
		2	41.5	30.0	50.0
1335	.912	1	35.8	27.5	42.0
		2	41.6	30.0	50.0
1435	.882	1	36.6	27.5	43.5
		2	41.5	29.5	51.0

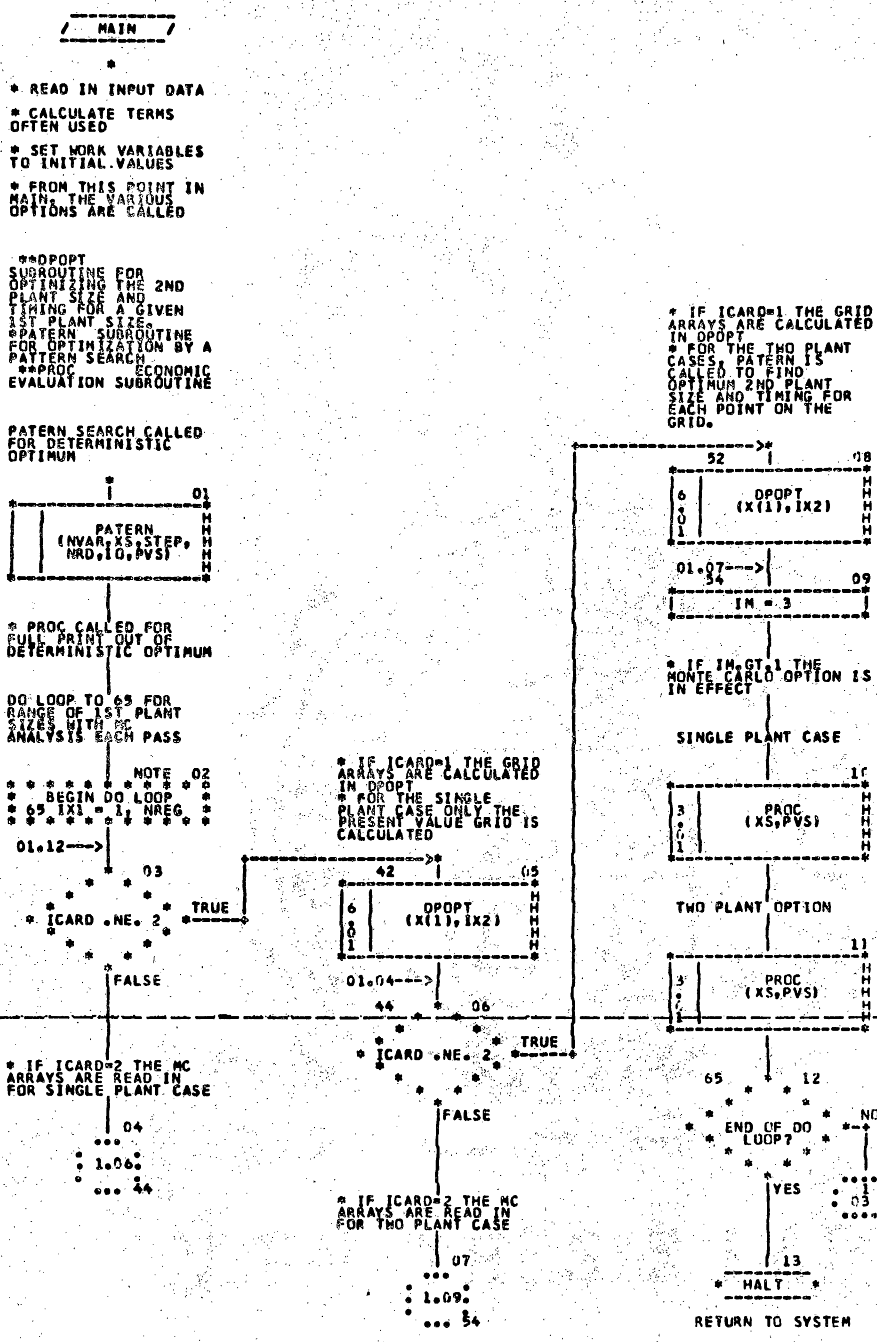

Figure 2. Basic Flow Diagram for MAIN Program and for Solution Technique

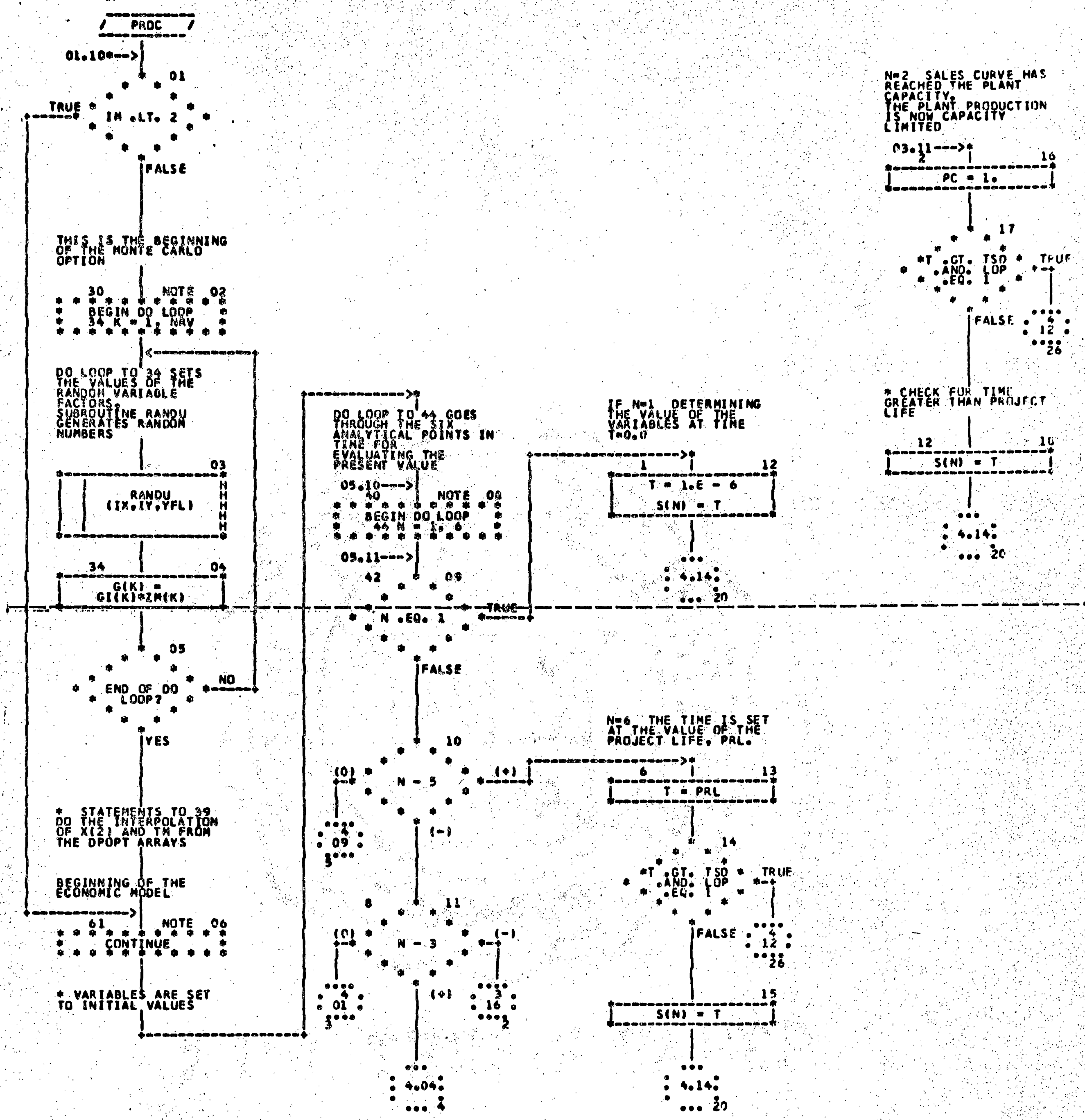

Figure 3. Flow Diagram for Economic Evaluation Subroutine (first part of three)

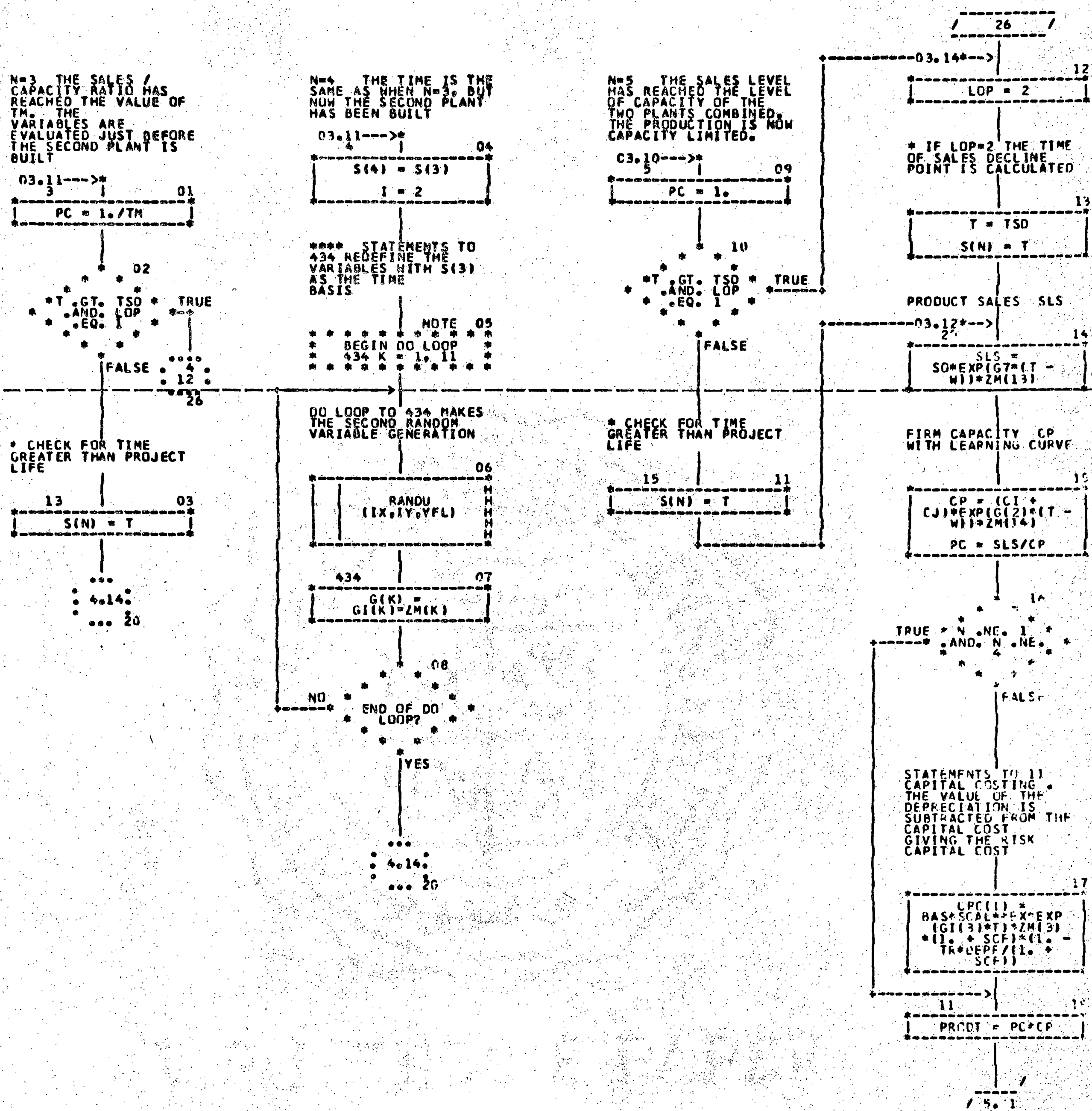

Figure 4. Flow Diagram for Economic Evaluation Subroutine (second part of three)

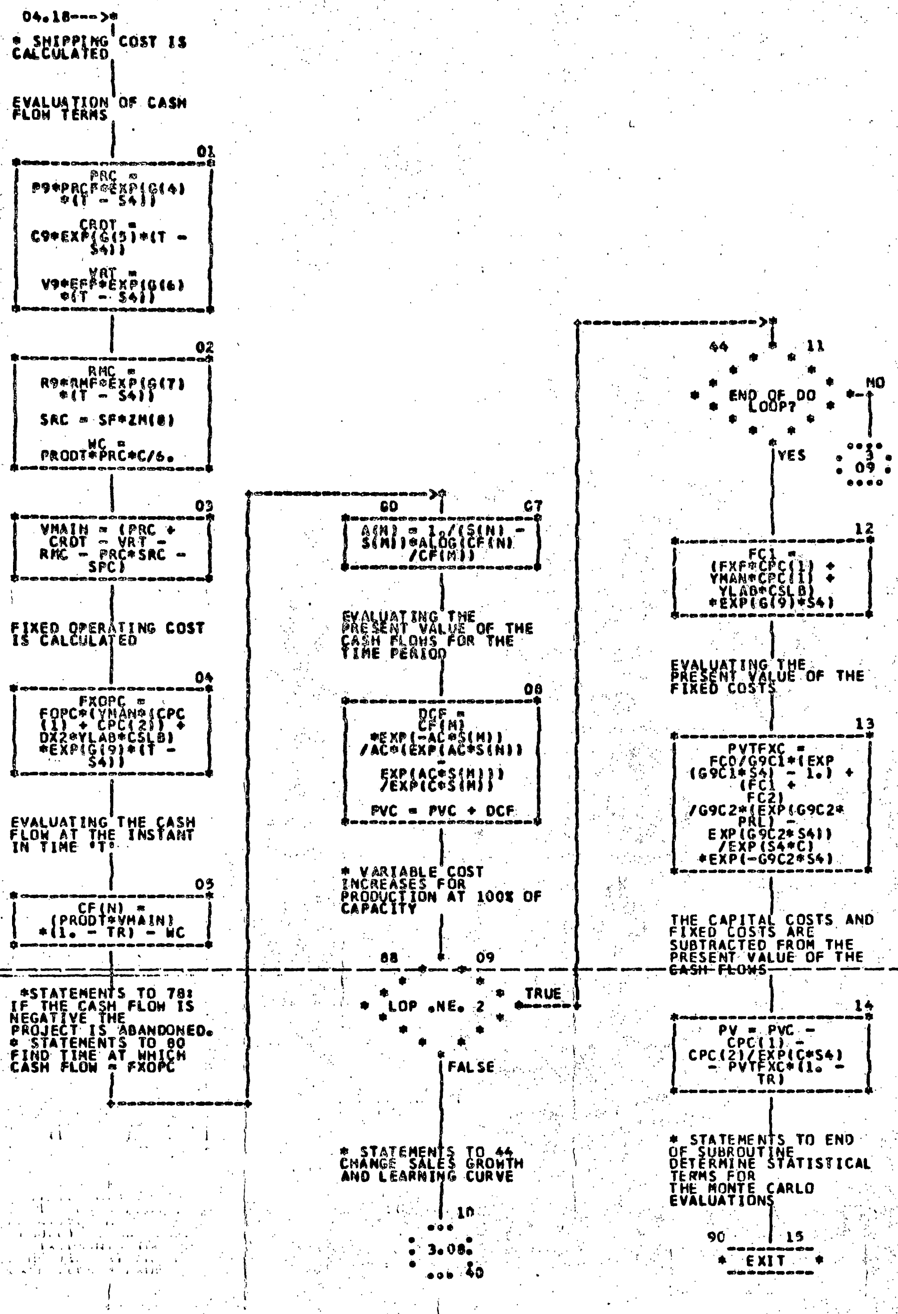

Figure 5. Flow Diagram for Economic Evaluation Subroutine (third part of three)

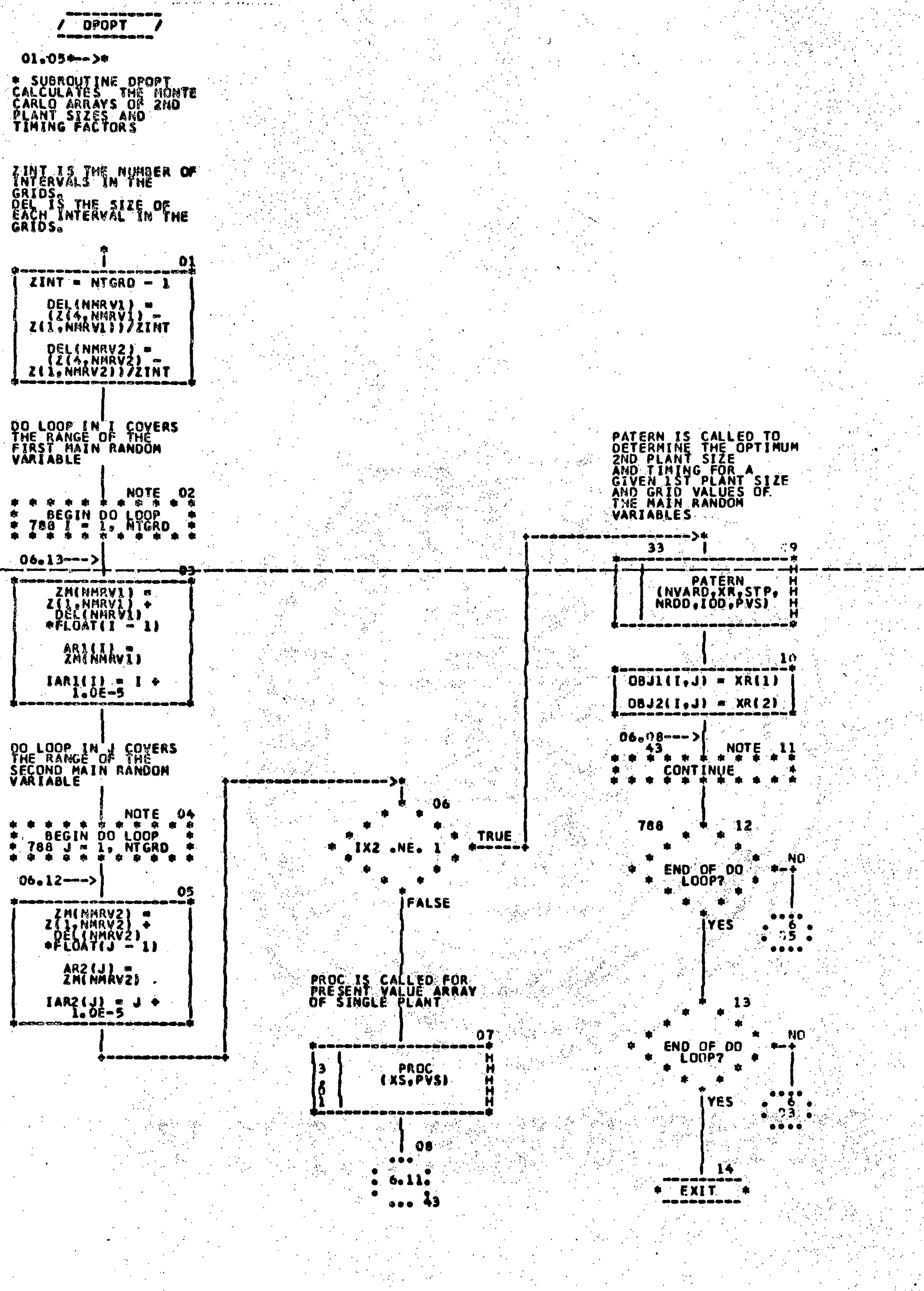

Figure 6. Flow Diagram for Subroutine DPOPT

```
C
C     COMPUTER PROGRAM FOR MONTE CARLO RISK ANALYSIS OF A CAPITAL
C     INVESTMENT VENTURE IN A TIME DEPENDENT ENVIRONMENT. AN OPTION
C     OF ONE OR TWO PLANTS IS INCLUDED.
C
C        MAIN PROGRAM
C
C
C    IN THE MAIN PROGRAM THE INPUT VARIABLES ARE READ IN. ALSO THE
C   OPTIONS DESIRED ARE SPECIFIED.
C
C
C***********************************************************************
C    DPOPT    SUBROUTINE CALCULATES ARRAYS TO OPTIMIZE X(2) AND TM
C            WITH THE SALES AND SELLING PRICE CURVES GIVEN
C    ICARD    SPECIFIES INPUT OF ARRAYS FOR SELECTING X(2) IN MONTE CARLO
C             ICARD=1   INPUT FROM SUBROUTINE DPOPT
C             ICARD=2   INPUT FROM CARDS
C    IOD     OUTPUT PARAMETER FOR PATERN CALLED FROM SUBROUTINE DPOPT
C    ISPC    IF ISPC=2, SINGLE PLANT CASE IS IN EFFECT
C    JIX2    INDICATES WHETHER THE SINGLE PLANT ARRAY IS AVAILABLE
C            JIX2=1  ARRAY NOT AVAILABLE
C            JIX2=2  ARRAY IS AVAILABLE
C    NMRV1   NUMBER OF THE FIRST MAIN RANDOM VARIABLE
C    NMRV2   THE NUMBER OF THE SECOND MAIN RANDOM VARIABLE
C    NRDD    NUMBER OF STEP SIZE REDUCTIONS IN SUBROUTINE DPOPT
C    NREG    NUMBER OF DIFFERENT VALUES OF X(1)
C    NSI     NUMBER OF DIFFERENT LEVELS OF INITIAL SALES
C    NVARD   NUMBER OF VARIABLES IN PATERN CALLED FROM SUBROUTINE DPOPT
C    PATERN   NAME OF THE SUBROUTINE WHICH CONDUCTS THE PATTERN SEARCH
C            ARGUMENT LIST INCLUDES  NVAR,XS,STEP,NRD,IO,PVS
C    NVAR   THE NUMBER OF VARIABLES FOR THE PATTERN SEARCH
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C   XS    AN ARRAY OF THE INDEPENDENT VARIABLES FOR THE PATTERN SEARCH   MAI  330
            THE ARRAY VALUES MUST BE SCALED                              MAI  331
C   STEP  AN ARRAY OF INITIAL  STEP SIZES                                MAI  340
C   NRD    NUMBER OF TIMES THE STEP LENGTH IS REDUCED IN PATTERN SEARCH  MAI  350
C   IO     THE TYPE OF PRINTED OUTPUT FROM THE PATTERN SEARCH            MAI  360
C   PROC    THE NAME GIVEN THE ECONOMIC MODEL SUBROUTINE                 MAI  370
C          CALLING ARGUMENTS  XS AND THE PRESENT VALUE, PVS              MAI  380
C                                                                        MAI  390
C************************************************************************MAI  400
C                                                                        MAI  410
C******** INPUT VARIABLES  ********************************************* MAI  420
C                                                                        MAI  430
C                                                                        MAI  440
C   IM    VARIABLE INDICATING WHETHER THE MONTE CARLO WILL BE USED       MAI  450
C         IM=1  MONTE CARLO TECHNIQUE WILL NOT BE USED                   MAI  460
C         IM=2 MONTE CARLO WILL BE USED WITH ONE RANDOM NUMBER GENERATIONMAI  470
C         IM=3 MONTE CARLO WILL BE USED WITH TWO RANDOM NUMBER GENERATIONMAI  471
C   IPRINT  A CONTROL NUMBER FOR OUTPUT FROM THE PROGRAM                 MAI  480
C            IPRINT = 1 NO PRINTED OUTPUT FROM THE ECONOMIC SUBROUTINE   MAI  490
C            IPRINT = 2 PV,X(2),TM  OUTPUT ONLY                          MAI  500
C            IPRINT = 3 SAME AS 2 WITH OUTPUT AT EACH VALUE OF N         MAI  510
C            IPRINT = 4 COMPLETE OUTPUT.  APPROX 25 LINES PER CASE.      MAI  520
C            IPRINT = 5  EXCEPTION OUTPUTS ONLY, USE WITH                MAI  530
C                      PATERN OR MONTE CARLO.                            MAI  540
C   ITIMES THE NUMBER OF TIMES THE ECONOMIC MODEL WILL BE LOOPED         MAI  550
C        THROUGH FOR THE MONTE CARLO EVALUATION                          MAI  560
C   J    INDICATES THE FINAL PRODUCT BEING CONSIDERED                    MAI  570
C        J=1  ETHYLENE                                                   MAI  580
C   JPRNI , JPRN3 , JPRN4  OUTPUT CONTROL NUMBERS FOR THE                MAI  590
C              NUMBER TIMES AN EXCEPTION OUTPUT WILL BE PRINTED.         MAI  600
C   NRV  NUMBER OF RANDOM VARIABLES                                      MAI  610
C   NTECON  NUMBER OF TIMES THE ECONOMIC SUBROUTINE IS CALLED            MAI  620
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C
C
C*********************************************************************
C
C
C    AR1     AN ARRAY OF ZM(NMRV1)
C    AR2     AN ARRAY OF ZM(NMRV2)
C    AS    LOWER VALUE OF THE SCALE-UP EXPONENT
C    BAS   THE BASE COST FOR CAPITAL COSTING BY SCALE-UP   DOLLARS
C    BE    THE LEVEL OF PRODUCTION (AS FRACTION OF CAPACITY) AT
C          WHICH THE VARIABLE COST BEGINS TO INCREASE
C    BS    UPPER VALUE OF THE SCALE-UP EXPONENT
C    C     THE COST OF CAPITAL WITH CONTINUOUS DISCOUNTING  FRACTION/YR
C    CGR   THE TOTAL INDUSTRY CAPACITY GROWTH RATE
C    CHCKZ  A CHECK ARRAY FOR THE PROBABILITY DISTRIBUTIONS AROUND
C            EACH OF THE RANDOM VARIABLES.  THE VALUE OF CHCKZ FOR
C            EACH VARIABLE SHOULD BE 1.00
C    CO    THE COST OF CAPITAL WITH COMPOUNDING ANNUALLY   FRACTION/YR
C    CPBS   THE BASE CAPACITY FOR CAPITAL COSTING    LBS/YR
C    CP9   THE TOTAL INDUSTRY CAPACITY IN 1969      LBS/YR
C    CR9   BY-PRODUCT CREDIT (1969)      DOL/LB
C    CS    THE MULTIPLE OF THE BASE CAPACITY AT WHICH THE EXPONENT
C          BEGINS TO INCREASE
C    CSLB    COST OF LABOR    DOL/MAN-YR
C    DEL     SIZE OF INTERVAL FOR X(1)   LBS/YR
C    DEPF   DEPRECIATION FACTOR.  THE PRESENT VALUE OF THE DEPRECIATION
C           FROM A GIVEN PLANT. FRACTION OF CAPITAL COST AT THE TIME
C           OF THE PLANT COMPLETION
C    DLE   SIZE OF INTERVAL FOR INITIAL SALES  LBS/YR
C    DM9   THE TOTAL INDUSTRY DEMAND IN 1969    LBS/YR
C    DS    THE MULTIPLE OF THE BASE CAPACITY AT WHICH THE EXPONENT
C          LEVELS OUT TO THE VALUE OF 'BS'
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C    EFFI  EFFICIENCY FOR PRODUCTION AT 100% OF CAPACITY.
C           EFFI IS GREATER THAN 1.0 TO INDICATE A DECREASE IN
C           OPERATING EFFICIENCY AT HIGH LEVELS OF PRODUCTION.
C    FE    A MULTIPLIER FACTOR FOR THE INCREASE IN VARIABLE COST
C    FXF    THE FIXED COST FACTOR BASED ON CAPACITY. (1969)  DOL/LB CAP
C    G     AN ARRAY OF GROWTH VALUES    FRACTION/YR
C    GI    INPUT ARRAY OF GROWTH FACTORS CORRESPONDING TO THE
C           RANDOM VARIABLE WITH SAME SUBSCRIPT.  EXCEPTION..
C           GI(11) IS THE SALES GROWTH AFTER THE TIME OF SALES
C            DECLINE ( TSD ).    FRACTION/YR
C    GR     THE GROWTH RATE FOR THE TOTAL INDUSTRY DEMAND FRACTION/YR
C    IAR1, IAR2  ARRAYS OF INTERVAL NUMBERS FOR THE ARRAYS OF DPOPT
C    ISPC    PARAMETER TO INDICATE SINGLE PLANT CASE
C            ISPC=2  SINGLE PLANT CASE IS IN EFFECT
C            ISPC NOT EQUAL TO 2  TWO PLANT CASE IN EFFECT
C    NA    THE PLANT DEPRECIATION LIFE   YEARS
C    OBJ1    AN ARRAY OF SECOND PLANT SIZES FROM DPOPT
C    OBJ2    AN ARRAY OE TM VALUES FROM DPOPT
C    PRLI   EXPECTED PROJECT LIFE   YEARS
C    PR9   THE FINAL PRODUCT SELLING PRICE IN 1969   DOL/LB
C    PVAL    ARRAY OF PRESENT VALUES FOR TWO PLANT CASE.  IF PVAL IS
C            LESS THAN PVALO, THEN THE SECOND PLANT IS NOT BUILT.  DOL
C    PVALO   ARRAY OF PRESENT VALUES FOR SINGLE PLANT CASE    DOLLARS
C    PSV     NET PRESENT VALUE   IN 10.**6 DOLLARS
C    REG     TOTAL SPAN OF VALUES OF X(1)  IN 10.**9 LB/YR
C    RMF   RAW MATERIAL CONVERSION FACTOR.   LB RAW MATL / LB PRODUCT
C    RM9   RAW MATERIAL COST (1969)  DOL/LB
C    SCF   THE START-UP COST FACTOR.  FRACTION OF CAPITAL COST
C    SF     SALES, RESEARCH, AND ADMINISTRATION COST FACTOR   FRACTION
C           OF PRICE
C    SHC   THE BASE VALUE FOR SHIPPING COST   DOL/LB
C    SHD    A MULTIPLIER FACTOR FOR THE INCREASE OF SHIPPING COSTS
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C   SI    THE INITIAL FIRM SALES           LB/YR                                  MAI 1270
C   SIBAS  FIRST VALUE OF INITIAL SALES       LBS/YR                              MAI 1280
C   SIREG   TOTAL SPAN OF INITIAL SALES     LBS/YR                                MAI 1290
C   STP     ARRAY OF INITIAL STEP SIZES FOR PATERN IN SUBROUTINE DPOPT            MAI 1300
C   TMO     THE VALUE OF TM FOR CASES WHEN THE SECOND PLANT IS NOT BUILT          MAI 1310
C   TR    THE INCOME TAX RATE      FRACTION                                       MAI 1320
C   TSDI   THE YEAR IN WHICH THE GROWTH OF THE FIRM SALES CURVE DECLINES          MAI 1330
C   VL     THE PRODUCTION VOLUME ABOVE WHICH THE SHIPPING COST FACTOR             MAI 1340
C          BEGINS TO INCREASE DUE TO A FARTHER AVERAGE SHIPPING DISTANCE          MAI 1350
C   VR9   THE VARIABLE COST FACTOR (1969)          DOL/LB PRODUCT                 MAI 1370
C   XMAXT   THE LATEST TIME AT WHICH THE SECOND PLANT MAY BE BUILT.               MAI 1380
C   XMPM   THE MINIMUM PRICE MARGIN BELOW WHICH THE                               MAI 1390
C          SECOND PLANT WILL NOT BE BUILT.  DOL/LB                                MAI 1400
C   XLIM AN ARRAY OF 3 VALUES FOR THE CDF CALCULATION FOR PRESENT VALUE           MAI 1410
C        XLIM(1)  LOWER LIMIT OF PRESENT VALUE    DOLLARS                         MAI 1420
C        XLIM(2) NUMBER OF INTERVALS FOR CDF PRESENTATION                         MAI 1430
C        XLIM(3) UPPER LIMIT OF PRESENT VALUE     DOLLARS                         MAI 1440
C   XR10    INITIAL VALUE OF XR(1) FOR PATERN IN SUBROUTINE DPOPT                 MAI 1450
C   XR20    INITIAL VALUE OF XR(2) FOR PATERN IN SUBROUTINE DPOPT                 MAI 1460
C   XSBAS  FIRST VALUE OF X(1)     LBS/YR                                         MAI 1470
C   YLAB  LABOR COST    MEN PER SHIFT                                             MAI 1480
C   YLIM AN ARRAY OF 3 VALUES FOR THE CDF CALCULATION FOR 2ND PLANT SIZEMAI 1490
C   YMAN  MAINTENANCE COST.   EXPRESSED AS FRACTION OF CAPITAL COST.              MAI 1500
C   ZLIM AN ARRAY OF 3 VALUES FOR THE CDF CALCULATION FOR TIMING FACTOR           MAI 1510
C   ZM    AN ARRAY OF THE RANDOM VARIABLE FACTORS                                 MAI 1520
C   ZNR     NUMBER OF INTERVALS OF X(1)                                           MAI 1530
C   ZSI     NUMBER OF INTERVALS OF INITIAL SALES                                  MAI 1540
C                                                                                 MAI 1550
C                                                                                 MAI 1560
C*************************************************************************MAI 1570
C                                                                                 MAI 1580
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C         MAIN PROGRAM
C
      REAL*4 IAR1, IAR2
      COMMON/BLOC1/     J,NA,IV,IM,          X(2),TM,VP,C ,TR,BAS,CPBS,
     1 CP9,DM9,PR9,   FXF,VR9,RMF,   RM9,GI(15),   AS,BS,CS,DS,BE,FE,
     2  SCF,SHC,CR9,       SI,SF,VL ,G(15)  ,DEPF,TSDI, PRLI,  CSLB,
     3 XNA,SHD,GR,CGR,    SBA,  ITIMES,XLIM(3),NPRIN2,NPRIN3,NPRIN4,
     4 GD,CG,ISPC,   EFFI,NRV,XMPM,YMAN,YLAB,XMAXT,   JPRN2,JPRN3,JPRN4 ,
     5 YLIM(3), ZLIM(3)  ,JPRN5, NPRIN5, ISING ,X2MIN  , NTECON
      COMMON/BLOC5/PVALO(11,11),PVAL(11,11),OBJ1(11,11),OBJ2(11,11),
     1 Z(6,15),AR1(11),AR2(11),IAR1(11),IAR2(11), ZM(15),IDP,JDP,NTGRD,
     2 NCDF, NMRV1, NMRV2, JIX2, NVARD, NRDD, IOD, STP(3),TMO,XR10,XR20,
     3 IPRINT
      DIMENSION ARAX(51), ARAPV(51)
      DIMENSION  XS(3), STEP(3), CHCKZ(15)
  888 FORMAT(2X,I5)
  101 FORMAT(15X,E14.7)
  111 FORMAT(2X,G8.3,5G10.3)
  215 FORMAT(1X,15F8.3)
  301 FORMAT(11G7.3)
  303 FORMAT(3G10.5)
  306 FORMAT(3I8,3G10.5)
  309 FORMAT(9G8.1)
  313 FORMAT(2X,13F6.3)
  315 FORMAT(2I5,E12.5, I5,F10.5,I5)
  317 FORMAT(5I5,3F10.4)
  327 FORMAT(10I5)
  329 FORMAT(8I10)
  413 FORMAT(/'  **  THE INITIAL LEVEL OF SALES IS ', E12.5,' LB/YR' / )
  605 FORMAT(1X,I2,9X,6F8.2)
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606 FORMAT(1X,I2,6X,F7.3,5F11.3)                                        MAI 1890
607 FORMAT(4X,'J'6X,'NA',6X,'NRV',3X,'ITIMES',4X,'IM',5X,'IPRINT',2X,  MAI 1900
   1  'IPAT',3X,'JPRN2',3X,' JPRN3',4X,' JPRN4' / I5,9I8 // )           MAI 1910
609 FORMAT('  NVAR  NRD  IO XS(1) XS(2) XS(3)         ' /3I5,3F6.3//   )MAI 1920
611 FORMAT(4X,'IDP',7X,'JDP',6X,'JPRN5',6X,  'NCDF',5X,'NMRV1',         MAI 1930
   1  5X,'NMRV2',5X,  'NTGRD',5X,'ISING'  /   I6,7I10 // )              MAI 1940
613 FORMAT(18X,'XLIM', 16X,'YLIM', 16X,'ZLIM' / 1X,7E9.2,2E8.1  //   ) MAI 1950
615 FORMAT(5X,'ICARD',4X,'NSI',  6X,'SIREG',9X,'NREG',  6X,'REG',       MAI 1960
   110X,'ISPC'  /2I8,4X, E12.5,I8,2X,E12.5, I10  //  )                  MAI 1970
617  FORMAT(6X,'NRDD',6X,  'IOD',5X,'NVARD',  5X,'JIX2',5X,'IDP',       MAI 1980
   1  4X,'TMO',6X,'XR10', 5X,'XR20' / 5I9, 3F9.4 //  )                  MAI 1990
626 FORMAT( ' VAR. NO.',4X,'Z1', 10X, 'Z2',10X,   'Z3',10X,'Z4',        MAI 2000
   1 10X,'Z5',10X,'Z6'     /  )                                         MAI 2010
666 FORMAT('  ****  VALUES OF INPUT VARIABLES    **********************MAI 2020
   1******************'  /)                                             MAI 2030
700 FORMAT(5X,'I',4X,'J', 3X,'ZM(',I2,')', 4X,'ZM(',I2,')', 5X,'XS(1)'MAI 2040
   1,5X,'XS(2)', 5X,'XS(3)',  3X,'PRES VAL'       )                     MAI 2050
702 FORMAT(/' ECONOMIC EVALUATION OF A SINGLE PLANT FOR THE RANGE OF  MAI 2060
   1THE MAIN VARIABLES' /)                                              MAI 2070
704 FORMAT(/' THE PATTERN SEARCH OPTIMIZATION OF 2ND PLANT SIZE AND TIMAI 2080
   1MING ' /)                                                           MAI 2090
706 FORMAT(1X,2F5.0,6F10.5)                                             MAI 2100
716 FORMAT(2X,2F2.0, 5F6.3,F9.4)                                        MAI 2110
801 FORMAT(/////  '  A COMPLETE PRINT OUT OF THE CASE WITH OPTIMUM PARMAI 2120
   1AMETERS  '  //  )                                                   MAI 2130
810 FORMAT(5X,'AS',7X,'BAS',  8X,'BE',8X,'BS', 7X,'CGR',8X,'CO',        MAI 2140
   1 6X,'CPBS',7X,'CP9' / 2X,8E10.3  // )                               MAI 2150
812 FORMAT(5X,'CR9', 8X,'CS',7X,'DM9',  8X,'DS',6X,'EFFI', 8X,'FE',     MAI 2160
   1  7X,'FXF', 8X,'GR' / 2X,8E10.3  // )                               MAI 2170
814 FORMAT(5X,'PRLI', 7X,'PR9', 7X,'RMF', 7X,'RM9', 7X,'SCF',          MAI 2180
   1 8X,'SF',7X,'SHC' 7X,'SHD' / 2X,8E10.3 // )                         MAI 2190
816 FORMAT(5X,'SI', 8X,'TR', 6X,'TSDI',8X,'VL', 7X,'VR9', 6X,          MAI 2200
```

```
     1 'XMAXT', 6X,'XMPM', 7X,'YLAB' / 2X,8E10.3  // )
 818 FORMAT(4X, 'GI(1)',5X,'GI(2)',5X,'GI(3)',5X,'GI(4)', 5X,'GI(5)',
     1  5X,'GI(6)', 5X,'GI(7)', 5X,'GI(8)' / 2X,8E10.3  //)
 820 FORMAT(4X,'GI(9)',5X,'GI(10)', 4X,'GI(11)', 4X,'GI(12)', 4X,
     1  'GI(13)',  4X, 'GI(14)',4X,'GI(15)' / 2X,7E10.3 // )
 827 FORMAT(//' ***  NUMBER OF TIMES THE ECONOMIC SUBROUTINE WAS CALLED
     1 EQUALS',I6 /)
      READ(5,327) J,NA,NRV,ITIMES,  IM,IPRINT,IPAT ,JPRN2,JPRN3,JPRN4
      READ(5,329)  IDP,JDP,JPRN5,NCDF,  NMRV1,NMRV2,NTGRD  ,ISING
      READ(5,309)  XLIM,YLIM,ZLIM
      READ(5,306)  NVAR,NRD,IO,XS
      READ(5,315)  ICARD,NSI, SIREG,NREG, REG,ISPC
      READ(5,317)  NRDD,IOD, NVARD,JIX2, IDP,TMO, XR1O,XR2O
      READ(5,301) BAS,CPBS,GR,CP9,  DM9,CGR,PR9, FXF,VR9,RMF,RM9
      READ(5,301) AS,BS,CS,DS,BE,FE,   CO,TR,SCF,SHC,CR9
      READ(5,301) PRLI,SI,SF,VL,SHD,   TSDI,XMAXT,XMPM,YMAN, YLAB,EFFI
      READ(5,313) GI

C***********   INPUT CHANGES   ****************************************
C
C
C*********************************************************************
      XNA=NA
      NRVC=NRV+1
      WRITE(6,666)
      WRITE(6,607)J,NA,NRV,ITIMES,  IM,IPRINT,IPAT ,JPRN2,JPRN3,JPRN4
      WRITE(6,611) IDP,JDP,JPRN5,NCDF,  NMRV1,NMRV2,NTGRD  ,ISING
      WRITE(6,613)  XLIM,YLIM,ZLIM
      WRITE(6,609) NVAR,NRD,IO,XS
      WRITE(6,615) ICARD,NSI, SIREG,NREG, REG,ISPC
      WRITE(6,617) NRDD,IOD, NVARD,JIX2, IDP,TMO, XR1O,XR2O
      WRITE(6,810)  AS,BAS,BE,  BS,CGR,CO,  CPBS,CP9
```

```
      WRITE(6,812)  CR9,CS, DM9,DS, EFFI,FE, FXF,GR
      WRITE(6,814)  PRLI,PR9, RMF, RM9,SCF, SF,SHC, SHD
      WRITE(6,816)  SI,TR, TSDI,VL, VR9,XMAXT, XMPM,YLAB
      WRITE(6,818)  GI(1),GI(2), GI(3),GI(4), GI(5),GI(6), GI(7),GI(8)
      WRITE(6,820) GI(9),GI(10), GI(11),GI(12), GI(13),GI(14),GI(15)
      DO 23 K=1,NRVC
      ZM(K)=1.0
   23 G(K)= GI(K)*ZM(K)
      WRITE(6,626)
      DO 36 K=1,NRV
      READ(5,111) Z(1,K), Z(2,K), Z(3,K),Z(4,K),Z(5,K), Z(6,K)
      CHCKZ(K)  = Z(5,K)*0.5*(Z(1,K)+Z(2,K))  +  (Z(6,K)-Z(5,K))
     1 *0.5*(Z(2,K)+Z(3,K))  +  (1.-Z(6,K))*0.5*(Z(3,K)+Z(4,K))
   36 WRITE(6,606) K,Z(1,K),  Z(2,K),Z(3,K),  Z(4,K),Z(5,K),  Z(6,K)
      WRITE(6,215)CHCKZ
      C= EXP(CO) -1.
      X(1) = XS(3) * 1.0E9
      DEPF = 2./(XNA*(XNA+1.)) * ( (XNA+1.)/C *(1.-EXP(-C*XNA))    +
     1  (C*XNA+1.)/(C*C) *EXP(-C*XNA)  -  1./(C*C)  )
      WRITE(6,101)  DEPF
      SBA= (BS-AS) / (DS-CS)
      ZSI=NSI-1
      DLE=SIREG/ZSI
      SIBAS=SI-0.5*ZSI*DLE
      ZNR=NREG-1
      DEL=REG/ZNR
      NTECON=0
      DO 38 IZ=1,NVAR
      STEP(IZ)=0.1
      STP(IZ)=0.1
   38 CONTINUE
```

```
C
C** FROM THIS POINT IN THE MAIN PROGRAM, THE VARIOUS OPTIONS ARE CALLED
C
      IPRINT=2
      IPRINT=3
      IPRINT=4
      IPRINT=1
C*** THE VALUE OF THE INITIAL SALES LEVEL IS SET
      DO 65 ISI=1,NSI
      SI=SIBAS+DLE*FLOAT(ISI-1)
      WRITE(6,413)  SI
      XS(1)=0.852
      XS(2)=0.764
      XS(3)=0.790
      IM=1
      IO=4
C*** THE DETERMINISTIC OPTIMUM IS FOUND
      CALL PATERN(NVAR,XS,STEP,NRD,IO,PVS)
      X(1) = XS(3) * 1.0E9
      IPRINT=4
      CALL PROC(XS,PVS)
      IPRINT=1
      XSBAS=XS(3)-(ZNR-1.)*DEL
C***  FIRST PLANT SIZE IS CHOSEN
      DO 55 IX1=1,NREG
      XS(3)=XSBAS+DEL*FLOAT(IX1-1)
      X(1)=XS(3)*1.E9
      IM=1
      ICARD=2
      ICARD=1
C** PRESENT VALUE GRID FOR SINGLE PLANT CASE IS EVALUATED IN
```

```
C     DPOPT OR READ IN ON CARDS                                        MAI 3140
      IF(ICARD.NE.2)  GO TO 42                                         MAI 3150
      WRITE(6,702)                                                     MAI 3160
      WRITE(6,700)  NMRV1, NMRV2                                       MAI 3170
      DO 40 M=1,NTGRD                                                  MAI 3180
      DO 40 N=1,NTGRD                                                  MAI 3190
      READ(5,716) IAR1(M),IAR2(N),AR1(M),AR2(N),OBJ1(M,N),OBJ2(M,N),   MAI 3200
     1 XS(3), PSV                                                      MAI 3210
      PVALO(M,N)=PSV*1.E6                                              MAI 3220
      WRITE(6,706)IAR1(M),IAR2(N),AR1(M),AR2(N),OBJ1(M,N),OBJ2(M,N),   MAI 3230
     1 XS(3), PSV                                                      MAI 3240
   40 CONTINUE                                                         MAI 3250
      GO TO 44                                                         MAI 3260
   42 CONTINUE                                                         MAI 3270
      IX2=1                                                            MAI 3280
      CALL DPOPT(X(1),IX2)                                             MAI 3290
   44 CONTINUE                                                         MAI 3300
      ICARD=2                                                          MAI 3310
      ICARD=1                                                          MAI 3320
C***  PRESENT VALUE, SECOND PLANT SIZE, AND TIMING FACTOR GRIDS ARE     MAI 3330
C     EVALUATED IN DPOPT OR READ IN ON CARDS                           MAI 3340
      IF(ICARD.NE.2)  GO TO 52                                         MAI 3350
      WRITE(6,704)                                                     MAI 3360
      WRITE(6,700)  NMRV1, NMRV2                                       MAI 3370
      DO 50 M=1,NTGRD                                                  MAI 3380
      DO 50 N=1,NTGRD                                                  MAI 3390
      READ(5,716) IAR1(M),IAR2(N),AR1(M),AR2(N),OBJ1(M,N),OBJ2(M,N),   MAI 3400
     1 XS(3), PSV                                                      MAI 3410
      PVAL(M,N)=PSV*1.E6                                               MAI 3420
      WRITE(6,706)IAR1(M),IAR2(N),AR1(M),AR2(N),OBJ1(M,N),OBJ2(M,N),   MAI 3430
     1 XS(3), PSV                                                      MAI 3440
   50 CONTINUE                                                         MAI 3450
```

```
      GO TO 54
   52 CONTINUE
      IX2=2
      CALL DPOPT(X(1),IX2)
   54 CONTINUE
      IM=2
      IM=3
C***  MONTE CARLO ANALYSIS FOR SINGLE PLANT CASE
      ISPC=2
      CALL PROC(XS,PVS)
      ISPC=1
C***  MONTE CARLO ANALYSIS FOR TWO PLANT CASE
      CALL PROC(XS,PVS)
      IM=1
   55 CONTINUE
   65 CONTINUE
      WRITE(6,827)  NTECON
      END
```

```
C
C
C       PROC    ECONOMIC SUBROUTINE
C
C*************************************************************************
C*************************************************************************
C
C**************   VARIABLES   ********************************************
C
C   A      A WORK ARRAY FOR EVALUATING THE PRESENT VALUES
C   CDF    CUMULATIVE DISTRIBUTION FUNCTION
C   CF     AN ARRAY OF THE POINT VALUES OF CASH FLOWS FOR EACH TIME 'T'
C   CFC     AN ARRAY OF THE NINE POINT-VALUES OF THE CASH FLOW.
C   CI     INITIAL PLANT CAPACITY    LBS/YR
C   CJ     INITIAL CAPACITY OF THE SECOND PLANT   LBS/YR
C   CPC    ARRAY OF RISK CAPITAL FOR EACH PLANT   DOLLARS
C   CRDT   BY-PRODUCT CREDIT    DOL/LB
C   C9      WORK TERM FOR BY-PRODUCT CREDIT
C   DCF     THE DISCOUNTED CASH FLOW  TO TIME ZERO    DOLLARS
C   DM     TOTAL INDUSTRY DEMAND   LBS/YR
C   EFF    EFFICIENCY TERM TO INCREASE THE VARIABLE COSTS AT VERY HIGH
C          LEVELS OF PRODUCTION
C   EX     EXPONENT FOR CAPITAL COSTING BY SCALE-UP
C   FOPC    WORK TERM FOR FIXED OPERATING COST
C   FX1  FIXED COST OF PLANT 1  DOL/YR
C   FX2  FIXED COST OF PLANT 2  DOL/YR
C   FXT    FIXED COST       DOL/YR
C   G7   WORK TERM FOR SALES GROWTH RATE
C   G9C1    WORK TERM FOR CHANGES IN FIXED COSTS
C   G9C2    WORK TERM FOR CHANGES IN FIXED COSTS
C   I      COUNTER INDICATING WHICH PLANT IS BEING CONSIDERED
C   IFC     A COUNTER FOR CFC AND SC
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```
C    IIT    COUNTER FOR THE MONTE CARLO                                   PRO  350
C    ISING   INDICATOR FOR SELECTIVE MONTE CARLO                          PRO  360
C             ISING=1  STANDARD MONTE CARLO IN EFFECT                     PRO  370
C             ISING=2  ONE RANDOM VARIABLE WILL BE HELD CONSTANT          PRO  380
C    IY     INITIAL VALUE FOR SUBROUTINE RANDU                            PRO  390
C    LOP    VARIABLE INDICATING CHANGE IN SALES CURVE GROWTH RATE         PRO  400
C           LOP=1 GROWTH HAS NOT BEEN CHANGED                             PRO  410
C           LOP=2 GROWTH WAS FIRST CHANGED DURING THIS TIME PERIOD        PRO  420
C           LOP=3 GROWTH HAS BEEN CHANGED                                 PRO  430
C    NPRINT2, NPRINT3, NPRINT4  COUNTERS FOR CONTROL OF OUTPUT            PRO  440
C           OF EXCEPTION STATEMENTS                                       PRO  450
C    NT2PNB  THE NUMBER OF TIMES THE SECOND PLANT IS NOT BUILT            PRO  460
C    PC     RATIO OF PRODUCTION TO CAPACITY                               PRO  470
C    PCD    RATIO OF TOTAL DEMAND TO TOTAL CAPACITY                       PRO  480
C    PCT    PER CENT OF PRESENT VALUES FOR EACH INTERVAL                  PRO  490
C    PRC    SELLING PRICE OF THE FINAL PRODUCT      DOLLARS/LB            PRO  500
C    PRCF   PRICE VOLUME FACTOR                                           PRO  510
C    PRL    PROJECT LIFE IN YEARS FOR ECONOMIC EVALUATION                 PRO  520
C    PRODT TOTAL PRODUCTION FOR THE FIRM      LBS/YR                      PRO  530
C    PVC   PRESENT VALUE OF THE CASH FLOWS TO DATE    DOLLARS             PRO  540
C    P9      WORK TERM FOR SELLING PRICE                                  PRO  550
C    Q      SAME AS Y                                                     PRO  560
C    RMC    RAW MATERIAL COST        DOL/LB                               PRO  570
C    R9      WORK TERM FOR RAW MATERIAL COST                              PRO  580
C    S     AN ARRAY OF THE SIX TIME PERIODS                               PRO  590
C    S4    TIME AT WHICH THE SECOND PLANT IS TO BE BUILT   YEAR           PRO  600
C    S4N    WORK TERM FOR END OF PROJECT LIFE                             PRO  610
C    SBA    A COLLECTION OF TERMS EVALUATED IN MAIN                       PRO  620
C    SC      AN ARRAY OF THE NINE POINT-VALUES OF TIME                    PRO  630
C    SHR    SHARE OF TOTAL MARKET HELD BY FIRM                            PRO  640
C    SO     THE LEVEL OF SALES UPON WHICH THE SALES GROWTH IS BASED       PRO  650
C    SPC    SHIPPING COST    DOL/LB                                       PRO  660
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C    SPE  COLLECTION OF TERMS FOR CONVENIENCE                             PRO  670
C    SRC   SARE COST      DOL/LB                                          PRO  680
C    STATS  ARRAY OF OUTPUT VALUES FROM TAB1                              PRO  690
C            STATS(1) TOTAL                                               PRO  700
C            STATS(2) MEAN OF PRESENT VALUES                              PRO  710
C            STATS(3) STANDARD DEVIATION OF PRESENT VALUES                PRO  720
C    T     TIME   IN YEARS                                                PRO  730
C    TCP   TOTAL INDUSTRY CAPACITY     LBS/YR                             PRO  740
C    TM   THE TIMING OF THE SECOND PLANT.  ACTUALLY IS THE RATIO OF       PRO  750
C         SALES TO CAPACITY                                               PRO  760
C    TSD   TIME OF SALES GROWTH CHANGE                                    PRO  770
C    VMAIN  A COLLECTION OF THE MAIN VARIABLES     DOL/LB                 PRO  780
C    VRT   VARIABLE COST      DOL/LB                                      PRO  790
C    V9     WORK TERM FOR VARIABLE COST                                   PRO  800
C    W     TIME OF THE SALES DECLINE                                      PRO  810
C    WC    WORKING CAPITAL       DOL/LB                                   PRO  820
C    X    AN ARRAY OF THE CAPACITY OF EACH PLANT     LBS/YR               PRO  830
C         X(1) FIRST PLANT                                                PRO  840
C         X(2) SECOND PLANT                                               PRO  850
C    XNA   REAL NUMBER VALUE OF DEPRECIATION LIFE                         PRO  860
C    Y     INPUT ARRAY TO TAB1 FOR MONTE CARLO                            PRO  870
C    ZM    ARRAY OF RANDOM VARIABLE FACTORS                               PRO  880
C          FOR DETERMINISTIC EVALUATIONS EACH MEMBER OF THE ARRAY         PRO  890
C          HAS THE VALUE 1.0                                              PRO  900
C          ZM(1)  SALES OF THE FIRM.  A GROWTH RV.                        PRO  910
C          ZM(2)  PLANT CAPACITY.  A GROWTH RV.                           PRO  920
C          ZM(3)  CAPITAL COST OF THE PLANT                               PRO  930
C          ZM(4)  SELLING PRICE OF THE FINAL PRODUCT.  A GROWTH RV.       PRO  940
C          ZM(5)  BY-PRODUCT CREDIT.  A GROWTH RV                         PRO  950
C          ZM(6)  VARIABLE COST.  A GROWTH RV.                            PRO  960
C          ZM(7)  RAW MATERIAL COST.  A GROWTH RV.                        PRO  970
C          ZM(8)  SARE COST.                                              PRO  980
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C          ZM(9)  FIXED COST.  A GROWTH RV.
C          ZM(10) TIME OF CHANGE IN GROWTH OF THE SALES CURVE
C          ZM(11) THE NEW VALUE OF THE SALES CURVE GROWTH.  A GROWTH RV.
C          ZM(12) THE TOTAL PROJECT LIFE
C          ZM(13) THE INITIAL SALES LEVEL
C          ZM(14) THE INITIAL CAPACITY
C    ZM14   WORK TERM FOR THE INITIAL CAPACITY RANDOM VARIABLE
C***********************************************************************
C
C
      SUBROUTINE PROC(XS,PVS)
      REAL*4 IAR1, IAR2
      COMMON/BLOC1/      J,NA,IV,IM,          X(2),TM,VP,C ,TR,BAS,CPBS,
     1 CP9,DM9,PR9,  FXF,VR9,RMF,  RM9,GI(15),  AS,BS,CS,DS,BE,FE,
     2  SCF,SHC,CR9,      SI,SF,VL ,G(15)  ,DEPF,TSDI, PRLI,  CSLB,
     3 XNA,SHD,GR,CGR,   SBA,  ITIMES,XLIM(3),NPRIN2,NPRIN3,NPRIN4,
     4 GD,CG,ISPC,  EFFI,NRV,XMPM,YMAN,YLAB,XMAXT,  JPRN2,JPRN3,JPRN4 ,
     5 YLIM(3), ZLIM(3)  ,JPRN5, NPRIN5, ISING ,X2MIN  , NTECON
      COMMON/BLOC5/PVALO(11,11),PVAL(11,11),OBJ1(11,11),OBJ2(11,11),
     1 Z(6,15),AR1(11),AR2(11),IAR1(11),IAR2(11), ZM(15),IDP,JDP,NTGRD,
     2 NCDF, NMRV1, NMRV2, JIX2, NVARD, NROD, IOD, STP(3),TMO,XR10,XR20,
     3 IPRINT
      DIMENSION  Y(2000),PLANT2(2000), TIM(2000),
     1 CDF(40), FREQ(40), PCT(40), STATS(5), A(6), CPC(2), CF(6), S(6),
     2  AI(4), U(2), V(2), H(2), E(2), F(2), XS(3)
      DIMENSION PV1(2), PV2(2), HPV2(2), FPV1(2)
      DIMENSION CFC(10), SC(10)
  102 FORMAT(12X,2E14.7)
  104 FORMAT(8X,4E14.7)
  106 FORMAT(6X,6E14.7)
  108 FORMAT(2X,8E14.7)
  111 FORMAT(2X,'PROJECT LIFE ENDED BY T =',F12.5,' CASH FLOW =',E12.5)
```

```
114 FORMAT(3X,' CUMULATIVE DISTRIBUTION FUNCTION OF PRESENT VALUES' /
   1 5(1X,8F9.4/))
115 FORMAT('  MEAN OF PV =',E12.5,   ' STANDARD DEVIATION OF PV =',
   1 E12.5,   '  ITIMES =',I4)
118 FORMAT(3X,' CUMULATIVE DISTRIBUTION FUNCTION OF SECOND PLANT SIZE'
   1 / 5(1X,8F9.4/))
119 FORMAT(3X,' CUMULATIVE DISTRIBUTION FUNCTION OF TIMING FACTOR' /
   1 5(1X,8F9.4/))
121 FORMAT(' MEAN OF 2ND PLANT =',E12.5,  ' STD DEV OF 2ND PLANT =',
   1 E12.5, '  ITIMES =',I4  )
122 FORMAT('  MEAN OF TIMING =',E12.5,  '  STD. DEV. OF TIMING =',
   1  E12.5,  '  ITIMES =',I5 )
125 FORMAT('    NUMBER OF TIMES 2ND PLANT NOT BUILT =',I5)
407 FORMAT(1X,I2,7E14.7)
801 FORMAT(///// ' THE MONTE CARLO OPTION IS IN EFFECT.  SINGLE PLANT
   1CASE  ' // )
802 FORMAT('   A(M)=',F9.5,5X,'PRESENT VALUE OF CASH FLOW TO TIME "T"
   1 IS',E12.5)
803 FORMAT(///// ' THE MONTE CARLO OPTION IS IN EFFECT.  TWO PLANT CAS
   1E  '  // )
804 FORMAT(' IIT=',I4, '  PV=',E12.5, '  X(1)=',E12.5,  '  X(2)=',
   1  E12.5, '   TM=',F8.4  )
807 FORMAT(' N',3X,'CF(N)', 7X,'T',7X, 'SLS',8X,'CP', 7X,'VMAIN',
   1 6X, 'PRC',7X, 'VRT', 6X,'FXOPC'/I2,8E10.3  )
905 FORMAT(1X,10E12.5 / 1X,10E12.5   )
888 FORMAT(2X,I5)
C**********************************************************************
      NPRIN4=0
      NPRIN5=0
      IIT=0
      NCDF=3
C   THIS IS THE BEGINNING OF THE MONTE CARLO OPTION
```

```
      IF(IM.LT.2)  GO TO 61
      NT2PNB=0
      IY=24151311
   30 CONTINUE
C   DO LOOP TO 34 SETS THE VALUES OF THE RANDOM VARIABLE FACTORS.
      DO 34 K=1,NRV
      IX=IY
C   SUBROUTINE RANDU GENERATES RANDOM NUMBERS
      CALL RANDU(IX,IY,YFL)
      IF(YFL .LT. Z(5,K)) ZM(K)= Z(1,K) + (Z(2,K)-Z(1,K))/Z(5,K)*YFL
      IF(YFL.GE.Z(5,K) .AND. YFL.LE.Z(6,K))ZM(K)= Z(2,K) + (Z(3,K)-
     1  Z(2,K)) / (Z(6,K)-Z(5,K))*(YFL - Z(5,K))
      IF(YFL .GT. Z(6,K)) ZM(K)= Z(3,K) + (Z(4,K)-Z(3,K)) / (1.-Z(6,K))
     1  * (YFL-Z(6,K))
      IF(ISING.EQ.2)  ZM(ISG)=1.0
      G(K)= GI(K)*ZM(K)
      IF(K.GT.12) G(K)=GI(K)
   34 CONTINUE
      IIT=IIT+1
C*******  STATEMENTS TO 39 DO X(2) AND TM INTERPOLATION FROM
C          THE DPOPT ARRAYS
      IF(IDP.NE.2) GO TO 39
      IF(ISING.EQ.2)  GO TO 39
      IF(ISPC.EQ.2)  XS(1)=0.0
      IF(ISPC.EQ.2)  GO TO 39
      ILO = CURVE(AR1,IAR1,ZM(NMRV1),NTGRD)
      IHI = ILO+1
      JLO = CURVE(AR2,IAR2,ZM(NMRV2),NTGRD)
      JHI=JLO+1
      U(1)= AR1(ILO)
      U(2)=AR1(IHI)
      KOUNT=1
```

```
      DO 38 L=JLO,JHI                                                   PRO 1960
      V(1)=OBJ1(ILO,L)                                                  PRO 1970
      V(2)= OBJ1(IHI,L)                                                 PRO 1980
      E(1) = OBJ2(ILO,L)                                                PRO 1990
      E(2)= OBJ2(IHI,L)                                                 PRO 2000
      PV2(1)=PVAL(ILO,L)                                                PRO 2010
      PV2(2)=PVAL(IHI,L)                                                PRO 2020
      PV1(1)=PVALO(ILO,L)                                               PRO 2030
      PV1(2)=PVALO(IHI,L)                                               PRO 2040
      HPV2(KOUNT)=CURVE(U,PV2,ZM(NMRV1),2)                              PRO 2050
      FPV1(KOUNT)=CURVE(U,PV1,ZM(NMRV1),2)                              PRO 2060
      H(KOUNT) = CURVE(U,V,ZM(NMRV1),2)                                 PRO 2070
      F(KOUNT) = CURVE(U,E,ZM(NMRV1),2)                                 PRO 2080
   38 KOUNT=KOUNT+1                                                     PRO 2090
      U(1)=AR2(JLO)                                                     PRO 2100
      U(2)=AR2(JHI)                                                     PRO 2110
      XS(1) = CURVE(U,H, ZM(NMRV2),2)                                   PRO 2120
      XS(2) = CURVE(U,F,  ZM(NMRV2),2)                                  PRO 2130
      PVX2=CURVE(U,HPV2,ZM(NMRV2),2)                                    PRO 2140
      PVX1=CURVE(U,FPV1,ZM(NMRV2),2)                                    PRO 2150
      IF(PVX1.GE.PVX2)  XS(1)=0.0                                       PRO 2160
   39 CONTINUE                                                          PRO 2170
      IF(IIT.GT.ITIMES) GO TO 90                                        PRO 2180
C***********************************************************************PRO 2190
C    BEGINNING OF THE ECONOMIC MODEL                                    PRO 2200
   61 CONTINUE                                                          PRO 2210
C    SETTING VARIABLES TO INITIAL VALUES                                PRO 2220
      IF(JDP.NE.2) X(1)=XS(3) * 1.E9                                    PRO 2230
      X(2)= XS(1)*1.E9                                                  PRO 2240
      TM=XS(2)                                                          PRO 2250
      IF(IM.LT.2)  GO TO 72                                             PRO 2260
      IF(X(2) .LT. 1.0E4)  X(2) = 0.0                                   PRO 2270
```

```
      IF(X(2).LT.1.0E4)  TM=TMO                                        PRO 2280
   72 CONTINUE                                                         PRO 2290
      DO 74 K=1,NRV                                                    PRO 2300
      IF(JDP.NE.2 .AND. IM.LT.2)  ZM(K)=1.0                            PRO 2310
      G(K) = GI(K)*ZM(K)                                               PRO 2320
   74 IF(K.GT.12) G(K)=GI(K)                                           PRO 2330
   76 CONTINUE                                                         PRO 2340
      IF(IPRINT.NE.4)  GO TO 898                                       PRO 2350
  998 CONTINUE                                                         PRO 2360
  898 CONTINUE                                                         PRO 2370
      CI=X(1)                                                          PRO 2380
      CJ=0.0                                                           PRO 2390
      CPC(2)=0.0                                                       PRO 2400
      C9=CR9                                                           PRO 2410
      EFF=1.0                                                          PRO 2420
      FOPC=1.0                                                         PRO 2430
      G7=G(1)                                                          PRO 2440
      G(2) = GI(2)                                                     PRO 2450
      G9CI=G(9)-C                                                      PRO 2460
      I=1                                                              PRO 2470
      IFC=0                                                            PRO 2480
      ICJT=1                                                           PRO 2490
      ISTOP=1                                                          PRO 2500
      ITM=1                                                            PRO 2510
      LOP=1                                                            PRO 2520
      PRL=PRLI*ZM(12)                                                  PRO 2530
      PVC=0.0                                                          PRO 2540
      P9=PR9                                                           PRO 2550
      SO=SI                                                            PRO 2560
      R9=RM9                                                           PRO 2570
      S4=0.0                                                           PRO 2580
      S4N=XNA                                                          PRO 2590
```

```
      S(4)=0.0
      TSD=TSDI*ZM(10)
      V9=VR9
      W=0.0
      ZM14=ZM(14)
C*****************************************************************************
C    DO LOOP TO 44 GOES THROUGH THE SIX ANALYTICAL POINTS IN TIME FOR
C       EVALUATING THE PRESENT VALUE.
      DO 44 N=1,6
      IF(ISTOP.EQ.2  .AND.  N.NE.6)  GO TO 44
      GO TO 42
   40 LOP=3
   42 IF(N.EQ.1) GO TO 1
      IF(N-5) 8,5,6
    8 IF(N-3) 2,3,4
C    IF N=1  DETERMINING THE VALUE OF THE VARIABLES AT TIME   T=0.0.
    1 T=1.E-6
      S(N)=T
      GO TO 20
C    N=2  SALES CURVE HAS REACHED THE PLANT CAPACITY
C          THE PLANT PRODUCTION IS NOW CAPACITY LIMITED
    2 PC=1.
      T = W + 1./(G(2)-G7) * ALOG(  SO*ZM(13)/( PC*CI*ZM(14)) )
      IF(T.GT.0.0)  GO TO 222
      S(N)=1.E-6
      CF(N)=CF(1)
      GO TO 44
  222 CONTINUE
      IF(T.GT. TSD .AND. LOP.EQ.1) GO TO 26
      IF(T.LT.PRL)  GO TO 12
      T=PRL
   12 S(N)=T
```

```
      GO TO 20
C   N=3  THE SALES/CAPACITY  RATIO HAS REACHED THE VALUE OF TM.  THE
C        VARIABLES ARE EVALUATED JUST BEFORE THE 2ND PLANT IS BUILT.
    3 PC=1./TM
      IF(ISTOP.EQ.2) GO TO 300
      T = W + 1./(G(2)-G7) * ALOG(  SO*ZM(13)/( PC*CI*ZM(14)) )
      IF(T.LT.S(2))  T=S(2)
  300 CONTINUE
      IF(T.GT.0.0)  GO TO 333
      S(N)=1.E-6
      CF(N)=CF(1)
      GO TO 44
  333 CONTINUE
      IF(T.GT. TSD .AND. LOP.EQ.1) GO TO 26
      IF(T.LT.PRL) GO TO 13
      T=PRL
   13 S(N)=T
      GO TO 20
C   N=4   THE TIME IS THE SAME AS WHEN N=3 BUT NOW THE SECOND PLANT HAS
C           BEEN BUILT.
    4 S(4)=S(3)
      S4=S(3)
      T=S(3)
      I=2
      CJ=X(2)
C
C** STATEMENTS TO 435 REDEFINE THE VARIABLES FOR S(3) AS THE TIME BASIS
      SO=SO*EXP(G7*(T-W))
      CI=CI*EXP(G(2)*(T-W))
      W=S(3)
      P9=P9*EXP(G(4)*T)
      C9=C9*EXP(G(5)*T)
```

```
      V9=V9*EXP(G(6)*T)
      R9=R9*EXP(G(7)*T)
      FOPC=EXP(G(9)*T)
      IF(IM.LT.3)  GO TO 435
      DO 434 K=1,11
      IX=IY
      IF(K.EQ.10)  GO TO 434
      CALL RANDU(IX,IY,YFL)
      IF(YFL .LT. Z(5,K)) ZM(K)= Z(1,K) + (Z(2,K)-Z(1,K))/Z(5,K)*YFL
      IF(YFL.GE.Z(5,K) .AND. YFL.LE.Z(6,K))ZM(K)= Z(2,K) + (Z(3,K)-
     1 Z(2,K)) / (Z(6,K)-Z(5,K))*(YFL - Z(5,K))
      IF(YFL .GT. Z(6,K)) ZM(K)= Z(3,K) + (Z(4,K)-Z(3,K)) / (1.-Z(6,K))
     1 * (YFL-Z(6,K))
      IF(ISING.EQ.2)  ZM(ISG)=1.0
      G(K)= GI(K)*ZM(K)
  434 CONTINUE
  435 CONTINUE
      G7=G(1)
      IF(LOP.GT.1)  G7=G(11)
      IF(LOP.GT.1)  G(2)=GI(14)*ZM(2)
      GO TO 20
C   N=5   THE SALES LEVEL HAS REACHED THE LEVEL OF CAPACITY OF THE TWO
C        PLANTS COMBINED.  THE PRODUCTION IS NOW CAPACITY LIMITED.
    5 PC=1.
      IF(ISTOP.EQ.2) GO TO 500
      SPE=(CI+CJ)/SO*EXP(-W*(G(2)-G7))
      T = 1./(G(2)-G7) *(ALOG(ZM(13)/PC/ZM(14))  -  ALOG(SPE)  )
  500 CONTINUE
      IF(T.LT.0.0)  T=1.E-6
      IF(T.LT. S(4)) T=S(4)
      IF(T.GT. TSD .AND. LOP.EQ.1) GO TO 26
      IF(T.LT.PRL) GO TO 15
```

```
      T=PRL
   15 S(N)=T
      GO TO 20
C    N=6  THE TIME IS SET AT THE VALUE OF THE PROJECT LIFE  PRL.
    6 T=PRL
      IF(T.GT. TSD .AND. LOP.EQ.1) GO TO 26
      S(N)=T
      GO TO 20
   26 LOP=2
      T=TSD
      S(N)=T
C*********************************************************************
   20 CONTINUE
C    PRODUCT SALES  SLS
      SLS = SO * EXP(G7*(T-W)) * ZM(13)
C    FIRM CAPACITY  CP WITH LEARNING CURVE
      CP=(CI+CJ)*EXP(G(2)*(T-W))*ZM(14)
      PC=SLS/CP
C    STATEMENTS TO 11   CAPITAL COSTING
      IF(N.NE.1 .AND. N.NE.4) GO TO 11
      SCAL = X(I)/CPBS
      EX=AS
      IF(SCAL.GT.DS) EX=BS
      IF(SCAL.LE.DS .AND. SCAL.GE.CS) EX=AS+SBA*(SCAL-CS)
C    THE VALUE OF THE DEPRECIATION IS SUBTRACTED FROM THE CAPITAL COST
C     GIVING THE RISK CAPITAL COST.
      CPC(I) = BAS*SCAL**EX*EXP(GI(3)*T)* ZM(3) * (1.+SCF)
     1* (1.  -  TR*DEPF/(1.+SCF)  )
   11 CONTINUE
      PRODT=CP
      IF(PC.LT.0.999)  PRODT=PC*CP
      IF(PC.LT.0.999)  EFF=1.0
```

```
      PRCF=1.0
      IF(PRODT.LE.VL)  SPC=SHC+SHD*(1.0-PRODT/VL)
      IF(PRODT.GT.VL)  SPC=SHC+0.1*SHD*(PRODT/VL-1.0)
      PRC=P9*PRCF*EXP(G(4)*(T-S4))
      CRDT=C9*EXP(G(5)*(T-S4))
      VRT=V9*EFF*EXP(G(6)*(T-S4))
      RMC=R9*RMF*EXP(G(7)*(T-S4))
      SRC=   SF*ZM(8)
      WC= PRODT*PRC*C/6.
      VMAIN = (PRC+CRDT - VRT-RMC    -PRC*SRC-SPC)
      DX2=1.
      IF(CJ.GT.1.0)  DX2=2.
      FXOPC=FOPC*((FXF+YMAN)*(CPC(1)+CPC(2))+DX2*YLAB*CSLB)*EXP(G(9)*(T-
     1 S4))
C************************************************************************
C   EVALUATING THE CASH FLOW AT THE INSTANT IN TIME 'T'
      CF(N) = (PRODT*VMAIN) * (1.-TR) - WC
      IFC=IFC+1
      IF(ISTOP.EQ.2)  IFC=10
      CFC(IFC)=CF(N)
      SC(IFC)=S(N)
      IF(IPRINT.GT.2) WRITE(6,807) N,CF(N),T,SLS,CP,VMAIN,PRC,VRT,FXOPC
      PT=1./PC
      IF(IPRINT.GT.3) WRITE(6,108) CRDT,RMC,SPC,SRC,PRODT,PT,WC,W
C************************************************************************
C   STATEMENTS TO 78   IF THE CASH FLOW IS LESS THAN FXOPC THE
C   PROJECT IS ABANDONED.
      M=N-1
      IF(N.EQ.1) GO TO 44
      IF(N.LT.4)  GO TO 80
      IF(CF(N).GE. FXOPC)  GO TO 78
      IF(CF(N).GT.0.0  .AND.  LOP.EQ.2)  GO TO 80
```

```
      IF(T.LT.0.01) GO TO 78
      IF(N.EQ.6) GO TO 78
      IF(N.EQ.4) GO TO 44
      NPRIN4 = NPRIN4 + 1
      ISTOP=2
      IF(IPRINT.NE.1 .AND. NPRIN4.LT.JPRN4)   WRITE(6,111) T , CF(N)
      PRL=T
      CF(5)=CFC(IFC-1)
      S(5)=SC(IFC-1)
      GO TO 44
   78 CONTINUE
C*****************************************************************************
      IF(CF(N).GE. FXOPC  .AND.  ISTOP.EQ.1)  GO TO 80
      NPRIN5 = NPRIN5 + 1
      ISTOP =2
      IF(ITM.NE.1)  GO TO 789
      T=T-1.0
      PRL=T
      IF(CF(N).GE.FXOPC)  T=T+2.0
      IF(CF(N).GE.FXOPC)  GO TO 789
  903 CONTINUE
      IF(CJ.GT.1.0 .AND. T.LT.S4)  ICJT=2
      IF(IM.GT.2 .AND. T.LT.S4)  ICJT=2
      IF(T.LE.1.0E-6)  ICJT=2
      IF(ICJT.EQ.2)  T=T+2.0
      IF(ICJT.EQ.2)  GO TO 789
      GO TO 42
  789 IF(ITM.EQ.1)  ITM=2
      T=T - 0.05
      PRL=T
      IF(ITM.EQ.2)  GO TO 790
      IF(CF(N).GE.FXOPC)  GO TO 80
```

```
      IF(CJ.GT.1.0 .AND.  T.LT.S4)  GO TO 80
  904 CONTINUE
      IF(IM.GT.2 .AND. T.LT.S4)  GO TO 80
      IF(T.LE.1.E-6)  GO TO 80
  790 ITM=3
      GO TO 42
   80 CONTINUE
      IF( ABS(S(M)-S(N)).LT.  0.001  ) GO TO 84
      A(M) = 1./ (S(N)   - S(M)) * ALOG(CF(N)  /CF(M))
C** EVALUATING THE PRESENT VALUE OF CASH FLOWS FOR THE GIVEN TIME PERIOD
      AC=A(M)-C
      DCF = CF(M)*EXP(-AC*S(M))/AC  *  (EXP(AC*S(N)) - EXP(AC*S(M)))
     1  /  EXP(C*S(M))
      PVC=PVC+DCF
      IF(IPRINT.GT.3)  WRITE(6,802) A(M), PVC
   84 CONTINUE
      IF(PC.LT.0.999) GO TO 88
      IF(EFF.GT.1.0) GO TO 88
      S(M)=S(N)
      EFF=EFFI
      GO TO 11
   88 CONTINUE
C    STATEMENTS TO 44 CHANGE THE SALES CURVE GROWTH TO NEW VALUE G(11)
C    AND CHANGE THE LEARNING CURVE TO THE NEW VALUE GI(14)
      IF(LOP.NE.2) GO TO 44
      CF(M)=CF(N)
      SO = SO*EXP(G7*(T-W))
      S(M)=S(N)
      G7=G(11)
      CJ=CJ*EXP(G(2)*(T-W))
      CI=CI*EXP(G(2)*(T-W))
      G(2) = GI(14) * ZM(2)
```

```
      W=S(N)
      GO TO 40
   44 CONTINUE
C*******************************************************************************
C   THE PRESENT VALUE OF THE FIXED COSTS IS EVALUATED SEPARATELY
      FC0= FXF*CPC(1)+YMAN*CPC(1)+YLAB*CSLB
      FC1=(FXF*CPC(1)+YMAN*CPC(1)+YLAB*CSLB) *EXP(G(9)*S4)
      FC2=(FXF*CPC(2)+YMAN*CPC(2)+YLAB*CSLB) *EXP(G(9)*S4)
      IF(X(2).LT.1.0)  FC2=0.0
      G9C2=G(9)-C
      PVTFXC=FC0/G9C1*(EXP(G9C1*S4)-1.) + (FC1+FC2)/G9C2*(EXP(G9C2*
     1 PRL)  -  EXP(G9C2*S4) ) /  EXP(S4*C)   *EXP(-G9C2*S4)
C   THE CAPITAL COSTS AND THE PRESENT VALUE OF THE FIXED COSTS
C   ARE SUBTRACTED FROM THE PRESENT VALUE OF ALL OF THE CASH FLOWS
      PV = PVC - CPC(1) - CPC(2)/EXP(C*S4) - PVTFXC * (1.-TR)
      NTECON=NTECON+1
      PVS= -PV*1.E-6
      IF(X(2).LT.1.0)   XS(1)=0.0
      IF(X(2).LT.1.0)  XS(2)=TM
      VP=PV
      IF(IPRINT.EQ.3 .OR. IPRINT.EQ.4)  WRITE(6,104) CPC,CJ,PVTFXC
      IF(IPRINT.EQ.4)  WRITE(6,905)  CFC,SC
      IF(IPRINT.GT.1)  WRITE(6,804)  IIT, PV, X, TM
C*******************************************************************************
C   STATEMENTS TO END OF SUBROUTINE DETERMINE STATISTICAL TERMS FOR THE
C     MONTE CARLO EVALUATIONS.
      IF(IM.LT.2)  GO TO 63
      Y(IIT)=VP
      PLANT2(IIT) = XS(1)
      TIM(IIT)=XS(2)
      IF(XS(1) .LT. 1.0E-5)  TIM(IIT)=TMO
      IF(XS(1) .LT. 1.0E-5)  NT2PNB=NT2PNB+1
```

```
      GO TO 30
   90 CONTINUE
      IF(ISING.EQ.2  .OR.  NT2PNB+2.GE.ITIMES)  NCDF=1
      ITI=ITIMES
      IF(ISPC.EQ.2)  WRITE(6,801)
      IF(ISPC.NE.2)  WRITE(6,803)
      DO 97 ITMC=1,NCDF
C    SUBROUTINE TAB1 DETERMINES THE MEAN AND STANDARD DEVIATION
      IF(ITMC.EQ.1)  CALL TAB1(Y,Y,1,XLIM,FREQ,PCT,STATS,ITIMES,1)
      IF(ITMC.EQ.1) STATPV = STATS(2)
      IF(ITMC.EQ.1)  WRITE(6,115)  STATS(2), STATS(3), ITIMES
      IF(ITMC.EQ.2)CALL TAB1(PLANT2,PLANT2,1,YLIM,FREQ,PCT,STATS,ITI,1)
      IF(ITMC.EQ.2)  WRITE(6,121)  STATS(2), STATS(3), ITIMES
      IF(ITMC.EQ.2)  WRITE(6,125) NT2PNB
      IF(ITMC.EQ.3)CALL TAB1(TIM,PLANT2,1,ZLIM,FREQ,PCT,STATS,ITIMES,1)
      IF(ITMC.EQ.3)  WRITE(6,122)  STATS(2), STATS(3), ITIMES
      LIM=XLIM(2)
      CDF(1)= PCT(1)
C    DO LOOP TO 92 CACULATES THE CUMULATIVE DISTRIBUTION FUNCTION
      DO 92 ICD=2,LIM
      CDF(ICD)= CDF(ICD-1) + PCT(ICD)
   92 CONTINUE
      IF(ITMC.EQ.1)  WRITE(6,114) CDF
      IF(ITMC.EQ.2)  WRITE(6,118)  CDF
      IF(ITMC.EQ.3)  WRITE(6,119)  CDF
   97 CONTINUE
      PVS = -STATPV * 1.E-6
   63 CONTINUE
  999 CONTINUE
      RETURN
      END
```

```
C*********************************************************************
C
      SUBROUTINE DPOPT(XO1,IX2)
      REAL*4 IAR1, IAR2
      COMMON/BLOC5/PVALO(11,11),PVAL(11,11),OBJ1(11,11),OBJ2(11,11),
     1 Z(6,15),AR1(11),AR2(11),IAR1(11),IAR2(11), ZM(15),IDP,JDP,NTGRD,
     2 NCDF, NMRV1, NMRV2, JIX2, NVARD, NRDD, IOD, STP(3),TMO,XR1O,XR2O,
     3 IPRINT
      DIMENSION DEL(15), XR(3)
  700 FORMAT(5X,'I',4X,'J', 3X,'ZM(',I2,')', 4X,'ZM(',I2,')', 5X,'XS(1)'
     1,5X,'XS(2)', 5X,'XS(3)',  3X,'PRES VAL'        )
  702 FORMAT(/' ECONOMIC EVALUATION OF A SINGLE PLANT FOR THE RANGE OF
     1THE MAIN VARIABLES' /)
  704 FORMAT(/' THE PATTERN SEARCH OPTIMIZATION OF 2ND PLANT SIZE AND TI
     1MING ' /)
  706 FORMAT(1X,2I5,5F10.5,E12.5)
  707 FORMAT(2X,E14.7,2I5,5E14.7)
  708 FORMAT(2X,E11.4,2I5,5E11.4)
  716 FORMAT(2X,2I2,5F6.3,F9.4)
  717 FORMAT(' 1',2I2,5F6.3,F9.4)
  888 FORMAT(2X,I5)
      IF(IX2.EQ.1)  WRITE(6,702)
      IF(IX2.EQ.2)  WRITE(6,704)
      WRITE(6,700)  NMRV1,NMRV2
      STP1=STP(1)
      DO 11 IZM=1,15
   11 ZM(IZM)=1.0
      IF(IX2.EQ.1)  JIX2=2
      IF(JIX2.EQ.2)  GO TO 15
      DO 13 I=1,NTGRD
      DO 13 J=1,NTGRD
   13 PVALO(I,J)=0.0
```

```
   15 CONTINUE
C    ZINT  NUMBER OF INTERVALS ON GRID
C    DEL  SIZE OF INTERVAL ON GRID
      ZINT=NTGRD-1
      DEL(NMRV1) = (Z(4,NMRV1)-Z(1,NMRV1)) / ZINT
      DEL(NMRV2) = (Z(4,NMRV2)-Z(1,NMRV2)) / ZINT
      IDP=2
      JDP=2
      NCDF=3
      XR(3) = XO1 * 1.E-9
C**   DO LOOPS TO 788 COVER THE FULL RANGES OF THE MAIN RANDOM VARIABLES
      DO 788 II=1,NTGRD
      I=II
      ZM(NMRV1) = Z(1,NMRV1)  +   DEL(NMRV1) * FLOAT(I-1)
      AR1(I) = ZM(NMRV1)
      IAR1(I) = I +  1.0E-5
      DO 788 J=1,NTGRD
      ZM(NMRV2) = Z(1,NMRV2)  +  DEL(NMRV2) * FLOAT(J-1)
      AR2(J) = ZM(NMRV2)
      IAR2(J) = J + 1.0E-5
      IF(IX2.NE.1)  GO TO 33
C**   SINGLE PLANT CASE
      XR(1)=0.0
      XR(2)=TMO
      CALL PROC(XR,PVS)
      PSV=-PVS
      PVALO(I,J)=-PVS*1.E6
      GO TO 43
   33 CONTINUE
      XR(1)=XR10
      XR(2)=XR20
      IF(IX2.NE.2)  GO TO 43
```

```
C**  TWO PLANT OPTIMIZATION
      CALL PATERN(NVARD,XR,STP,NRDD,IOD,PVS)
      PSV=-PVS
      PVAL(I,J) = -PVS*1.E6
      IF(XR(1).LE.STP1)  XR(1)=0.0
      IF(XR(1).LE.STP1)  XR(2)=TMO
      IF(XR(1).LE.STP1)  PVAL(I,J)=PVALO(I,J)
      IF(XR(1).LE.STP1)  PSV=PVALO(I,J)*1.E-6
      OBJ1(I,J) = XR(1)
      OBJ2(I,J) = XR(2)
   43 CONTINUE
      WRITE(6,706)  I,J,  AR1(I),AR2(J), XR,PSV
  788 CONTINUE
      JDP=1
      RETURN
      END
```

```
C*****************************************************************************
C
      SUBROUTINE BOUNDS(XS,IOUT)
C**   IN SUBROUTINE BOUNDS THE BOUNDARIES OR CONSTRAINTS FOR THE
C     INDEPENDENT VARIABLES ARE SET.
      DIMENSION XS(3)
      IOUT=0
      IF(XS(1) .LT. 0.0) IOUT=1
      IF(XS(2) .LE. 0.0) IOUT=1
      IF(XS(2).GT.1.0)  IOUT=1
      IF(XS(3) .LT. 0.0) IOUT=1
      RETURN
      END

*****************************************************************************

      SUBROUTINE PATERN(NP,P,STEP,NRD,IO,VALUE)
      DIMENSION P(3) , STEP(3) , B1(10), B2(10), T(10), S(10)
      IF(NP.EQ.2) T(3) = P(3)
C
  616 CONTINUE
C*****PROGRAM FOR CONSTRAINED OPTIMIZATION OF RESPONSE SURFACE FUNCTION
C*****NOTE. DIMENSION OF ARRAYS MUST BE SAME AS THOSE FOR PROBLEM.
C
      IF(IO.GT.0) WRITE(6,746)
  746 FORMAT(// 2X,'SEARCH FOR CONSTRAINED SOLUTION' //)
C*****STARTING POINT
C
      L=1
      CC2=-9999.9
      ATEST=0.0001
      ATEST=0.001
```

```
      ICK=2
      ITTER=0
      DO 5 I=1,NP
      B1(I)=P(I)
      B2(I)=P(I)
      T(I)=P(I)
    5 S(I)=STEP(I)*10.
C
C*****INITIAL BOUNDARY CHECK AND OBJECTIVE FUNCTION EVALUATION
C
      CALL BOUNDS(P,IOUT)
      IF(IOUT.LE.0)GO TO 10
      IF(IO.LE.0)GO TO 6
      WRITE(6,1005)
      WRITE(6,1000) (J,P(J),J=1,NP)
    6 RETURN
   10 CALL PROC(P,C1)
      IF(IO.LE.0)GO TO 11
      WRITE(6,1001)ITTER,C1
      WRITE(6,1000) (J,P(J),J=1,NP)
C
C*****BEGINNING PATTERN SEARCH PROCESS
C
   11 DO 99 INRD=1,NRD
      DO 12 I=1,NP
   12 S(I)=S(I)/10.
      IF(IO.LE.0)GO TO 20
      WRITE(6,1003)
      WRITE(6,1000) (J,S(J),J=1,NP)
   20 IFAIL=0.0
C
C*****PERTURBATION ABOUT T
```

```
C
      DO 30 I=1,NP
      IC=0
   21 P(I)=T(I)+S(I)
      IC=IC+1
      CALL BOUNDS(P,IOUT)
      IF(IOUT.GT.0)GO TO 23
      CALL PROC(P,C2)
      L=L+1
      IF(IO.LT.3)GO TO 22
      WRITE(6,1002)L,C2
      WRITE(6,1000) (J,P(J),J=1,NP)
   22 IF(C1-C2)23,23,25
   23 IF(IC.GE.2)GO TO 24
      S(I)=-S(I)
      GO TO 21
   24 IFAIL=IFAIL+1
      P(I)=T(I)
      GO TO 30
   25 T(I)=P(I)
      C1=C2
   30 CONTINUE
      IF(IFAIL.LT.NP)GO TO 35
      IF(ICK.EQ.2)GO TO 90
      IF(ICK.EQ.1)GO TO 35
      CALL PROC(T,C2)
      L=L+1
      IF(IO.LT.2)GO TO 31
      WRITE(6,1002)L,C2
      WRITE(6,1000) (J,T(J),J=1,NP)
   31 IF(C1-C2)32,34,34
   32 ICK=1
```

```
      DO 33 I=1,NP
      B1(I)=B2(I)
      P(I)=B2(I)
   33 T(I)=B2(I)
      GO TO 20
   34 C1=C2
   35 IB1=0
      DO 39 I=1,NP
      B2(I)=T(I)
      IF(ABS(B1(I)-B2(I)).LT.1.0E-5 )IB1=IB1+1
   39 CONTINUE
      IF(IB1.EQ.NP)GO TO 90
      ICK=0
      ITTER=ITTER+1
      IF(IO.LT.2)GO TO 40
      WRITE(6,1001)ITTER,C1
      WRITE(6,1000) (J,T(J),J=1,NP)
   40 SJ=1.0
C
C*****TESTING MAGNITUDE OF IMPROVEMENT
C*****IN VALUE OF THE OBJECTIVE FUNCTION
C
C
C*****ACCELERATION STEP
C
      DO 45 II=1,11
      DO 42 I=1,NP
      T(I)=B2(I)+SJ*(B2(I)-B1(I))
      IF(ABS(T(I)) .LT. 1.0E-5)  T(I)=0.0
   42 P(I)=T(I)
      SJ=SJ-0.1
      CALL BOUNDS(T,IOUT)
```

```
      IF(IOUT.LT.1)GO TO 46
      IF(II.EQ.11)ICK=1
   45 CONTINUE
   46 DO 47 I=1,NP
   47 B1(I)=B2(I)
      GO TO 20
   90 DO 91 I=1,NP
   91 T(I)=B2(I)
   99 CONTINUE
      DO 100 I=1,NP
  100 P(I)=T(I)
      VALUE=C1
      IF(IO.LE.0)RETURN
      WRITE(6,1004)L,C1
      WRITE(6,1000) (J,P(J),J=1,NP)
 1000 FORMAT(10X,5(I7,E13.6)/)
 1001 FORMAT(1H ,14HITERATION NO. ,I5/5X,6HVALUE=8E15.6,20X,
     110HPARAMETERS)
 1002 FORMAT(10X3HN/.,I4,8X,6HVALUE=,E15.6)
 1003 FORMAT(/1X28HSTEP SIZE FOR EACH PARAMETER// )
 1004 FORMAT(/2X,13HANSWERS AFTER ,I3,2X,23HFUNCTIONAL EVALUATIONS  //
     15X,6HVALUE=,E15.6,20X,18HOPTIMAL PARAMETERS)
 1005 FORMAT(1H1,35HINITIAL PARAMETERS OUT OF BOUNDS    )
  618 CONTINUE
      RETURN
      END
```

```
********************************************************************
      FUNCTION CURVE(X,Y,ARG,N)
      DIMENSION X(N),Y(N)
C     X=VECTOR OF INDEPENDENT VALUES (EQUAL INCREMENTS NOT REQUIRED)
C     Y=VECTOR OF DEPENDENT VALUES
C     N=NUMBER OF (X,Y) PAIRS
C     ARG=VALUE OF X FOR WHICH A VALUE OF CURVE IS COMPUTED BY
C         LINEAR INTERPOLATION
C     IER=ERROR CODE (THIS CODE MUST BE RETURNED THROUGH
C              COMMON IF THE INFORMATION THAT IT CONTAINS
C              IS TO BE USED IN THE CALLING PROGRAM)
C        =2 FOR X OUTSIDE THE RANGE, CURVE IS COMPUTED BY LINEAR
C               EXTRAPOLATION AND MAY BE VERY INACURATE
C        =1 FOR X INSIDE  THE RANGE, CURVE IS COMPUTED BY LINEAR
C               INTERPOLATION, ACURACY MAY BE INCREASED BY INCLUDING
C               MORE X'S
C     X MUST BE MONOTONICALLY INCREASING
C     Y MUST HAVE ONLY ONE VALUE FOR A GIVEN X
C
C     A BINARY SEACH IS USED TO LOCATE CORRECT INTERVAL
      IER=1
      IF(X(1)-ARG)3,1,2
    1 CURVE=Y(1)
      GO TO 50
    2 IER=2
      CURVE= (Y(2)-Y(1))/(X(2)-X(1))*(ARG-X(1))+Y(1)
      GO TO 50
    3 IF(X(N)-ARG)5,4,6
    4 CURVE=Y(N)
      GO TO 50
    5 IER=2
```

```
      CURVE= (Y(N)-Y(N-1))/(X(N)-X(N-1))*(ARG-X(N))+Y(N)
      GO TO 50
    6 M1=1
      M2=N
      L=(M2+M1)/2
   10 IF(ARG-X(L))7,11,8
   11 CURVE=Y(L)
      GO TO 50
    7 M2=L
      L=(M1+L)/2
      IF(L-M2)10,16,10
    8 M1=L
      L=(M2+L)/2
      IF(L-M1)10,15,10
   15 L=M1
C     L NOW HOLDS THE INDEX OF THE LOWER BOUND OF THE INTERVAL
C     CONTAINING X
   16 CURVE=(Y(L+1)-Y(L))/(X(L+1)-X(L))*(ARG-X(L))+Y(L)
   50 RETURN
      END
********************************************************************
      SUBROUTINE RANDU(IX,IY,YFL)
      IY=IX*65539
      IF(IY)5,6,6
    5 IY=IY+2147483647+1
    6 YFL=IY
      YFL=YFL*.4656613E-9
      RETURN
      END
```

```
C          ACTUAL  INPUT  DATA

    1   12   14  500    1    1    1   50   50   50
         2           1        20         3          1          4          7
 -8.0E6     40.0    7.0E7      0.0     40.0      2.0      0.0     40.0      1.4
       3         3        1         0.7          0.7         0.7
    1    3         .2E9    5        0.4     1
    2    0    2     2    2        0.4         0.7          0.7
  1.5E7    6.E8    1.101.85E10 1.4E10   1.08    .030     .03 .00513    1.2    .01
    0.7    0.88     2.0     3.0     0.9     10.    0.10    .480     0.1  0.001 .00274
    25.    3.E8    0.05    8.E8  5.E-4    6.0     20. 2.5E-33.25E-2    10.    1.04
   0.170   .030   .015-0.010-0.010-0.005-0.005   0.0  0.020   0.00  0.09  0.00 0.090
   0.015   0.0
1      .600        .960      1.160      1.200       .300       .800
2      .700        .940      1.100      1.200       .300       .700
3      .900        .940      1.020      1.240       .200       .800
4      .010        .680      1.400      1.800       .300       .700
5      .700        .940      1.100      1.200       .300       .700
6      .700        .940      1.100      1.200       .300       .700
7      .700        .940      1.100      1.200       .300       .700
8      .700        .940      1.100      1.200       .300       .700
9      .700        .900      1.100      1.300       .300       .700
10     .700        .940      1.100      1.200       .300       .700
11     .700        .940      1.100      1.200       .300       .700
12    1.000       1.000      1.000      1.000       .300       .700
13     .800        .900      1.100      1.200       .300       .700
14     .900        .950      1.050      1.100       .100       .900
```

```
C    SAMPLE COMPUTER OUTPUT

 ****  VALUES OF INPUT VARIABLES   ****************************************

    J       NA      NRV   ITIMES     IM      IPRINT  IPAT   JPRN2    JPRN3    JPRN4
    1       12      14     500       1         1      1      50       50       50
   IDP         JDP        JPRN5        NCDF       NMRV1       NMRV2      NTGRD      ISING
    2           1          20           3           1           4          5          0
                  XLIM                          YLIM                       ZLIM
 -0.80E 07 0.40E 02 0.70E 08 0.0       0.40E 02 0.20E 01 0.0          0.4E 02 0.1E 01

  NVAR  NRD  IO XS(1) XS(2) XS(3)
    3    3    1 0.700 0.700 0.700
    ICARD      NSI      SIREG          NREG      REG             ISPC
      1         3     0.20000E 09        5    0.40000E 00           1
     NRDD       IOD       NVARD       JIX2       IDP     TMO       XR10       XR20
       2         0          2          2          2   0.4000    0.7000     0.7000

    AS        BAS        BE         BS         CGR        CO         CPBS       CP9
 0.700E 00 0.150E 08 0.900E 00 0.880E 00 0.108E 01 0.100E 00 0.600E 9 0.185E11
    CR9        CS         DM9        DS         EFFI       FE         FXF        GR
 0.274E-02 0.200E 01 0.140E 11 0.300E 01 0.104E 01 0.100E 02 0.300E-01 0.110E1
    PRLI       PR9        RMF        RM9        SCF        SF         SHC        SHD
 0.250E 02 0.300E-01 0.120E 01 0.100E-01 0.100E 00 0.500E-01 0.100E-02 0.50E-3
    SI         TR         TSDI       VL         VR9        XMAXT      XMPM       YLAB
 0.700E 09 0.480E 00 0.600E 01 0.800E 09 0.513E-02 0.200E 02 0.250E-02 0.100E2

   GI(1)      GI(2)      GI(3)      GI(4)      GI(5)      GI(6)      GI(7)      GI(8)
 0.170E 00 0.300E-01 0.150E-01-0.100E-01-0.100E-01-0.500E-02-0.500E-02  0.0
   GI(9)      GI(10)     GI(11)     GI(12)     GI(13)     GI(14)     GI(15)
 0.200E-01 0.0        0.900E-01 0.0        0.900E-01 0.150E-01 0.0
```

VAR. NO.	Z1	Z2	Z3	Z4	Z5	Z6
1	0.600	0.960	1.160	1.200	0.300	0.800
2	0.700	0.940	1.100	1.200	0.300	0.700
3	0.900	0.940	1.020	1.240	0.200	0.800
4	0.010	0.680	1.400	1.800	0.300	0.700
5	0.700	0.940	1.100	1.200	0.300	0.700
6	0.700	0.940	1.100	1.200	0.300	0.700
7	0.700	0.940	1.100	1.200	0.300	0.700
8	0.700	0.940	1.100	1.200	0.300	0.700
9	0.700	0.900	1.100	1.300	0.300	0.700
10	0.700	0.940	1.100	1.200	0.300	0.700
11	0.700	0.940	1.100	1.200	0.300	0.700
12	1.000	1.000	1.000	1.000	0.300	0.700
13	0.800	0.900	1.100	1.200	0.300	0.700
14	0.900	0.950	1.050	1.100	0.100	0.900

** THE INITIAL LEVEL OF SALES IS 0.60000E 09 LB/YR

SEARCH FOR CONSTRAINED SOLUTION

```
ITERATION NO.      0
    VALUE=  -0.302156E 02
              1 0.852000E 00      2 0.764000E 00      3 0.790000E 00

STEP SIZE FOR EACH PARAMETER
              1 0.100000E 00      2 0.100000E 00      3 0.100000E 00
         N/.   2         VALUE=  -0.311296E 02
```

```
              1 0.952000E 00       2 0.764000E 00       3 0.790000E 00
      N/.   3          VALUE=  -0.309809E 02
              1 0.952000E 00       2 0.864000E 00       3 0.790000E 00
      N/.   4          VALUE=  -0.306828E 02
              1 0.952000E 00       2 0.664000E 00       3 0.790000E 00
      N/.   5          VALUE=  -0.323685E 02
              1 0.952000E 00       2 0.764000E 00       3 0.890000E 00
ITERATION NO.      1
    VALUE=  -0.323685E 02
              1 0.952000E 00       2 0.764000E 00       3 0.890000E 00
      N/.   6          VALUE=  -0.343941E 02
              1 0.115200E 01       2 0.764000E 00       3 0.990000E 00
      N/.   7          VALUE=  -0.338614E 02
              1 0.115200E 01       2 0.664000E 00       3 0.990000E 00
      N/.   8          VALUE=  -0.342505E 02
              1 0.115200E 01       2 0.864000E 00       3 0.990000E 00
      N/.   9          VALUE=  -0.350892E 02
              1 0.115200E 01       2 0.764000E 00       3 0.109000E 01
ITERATION NO.      2
    VALUE=  -0.350892E 02
              1 0.115200E 01       2 0.764000E 00       3 0.109000E 01
      N/.  10          VALUE=  -0.358362E 02
              1 0.145200E 01       2 0.764000E 00       3 0.129000E 01
      N/.  11          VALUE=  -0.351203E 02
              1 0.145200E 01       2 0.864000E 00       3 0.129000E 01
      N/.  12          VALUE=  -0.355520E 02
              1 0.145200E 01       2 0.664000E 00       3 0.129000E 01
      N/.  13          VALUE=  -0.357502E 02
              1 0.145200E 01       2 0.764000E 00       3 0.139000E 01
      N/.  14          VALUE=  -0.356113E 02
              1 0.145200E 01       2 0.764000E 00       3 0.119000E 01
ITERATION NO.      3
```

```
    VALUE=   -0.358362E 02
ITERATION NO.      4
    VALUE=   -0.360742E 02
                 1 0.135200E 01      2 0.764000E 00      3 0.129000E 01

STEP SIZE FOR EACH PARAMETER
                 1 0.999999E-02      2 0.999999E-02      3 0.999999E-02

ITERATION NO.      5
    VALUE=   -0.360900E 02
                 1 0.134199E 01      2 0.754000E 00      3 0.129000E 01
ITERATION NO.      6
    VALUE=   -0.361139E 02
                 1 0.132199E 01      2 0.754000E 00      3 0.129000E 01

ITERATION NO.      7
    VALUE=   -0.361468E 02
                 1 0.129199E 01      2 0.764000E 00      3 0.129000E 01
ITERATION NO.      8
    VALUE=   -0.361706E 02
                 1 0.125199E 01      2 0.774000E 00      3 0.129000E 01

ITERATION NO.      9
    VALUE=   -0.361725E 02
                 1 0.120199E 01      2 0.784000E 00      3 0.130000E 01
ITERATION NO.     10
    VALUE=   -0.361740E 02
                 1 0.121199E 01      2 0.784000E 00      3 0.130000E 01

ITERATION NO.     11
    VALUE=   -0.361747E 02
                 1 0.122199E 01      2 0.774000E 00      3 0.129000E 01
```

```
ITERATION NO.     12
    VALUE=  -0.361748E 02
               1 0.123199E 01       2 0.774000E 00       3 0.129000E 01

STEP SIZE FOR EACH PARAMETER
               1 0.999999E-03       2-0.999999E-03       3-0.999999E-03


ITERATION NO.     13
    VALUE=  -0.361751E 02
               1 0.123098E 01       2 0.775000E 00       3 0.129100E 01
ITERATION NO.     14
    VALUE=  -0.361754E 02
               1 0.122898E 01       2 0.777000E 00       3 0.129300E 01

ITERATION NO.     15
    VALUE=  -0.361756E 02
               1 0.122598E 01       2 0.778000E 00       3 0.129499E 01
ITERATION NO.     16
    VALUE=  -0.361756E 02
               1 0.122198E 01       2 0.778999E 00       3 0.129699E 01

 ANSWERS AFTER131  FUNCTIONAL EVALUATIONS

    VALUE=  -0.361756E 02                          OPTIMAL PARAMETERS
               1 0.122198E 01       2 0.778999E 00       3 0.129699E 01
```

```
C     ECONOMIC SUBROUTINE PRINT OUT OF OPTIMUM CASE

 N   CF(N)         T         SLS          CP         VMAIN        PRC         VRT        FXOPC
 1 0.374E 07 0.100E-05 0.600E 09 0.130E 10 0.130E-01 0.300E-01 0.513E-02 0.184E7
 2 0.867E 07 0.551E 01 0.153E 10 0.153E 10 0.119E-01 0.284E-01 0.499E-02 0.206E7

   A(M)=  0.15292     PRESENT VALUE OF CASH FLOW TO TIME "T"  IS 0.23528E 08

 N   CF(N)         T         SLS          CP         VMAIN        PRC         VRT        FXOPC
 2 0.851E 07 0.551E 01 0.153E 10 0.153E 10 0.117E-01 0.284E-01 0.519E-02 0.206E7
 3 0.856E 07 0.600E 01 0.166E 10 0.155E 10 0.116E-01 0.283E-01 0.518E-02 0.208E7

   A(M)=  0.01084     PRESENT VALUE OF CASH FLOW TO TIME "T"  IS 0.25829E 08

 N   CF(N)         T         SLS          CP         VMAIN        PRC         VRT        FXOPC
 3 0.847E 07 0.841E 01 0.207E 10 0.161E 10 0.110E-01 0.276E-01 0.512E-02 0.218E7

   A(M)= -0.00423     PRESENT VALUE OF CASH FLOW TO TIME "T"  IS 0.35468E 08

 N   CF(N)         T         SLS          CP         VMAIN        PRC         VRT        FXOPC
 4 0.111E 08 0.841E 01 0.207E 10 0.283E 10 0.112E-01 0.276E-01 0.492E-02 0.446E7
 5 0.148E 08 0.126E 02 0.302E 10 0.302E 10 0.103E-01 0.264E-01 0.482E-02 0.485E7

   A(M)=  0.06919     PRESENT VALUE OF CASH FLOW TO TIME "T"  IS 0.53267E 08

 N   CF(N)         T         SLS          CP         VMAIN        PRC         VRT        FXOPC
 5 0.145E 08 0.126E 02 0.302E 10 0.302E 10 0.101E-01 0.264E-01 0.501E-02 0.485E7
 6 0.133E 08 0.250E 02 0.920E 10 0.363E 10 0.785E-02 0.234E-01 0.471E-02 0.621E7

   A(M)= -0.00658     PRESENT VALUE OF CASH FLOW TO TIME "T"  IS 0.79059E 08

 IIT=   0  PV= 0.36176E 08  X(1)= 0.12970E 10  X(2)= 0.12220E 10   TM=  0.7790
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ECONOMIC EVALUATION OF A SINGLE PLANT FOR THE RANGE OF THE MAIN VARIABLES

I	J	ZM(1)	ZM(4)	XS(1)	XS(2)	XS(3)	PRES VAL
1.	1.	0.60000	0.01000	0.0	0.40000	0.99700	35.44469
1.	2.	0.60000	0.30800	0.0	0.40000	0.99700	31.90999
1.	3.	0.60000	0.60700	0.0	0.40000	0.99700	28.49509
1.	4.	0.60000	0.90500	0.0	0.40000	0.99700	25.18970
1.	5.	0.60000	1.20300	0.0	0.40000	0.99700	21.98270
1.	6.	0.60000	1.50200	0.0	0.40000	0.99700	18.86139
1.	7.	0.60000	1.80000	0.0	0.40000	0.99700	15.80910
2.	1.	0.70000	0.01000	0.0	0.40000	0.99700	36.68970
2.	2.	0.70000	0.30800	0.0	0.40000	0.99700	33.11819
2.	3.	0.70000	0.60700	0.0	0.40000	0.99700	29.66629
2.	4.	0.70000	0.90500	0.0	0.40000	0.99700	26.32329
2.	5.	0.70000	1.20300	0.0	0.40000	0.99700	23.07860
2.	6.	0.70000	1.50200	0.0	0.40000	0.99700	19.91969
2.	7.	0.70000	1.80000	0.0	0.40000	0.99700	16.83018
3.	1.	0.80000	0.01000	0.0	0.40000	0.99700	37.60349
3.	2.	0.80000	0.30800	0.0	0.40000	0.99700	34.00620
3.	3.	0.80000	0.60700	0.0	0.40000	0.99700	30.53270
3.	4.	0.80000	0.90500	0.0	0.40000	0.99700	27.17380
3.	5.	0.80000	1.20300	0.0	0.40000	0.99700	23.91919
3.	6.	0.80000	1.50200	0.0	0.40000	0.99700	20.75739
3.	7.	0.80000	1.80000	0.0	0.40000	0.99700	17.67239
4.	1.	0.90000	0.01000	0.0	0.40000	0.99700	38.28830
4.	2.	0.90000	0.30800	0.0	0.40000	0.99700	34.67459
4.	3.	0.90000	0.60700	0.0	0.40000	0.99700	31.18729
4.	4.	0.90000	0.90500	0.0	0.40000	0.99700	27.81740
4.	5.	0.90000	1.20300	0.0	0.40000	0.99700	24.55469
4.	6.	0.90000	1.50200	0.0	0.40000	0.99700	21.38759
4.	7.	0.90000	1.80000	0.0	0.40000	0.99700	18.29999

5.	1.	1.00000	0.01000	0.0	0.40000	0.99700	38.81999
5.	2.	1.00000	0.30800	0.0	0.40000	0.99700	35.19579
5.	3.	1.00000	0.60700	0.0	0.40000	0.99700	31.69879
5.	4.	1.00000	0.90500	0.0	0.40000	0.99700	28.31960
5.	5.	1.00000	1.20300	0.0	0.40000	0.99700	25.04799
5.	6.	1.00000	1.50200	0.0	0.40000	0.99700	21.87109
5.	7.	1.00000	1.80000	0.0	0.40000	0.99700	18.77080
6.	1.	1.10000	0.01000	0.0	0.40000	0.99700	39.24399
6.	2.	1.10000	0.30800	0.0	0.40000	0.99700	35.61339
6.	3.	1.10000	0.60700	0.0	0.40000	0.99700	32.10889
6.	4.	1.10000	0.90500	0.0	0.40000	0.99700	28.72069
6.	5.	1.10000	1.20300	0.0	0.40000	0.99700	25.43719
6.	6.	1.10000	1.50200	0.0	0.40000	0.99700	22.24399
6.	7.	1.10000	1.80000	0.0	0.40000	0.99700	19.11938
7.	1.	1.20000	0.01000	0.0	0.40000	0.99700	39.58919
7.	2.	1.20000	0.30800	0.0	0.40000	0.99700	35.95549
7.	3.	1.20000	0.60700	0.0	0.40000	0.99700	32.44489
7.	4.	1.20000	0.90500	0.0	0.40000	0.99700	29.04630
7.	5.	1.20000	1.20300	0.0	0.40000	0.99700	25.74680
7.	6.	1.20000	1.50200	0.0	0.40000	0.99700	22.52919
7.	7.	1.20000	1.80000	0.0	0.40000	0.99700	19.36629

THE PATTERN SEARCH OPTIMIZATION OF 2ND PLANT SIZE AND TIMING

I	J	ZM(1)	ZM(4)	XS(1)	XS(2)	XS(3)	PRES VAL
1.	1.	0.60000	0.01000	1.30000	0.75090	0.99700	42.02589
1.	2.	0.60000	0.30800	1.23000	0.75070	0.99700	36.61580
1.	3.	0.60000	0.60700	1.20600	0.73000	0.99700	31.49879
1.	4.	0.60000	0.90500	1.20200	0.71000	0.99700	26.62360
1.	5.	0.60000	1.20300	1.20010	0.69000	0.99700	21.97530
1.	6.	0.60000	1.50200	0.97000	0.70030	0.99700	17.59389
1.	7.	0.60000	1.80000	0.81000	0.70010	0.99700	13.22990

2.	1.	0.70000	0.01000	1.35000	0.75011	0.99700	45.34099
2.	2.	0.70000	0.30800	1.28000	0.75013	0.99700	39.55980
2.	3.	0.70000	0.60700	1.21000	0.74000	0.99700	34.10680
2.	4.	0.70000	0.90500	1.20041	0.72000	0.99700	28.93129
2.	5.	0.70000	1.20300	1.20011	0.70000	0.99700	23.98270
2.	6.	0.70000	1.50200	1.12000	0.69017	0.99700	19.24759
2.	7.	0.70000	1.80000	0.90000	0.70019	0.99700	14.57530
3.	1.	0.80000	0.01000	1.40000	0.75000	0.99700	48.70389
3.	2.	0.80000	0.30800	1.33000	0.74020	0.99700	42.54489
3.	3.	0.80000	0.60700	1.25000	0.74010	0.99700	36.73450
3.	4.	0.80000	0.90500	1.20060	0.73010	0.99700	31.24460
3.	5.	0.80000	1.20300	1.20003	0.71010	0.99700	25.99629
3.	6.	0.80000	1.50200	1.20010	0.69020	0.99700	20.95270
3.	7.	0.80000	1.80000	1.10000	0.70010	0.99700	15.94590
4.	1.	0.90000	0.01000	1.45000	0.74022	0.99700	52.27789
4.	2.	0.90000	0.30800	1.38000	0.74011	0.99700	45.72949
4.	3.	0.90000	0.60700	1.30000	0.74017	0.99700	39.54900
4.	4.	0.90000	0.90500	1.22000	0.74009	0.99700	33.70929
4.	5.	0.90000	1.20300	1.20051	0.73011	0.99700	28.15070
4.	6.	0.90000	1.50200	1.20021	0.71023	0.99700	22.78519
4.	7.	0.90000	1.80000	1.19000	0.70014	0.99700	17.47009
5.	1.	1.00000	0.01000	1.47000	0.79000	0.99700	56.32700
5.	2.	1.00000	0.30800	1.40000	0.78090	0.99700	49.36240
5.	3.	1.00000	0.60700	1.33000	0.78070	0.99700	42.78459
5.	4.	1.00000	0.90500	1.25000	0.78050	0.99700	36.56219
5.	5.	1.00000	1.20300	1.20070	0.77003	0.99700	30.64960
5.	6.	1.00000	1.50200	1.20040	0.76010	0.99700	24.92360
5.	7.	1.00000	1.80000	1.20001	0.74020	0.99700	19.26529
6.	1.	1.10000	0.01000	2.24000	0.68000	0.99700	60.52170
6.	2.	1.10000	0.30800	1.49000	0.78080	0.99700	53.25439
6.	3.	1.10000	0.60700	1.41000	0.78000	0.99700	46.26360
6.	4.	1.10000	0.90500	1.34000	0.77060	0.99700	39.64249

6.	5.	1.10000	1.20300	1.26000	0.77050	0.99700	33.34380
6.	6.	1.10000	1.50200	1.20055	0.77040	0.99700	27.30179
6.	7.	1.10000	1.80000	1.20021	0.75031	0.99700	21.35989
7.	1.	1.20000	0.01000	2.58000	0.65000	0.99700	66.36060
7.	2.	1.20000	0.30800	2.31000	0.66000	0.99700	57.25439
7.	3.	1.20000	0.60700	1.50000	0.77040	0.99700	49.77629
7.	4.	1.20000	0.90500	1.43000	0.77050	0.99700	42.74680
7.	5.	1.20000	1.20300	1.36000	0.77030	0.99700	36.04179
7.	6.	1.20000	1.50200	1.28000	0.77000	0.99700	29.58490
7.	7.	1.20000	1.80000	1.23000	0.76000	0.99700	23.27269

C FIRST PLANT SIZE = 997 E6 LBS/YR

THE MONTE CARLO OPTION IS IN EFFECT. SINGLE PLANT CASE

MEAN OF PV = 0.27009E 08 STANDARD DEVIATION OF PV = 0.61295E 07 ITIMES = 500

CUMULATIVE DISTRIBUTION FUNCTION OF PRESENT VALUES

0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.4000	1.6000	4.2000	9.8000	16.0000	27.0000
37.6000	49.0000	60.0000	71.0000	82.8000	89.5999	94.9999	99.1999
99.7999	99.9999	99.9999	99.9999	99.9999	99.9999	99.9999	99.9999
99.9999	99.9999	99.9999	99.9999	99.9999	99.9999	99.9999	99.9999

THE MONTE CARLO OPTION IS IN EFFECT. TWO PLANT CASE

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MEAN OF PV = 0.33483E 08 STANDARD DEVIATION OF PV = 0.10275E 08  ITIMES = 500
  CUMULATIVE DISTRIBUTION FUNCTION OF PRESENT VALUES
   0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
   0.0       0.0       0.4000    1.4000    2.8000    7.0000   10.6000   15.2000
  22.2000   28.0000   35.8000   42.0000   50.6000   57.6000   65.2000   72.7999
  78.5999   82.7999   86.1999   89.7999   92.1999   94.5999   97.3999   98.1999
  98.5999   99.3999   99.5999   99.7999   99.7999   99.7999   99.7999   99.9998

MEAN OF 2ND PLANT = 0.1347E 01 STD DEV OF 2ND PLANT = 0.2201E 00  ITIMES = 500
  NUMBER OF TIMES 2ND PLANT NOT BUILT =   35
  CUMULATIVE DISTRIBUTION FUNCTION OF SECOND PLANT SIZE
   0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
   0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
   0.0       0.0       0.0       0.0       0.0       0.0       0.0      27.7419
  49.0322   60.0000   71.1828   80.0000   87.7419   88.8171   89.8924   92.0429
  93.1182   93.9784   94.6236   95.2687   95.4837   96.3440   96.9891   99.9999

MEAN OF TIMING = 0.75433E 00  STD. DEV. OF TIMING = 0.25850E-01  ITIMES =  500
  CUMULATIVE DISTRIBUTION FUNCTION OF TIMING FACTOR
   0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
   0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
   0.0       0.0       0.2151    4.3011   18.0645   82.1505  100.0000  100.0000
 100.0000  100.0000  100.0000  100.0000  100.0000  100.0000  100.0000  100.0000
 100.0000  100.0000  100.0000  100.0000  100.0000  100.0000  100.0000  100.0000
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ECONOMIC EVALUATION OF A SINGLE PLANT FOR THE RANGE OF THE MAIN VARIABLES

I	J	ZM(1)	ZM(4)	XS(1)	XS(2)	XS(3)	PRES VAL
1.	1.	0.60000	0.01000	0.0	0.40000	1.09700	37.16679
1.	2.	0.60000	0.30800	0.0	0.40000	1.09700	33.34839
1.	3.	0.60000	0.60700	0.0	0.40000	1.09700	29.66330
1.	4.	0.60000	0.90500	0.0	0.40000	1.09700	26.10039
1.	5.	0.60000	1.20300	0.0	0.40000	1.09700	22.64789
1.	6.	0.60000	1.50200	0.0	0.40000	1.09700	19.29160
1.	7.	0.60000	1.80000	0.0	0.40000	1.09700	16.01309
2.	1.	0.70000	0.01000	0.0	0.40000	1.09700	38.90929
2.	2.	0.70000	0.30800	0.0	0.40000	1.09700	35.03259
2.	3.	0.70000	0.60700	0.0	0.40000	1.09700	31.28729
2.	4.	0.70000	0.90500	0.0	0.40000	1.09700	27.66190
2.	5.	0.70000	1.20300	0.0	0.40000	1.09700	24.14510
2.	6.	0.70000	1.50200	0.0	0.40000	1.09700	20.72209
2.	7.	0.70000	1.80000	0.0	0.40000	1.09700	17.37489
3.	1.	0.80000	0.01000	0.0	0.40000	1.09700	40.21739
3.	2.	0.80000	0.30800	0.0	0.40000	1.09700	36.30150
3.	3.	0.80000	0.60700	0.0	0.40000	1.09700	32.51720
3.	4.	0.80000	0.90500	0.0	0.40000	1.09700	28.85339
3.	5.	0.80000	1.20300	0.0	0.40000	1.09700	25.29829
3.	6.	0.80000	1.50200	0.0	0.40000	1.09700	21.83780
3.	7.	0.80000	1.80000	0.0	0.40000	1.09700	18.45419
4.	1.	0.90000	0.01000	0.0	0.40000	1.09700	41.21570
4.	2.	0.90000	0.30800	0.0	0.40000	1.09700	37.27170
4.	3.	0.90000	0.60700	0.0	0.40000	1.09700	33.46379
4.	4.	0.90000	0.90500	0.0	0.40000	1.09700	29.78189
4.	5.	0.90000	1.20300	0.0	0.40000	1.09700	26.21489
4.	6.	0.90000	1.50200	0.0	0.40000	1.09700	22.74969
4.	7.	0.90000	1.80000	0.0	0.40000	1.09700	19.36960

5.	1.	1.00000	0.01000	0.0	0.40000	1.09700	41.99550
5.	2.	1.00000	0.30800	0.0	0.40000	1.09700	38.03229
5.	3.	1.00000	0.60700	0.0	0.40000	1.09700	34.20819
5.	4.	1.00000	0.90500	0.0	0.40000	1.09700	30.51299
5.	5.	1.00000	1.20300	0.0	0.40000	1.09700	26.93570
5.	6.	1.00000	1.50200	0.0	0.40000	1.09700	23.46329
5.	7.	1.00000	1.80000	0.0	0.40000	1.09700	20.07809
6.	1.	1.10000	0.01000	0.0	0.40000	1.09700	42.62070
6.	2.	1.10000	0.30800	0.0	0.40000	1.09700	38.64470
6.	3.	1.10000	0.60700	0.0	0.40000	1.09700	34.80849
6.	4.	1.10000	0.90500	0.0	0.40000	1.09700	31.10179
6.	5.	1.10000	1.20300	0.0	0.40000	1.09700	27.51309
6.	6.	1.10000	1.50200	0.0	0.40000	1.09700	24.02820
6.	7.	1.10000	1.80000	0.0	0.40000	1.09700	20.62689
7.	1.	1.20000	0.01000	0.0	0.40000	1.09700	43.13229
7.	2.	1.20000	0.30800	0.0	0.40000	1.09700	39.14809
7.	3.	1.20000	0.60700	0.0	0.40000	1.09700	35.30240
7.	4.	1.20000	0.90500	0.0	0.40000	1.09700	31.58429
7.	5.	1.20000	1.20300	0.0	0.40000	1.09700	27.98109
7.	6.	1.20000	1.50200	0.0	0.40000	1.09700	24.47649
7.	7.	1.20000	1.80000	0.0	0.40000	1.09700	21.04619

THE PATTERN SEARCH OPTIMIZATION OF 2ND PLANT SIZE AND TIMING

I	J	ZM(1)	ZM(4)	XS(1)	XS(2)	XS(3)	PRES VAL
1.	1.	0.60000	0.01000	1.29000	0.77000	1.09700	42.66769
1.	2.	0.60000	0.30800	1.21000	0.77050	1.09700	37.15120
1.	3.	0.60000	0.60700	1.20050	0.75000	1.09700	31.92859
1.	4.	0.60000	0.90500	1.20040	0.73000	1.09700	26.95099
1.	5.	0.60000	1.20300	1.20000	0.70000	1.09700	22.20889
1.	6.	0.60000	1.50200	0.90000	0.72000	1.09700	17.76869
1.	7.	0.60000	1.80000	0.72000	0.75000	1.09700	13.37640

2.	1.	0.70000	0.01000	1.35000	0.77060	1.09700	46.29419
2.	2.	0.70000	0.30800	1.28000	0.76000	1.09700	40.39439
2.	3.	0.70000	0.60700	1.20031	0.76013	1.09700	34.82529
2.	4.	0.70000	0.90500	1.20021	0.74000	1.09700	29.53448
2.	5.	0.70000	1.20300	1.20000	0.71000	1.09700	24.47870
2.	6.	0.70000	1.50200	1.11000	0.70000	1.09700	19.65540
2.	7.	0.70000	1.80000	0.79000	0.74000	1.09700	14.94140
3.	1.	0.80000	0.01000	1.41000	0.76000	1.09700	49.84419
3.	2.	0.80000	0.30800	1.33000	0.76040	1.09700	43.55649
3.	3.	0.80000	0.60700	1.25000	0.76000	1.09700	37.62019
3.	4.	0.80000	0.90500	1.20010	0.75000	1.09700	32.00909
3.	5.	0.80000	1.20300	1.19700	0.73000	1.09700	26.64529
3.	6.	0.80000	1.50200	1.19500	0.71020	1.09700	21.49449
3.	7.	0.80000	1.80000	1.04000	0.71000	1.09700	16.41989
4.	1.	0.90000	0.01000	1.45000	0.76000	1.09700	53.49289
4.	2.	0.90000	0.30800	1.37000	0.76033	1.09700	46.80759
4.	3.	0.90000	0.60700	1.29000	0.76000	1.09700	40.49570
4.	4.	0.90000	0.90500	1.22000	0.75010	1.09700	34.53259
4.	5.	0.90000	1.20300	1.19600	0.74000	1.09700	28.85869
4.	6.	0.90000	1.50200	1.19400	0.72000	1.09700	23.38939
4.	7.	0.90000	1.80000	1.19000	0.70000	1.09700	17.99500
5.	1.	1.00000	0.01000	1.46000	0.80090	1.09700	57.33389
5.	2.	1.00000	0.30800	1.38000	0.80070	1.09700	50.24539
5.	3.	1.00000	0.60700	1.30000	0.80050	1.09700	43.54810
5.	4.	1.00000	0.90500	1.21000	0.80000	1.09700	37.21089
5.	5.	1.00000	1.20300	1.20000	0.75000	1.09700	31.24869
5.	6.	1.00000	1.50200	1.19300	0.73000	1.09700	25.44330
5.	7.	1.00000	1.80000	1.19200	0.72010	1.09700	19.72960
6.	1.	1.10000	0.01000	1.54000	0.80000	1.09700	61.81310
6.	2.	1.10000	0.30800	1.47000	0.79070	1.09700	54.28069
6.	3.	1.10000	0.60700	1.39000	0.79050	1.09700	47.16249
6.	4.	1.10000	0.90500	1.31000	0.79030	1.09700	40.42039

6.	5.	1.10000	1.20300	1.23000	0.79000	1.09700	34.00919
6.	6.	1.10000	1.50200	1.20000	0.78000	1.09700	27.85010
6.	7.	1.10000	1.80000	1.19000	0.77000	1.09700	21.78000
7.	1.	1.20000	0.01000	2.68000	0.62000	1.09700	67.28439
7.	2.	1.20000	0.30800	2.24000	0.69000	1.09700	58.15230
7.	3.	1.20000	0.60700	1.48000	0.79040	1.09700	50.83009
7.	4.	1.20000	0.90500	1.40000	0.79020	1.09700	43.67130
7.	5.	1.20000	1.20300	1.33000	0.78030	1.09700	36.84698
7.	6.	1.20000	1.50200	1.26000	0.78000	1.09700	30.28519
7.	7.	1.20000	1.80000	1.20010	0.78010	1.09700	23.87869

C FIRST PLANT SIZE = 1097 E6 LBS/YR

THE MONTE CARLO OPTION IS IN EFFECT. SINGLE PLANT CASE

MEAN OF PV = 0.29042E 08 STANDARD DEVIATION OF PV = 0.69264E 07 ITIMES = 500

CUMULATIVE DISTRIBUTION FUNCTION OF PRESENT VALUES

0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.4000	1.2000	3.2000	7.2000	12.6000	20.8000
30.0000	39.4000	48.8000	58.8000	69.4000	79.4000	87.2000	92.3999
96.3999	99.3999	99.7999	99.9999	99.9999	99.9999	99.9999	99.9999
99.9999	99.9999	99.9999	99.9999	99.9999	99.9999	99.9999	99.9999

THE MONTE CARLO OPTION IS IN EFFECT. TWO PLANT CASE

MEAN OF PV = 0.34320E 08 STANDARD DEVIATION OF PV = 0.10603E 08 ITIMES = 500

CUMULATIVE DISTRIBUTION FUNCTION OF PRESENT VALUES

0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.4000	1.2000	3.0000	6.2000	10.4000	15.4000
20.2000	27.8000	32.0000	39.0000	46.6000	53.8000	62.2000	68.4000
75.8000	80.3999	83.7999	87.7999	90.7999	92.7999	95.9999	97.9999
98.5999	99.1999	99.5999	99.7999	99.7999	99.7999	99.7999	99.9999

MEAN OF 2ND PLANT = 0.1321E 01 STD DEV OF 2ND PLANT = 0.1835E 00 ITIMES = 500

NUMBER OF TIMES 2ND PLANT NOT BUILT = 48

CUMULATIVE DISTRIBUTION FUNCTION OF SECOND PLANT SIZE

0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	32.0796
51.7699	63.2743	73.8938	83.4070	90.2654	93.3628	94.2477	94.6902
94.9114	95.5751	96.0176	96.2388	96.9026	97.5663	98.0087	99.9999

MEAN OF TIMING = 0.76828E 00 STD. DEV. OF TIMING = 0.26963E-01 ITIMES = 500

CUMULATIVE DISTRIBUTION FUNCTION OF TIMING FACTOR

0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	1.3274	15.0442	46.0177	100.0000	100.0000
100.0000	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000
100.0000	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000

ECONOMIC EVALUATION OF A SINGLE PLANT FOR THE RANGE OF THE MAIN VARIABLES

I	J	ZM(1)	ZM(4)	XS(1)	XS(2)	XS(3)	PRES VAL
1.	1.	0.60000	0.01000	0.0	0.40000	1.19700	38.51349
1.	2.	0.60000	0.30800	0.0	0.40000	1.19700	34.43369
1.	3.	0.60000	0.60700	0.0	0.40000	1.19700	30.49969
1.	4.	0.60000	0.90500	0.0	0.40000	1.19700	26.69958
1.	5.	0.60000	1.20300	0.0	0.40000	1.19700	23.02049
1.	6.	0.60000	1.50200	0.0	0.40000	1.19700	19.44690
1.	7.	0.60000	1.80000	0.0	0.40000	1.19700	15.95810
2.	1.	0.70000	0.01000	0.0	0.40000	1.19700	40.71809
2.	2.	0.70000	0.30800	0.0	0.40000	1.19700	36.55530
2.	3.	0.70000	0.60700	0.0	0.40000	1.19700	32.53729
2.	4.	0.70000	0.90500	0.0	0.40000	1.19700	28.65210
2.	5.	0.70000	1.20300	0.0	0.40000	1.19700	24.88739
2.	6.	0.70000	1.50200	0.0	0.40000	1.19700	21.22739
2.	7.	0.70000	1.80000	0.0	0.40000	1.19700	17.65199
3.	1.	0.80000	0.01000	0.0	0.40000	1.19700	42.51549
3.	2.	0.80000	0.30800	0.0	0.40000	1.19700	38.29279
3.	3.	0.80000	0.60700	0.0	0.40000	1.19700	34.21280
3.	4.	0.80000	0.90500	0.0	0.40000	1.19700	30.26379
3.	5.	0.80000	1.20300	0.0	0.40000	1.19700	26.43230
3.	6.	0.80000	1.50200	0.0	0.40000	1.19700	22.70219
3.	7.	0.80000	1.80000	0.0	0.40000	1.19700	19.05519
4.	1.	0.90000	0.01000	0.0	0.40000	1.19700	43.85139
4.	2.	0.90000	0.30800	0.0	0.40000	1.19700	39.58870
4.	3.	0.90000	0.60700	0.0	0.40000	1.19700	35.47020
4.	4.	0.90000	0.90500	0.0	0.40000	1.19700	31.48399
4.	5.	0.90000	1.20300	0.0	0.40000	1.19700	27.61769
4.	6.	0.90000	1.50200	0.0	0.40000	1.19700	23.85570
4.	7.	0.90000	1.80000	0.0	0.40000	1.19700	20.17920

5.	1.	1.00000	0.01000	0.0	0.40000	1.19700	44.90659
5.	2.	1.00000	0.30800	0.0	0.40000	1.19700	40.61420
5.	3.	1.00000	0.60700	0.0	0.40000	1.19700	36.47079
5.	4.	1.00000	0.90500	0.0	0.40000	1.19700	32.46529
5.	5.	1.00000	1.20300	0.0	0.40000	1.19700	28.58559
5.	6.	1.00000	1.50200	0.0	0.40000	1.19700	24.81760
5.	7.	1.00000	1.80000	0.0	0.40000	1.19700	21.14268
6.	1.	1.10000	0.01000	0.0	0.40000	1.19700	45.75629
6.	2.	1.10000	0.30800	0.0	0.40000	1.19700	41.44310
6.	3.	1.10000	0.60700	0.0	0.40000	1.19700	37.28159
6.	4.	1.10000	0.90500	0.0	0.40000	1.19700	33.26089
6.	5.	1.10000	1.20300	0.0	0.40000	1.19700	29.36890
6.	6.	1.10000	1.50200	0.0	0.40000	1.19700	25.59109
6.	7.	1.10000	1.80000	0.0	0.40000	1.19700	21.90790
7.	1.	1.20000	0.01000	0.0	0.40000	1.19700	46.45450
7.	2.	1.20000	0.30800	0.0	0.40000	1.19700	42.12679
7.	3.	1.20000	0.60700	0.0	0.40000	1.19700	37.95149
7.	4.	1.20000	0.90500	0.0	0.40000	1.19700	33.91719
7.	5.	1.20000	1.20300	0.0	0.40000	1.19700	30.01099
7.	6.	1.20000	1.50200	0.0	0.40000	1.19700	26.21750
7.	7.	1.20000	1.80000	0.0	0.40000	1.19700	22.51369

THE PATTERN SEARCH OPTIMIZATION OF 2ND PLANT SIZE AND TIMING

I	J	ZM(1)	ZM(4)	XS(1)	XS(2)	XS(3)	PRES VAL
1.	1.	0.60000	0.01000	1.27000	0.79000	1.19700	43.08449
1.	2.	0.60000	0.30800	1.20000	0.78000	1.19700	37.47159
1.	3.	0.60000	0.60700	1.20000	0.76000	1.19700	32.14650
1.	4.	0.60000	0.90500	1.20000	0.74000	1.19700	27.07259
1.	5.	0.60000	1.20300	1.13000	0.72000	1.19700	22.24629
1.	6.	0.60000	1.50200	0.79000	0.75000	1.19700	17.75829
1.	7.	0.60000	1.80000	0.0	0.40000	1.19700	15.95810

2.	1.	0.70000	0.01000	1.34000	0.78050	1.19700	47.00609
2.	2.	0.70000	0.30800	1.26000	0.78030	1.19700	40.99529
2.	3.	0.70000	0.60700	1.20000	0.77000	1.19700	35.31749
2.	4.	0.70000	0.90500	1.20000	0.75000	1.19700	29.91640
2.	5.	0.70000	1.20300	1.20000	0.73050	1.19700	24.75989
2.	6.	0.70000	1.50200	1.01000	0.73030	1.19700	19.85970
2.	7.	0.70000	1.80000	0.84000	0.75000	1.19700	15.09570
3.	1.	0.80000	0.01000	1.39000	0.78000	1.19700	50.85950
3.	2.	0.80000	0.30800	1.32000	0.78020	1.19700	44.44499
3.	3.	0.80000	0.60700	1.24000	0.77010	1.19700	38.38849
3.	4.	0.80000	0.90500	1.20070	0.76000	1.19700	32.65759
3.	5.	0.80000	1.20300	1.20050	0.74000	1.19700	27.17859
3.	6.	0.80000	1.50200	1.15000	0.72000	1.19700	21.91750
3.	7.	0.80000	1.80000	0.86000	0.75010	1.19700	16.78799
4.	1.	0.90000	0.01000	1.46000	0.77070	1.19700	54.63530
4.	2.	0.90000	0.30800	1.38000	0.77050	1.19700	47.81619
4.	3.	0.90000	0.60700	1.29000	0.77030	1.19700	41.37560
4.	4.	0.90000	0.90500	1.21000	0.77000	1.19700	35.28760
4.	5.	0.90000	1.20300	1.20030	0.75000	1.19700	29.49269
4.	6.	0.90000	1.50200	1.20020	0.73000	1.19700	23.91289
4.	7.	0.90000	1.80000	1.15000	0.72010	1.19700	18.43419
5.	1.	1.00000	0.01000	1.49000	0.77040	1.19700	58.56979
5.	2.	1.00000	0.30800	1.42000	0.77000	1.19700	51.33699
5.	3.	1.00000	0.60700	1.34000	0.77010	1.19700	44.50240
5.	4.	1.00000	0.90500	1.25000	0.77005	1.19700	38.03760
5.	5.	1.00000	1.20300	1.21000	0.76000	1.19700	31.89839
5.	6.	1.00000	1.50200	1.20000	0.74000	1.19700	25.98878
5.	7.	1.00000	1.80000	1.19800	0.73009	1.19700	20.19370
6.	1.	1.10000	0.01000	1.51000	0.82000	1.19700	62.83939
6.	2.	1.10000	0.30800	1.44000	0.81030	1.19700	55.17830
6.	3.	1.10000	0.60700	1.36000	0.81020	1.19700	47.93390
6.	4.	1.10000	0.90500	1.28000	0.81000	1.19700	41.07230

6.	5.	1.10000	1.20300	1.20050	0.80000	1.19700	34.54999
6.	6.	1.10000	1.50200	1.20001	0.76010	1.19700	28.27089
6.	7.	1.10000	1.80000	1.20000	0.74000	1.19700	22.11800
7.	1.	1.20000	0.01000	2.71000	0.64000	1.19700	68.38669
7.	2.	1.20000	0.30800	1.53000	0.81000	1.19700	59.44159
7.	3.	1.20000	0.60700	1.45000	0.81010	1.19700	51.75899
7.	4.	1.20000	0.90500	1.37000	0.80020	1.19700	44.47299
7.	5.	1.20000	1.20300	1.29000	0.80010	1.19700	37.53200
7.	6.	1.20000	1.50200	1.21000	0.80000	1.19700	30.86400
7.	7.	1.20000	1.80000	1.19800	0.79000	1.19700	24.34619

C FIRST PLANT SIZE = 1197 E6 LBS/YR

THE MONTE CARLO OPTION IS IN EFFECT. SINGLE PLANT CASE

MEAN OF PV = 0.30817E 08 STANDARD DEVIATION OF PV = 0.77227E 07 ITIMES = 500

CUMULATIVE DISTRIBUTION FUNCTION OF PRESENT VALUES

0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.4000	1.2000	3.2000	5.8000	10.6000	14.8000
25.0000	33.2000	42.4000	50.4000	59.8000	69.0000	77.0000	85.4000
89.6000	94.6000	97.6000	99.3999	99.7999	99.9999	99.9999	99.9999
99.9999	99.9999	99.9999	99.9999	99.9999	99.9999	99.9999	99.9999

THE MONTE CARLO OPTION IS IN EFFECT. TWO PLANT CASE

MEAN OF PV = 0.35093E 08 STANDARD DEVIATION OF PV = 0.10955E 08 ITIMES = 500

CUMULATIVE DISTRIBUTION FUNCTION OF PRESENT VALUES

0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.4000	1.2000	2.8000	5.4000	9.4000	12.6000
19.6000	27.2000	32.8000	38.8000	44.2000	51.6000	58.6000	64.8000
71.8000	78.0000	81.2000	85.5999	89.3999	91.1999	94.5999	96.5999
98.3999	98.5999	99.3999	99.5999	99.7999	99.7999	99.7999	99.9999

MEAN OF 2ND PLANT = 0.1306E 01 STD DEV OF 2ND PLANT = 0.1436E 00 ITIMES = 500

NUMBER OF TIMES 2ND PLANT NOT BUILT = 66

CUMULATIVE DISTRIBUTION FUNCTION OF SECOND PLANT SIZE

0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	34.7926
51.1521	62.6728	74.1935	83.1797	92.1658	97.0045	97.2350	97.9262
97.9262	98.1566	98.3870	98.3870	98.3870	98.6174	98.6174	99.9999

MEAN OF TIMING = 0.77650E 00 STD. DEV. OF TIMING = 0.23566E-01 ITIMES = 500

CUMULATIVE DISTRIBUTION FUNCTION OF TIMING FACTOR

0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	5.5300	46.3134	99.3087	100.0000
100.0000	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000
100.0000	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000

ECONOMIC EVALUATION OF A SINGLE PLANT FOR THE RANGE OF THE MAIN VARIABLES

I	J	ZM(1)	ZM(4)	XS(1)	XS(2)	XS(3)	PRES VAL
1.	1.	0.60000	0.01000	0.0	0.40000	1.29700	38.96339
1.	2.	0.60000	0.30800	0.0	0.40000	1.29700	34.64310
1.	3.	0.60000	0.60700	0.0	0.40000	1.29700	30.48000
1.	4.	0.60000	0.90500	0.0	0.40000	1.29700	26.46140
1.	5.	0.60000	1.20300	0.0	0.40000	1.29700	22.57339
1.	6.	0.60000	1.50200	0.0	0.40000	1.29700	18.79889
1.	7.	0.60000	1.80000	0.0	0.40000	1.29700	15.11440
2.	1.	0.70000	0.01000	0.0	0.40000	1.29700	41.58739
2.	2.	0.70000	0.30800	0.0	0.40000	1.29700	37.15860
2.	3.	0.70000	0.60700	0.0	0.40000	1.29700	32.88730
2.	4.	0.70000	0.90500	0.0	0.40000	1.29700	28.76070
2.	5.	0.70000	1.20300	0.0	0.40000	1.29700	24.76559
2.	6.	0.70000	1.50200	0.0	0.40000	1.29700	20.88469
2.	7.	0.70000	1.80000	0.0	0.40000	1.29700	17.09569
3.	1.	0.80000	0.01000	0.0	0.40000	1.29700	43.85599
3.	2.	0.80000	0.30800	0.0	0.40000	1.29700	39.34279
3.	3.	0.80000	0.60700	0.0	0.40000	1.29700	34.98599
3.	4.	0.80000	0.90500	0.0	0.40000	1.29700	30.77328
3.	5.	0.80000	1.20300	0.0	0.40000	1.29700	26.69009
3.	6.	0.80000	1.50200	0.0	0.40000	1.29700	22.71939
3.	7.	0.80000	1.80000	0.0	0.40000	1.29700	18.84090
4.	1.	0.90000	0.01000	0.0	0.40000	1.29700	45.65590
4.	2.	0.90000	0.30800	0.0	0.40000	1.29700	41.08409
4.	3.	0.90000	0.60700	0.0	0.40000	1.29700	36.66629
4.	4.	0.90000	0.90500	0.0	0.40000	1.29700	32.38959
4.	5.	0.90000	1.20300	0.0	0.40000	1.29700	28.23949
4.	6.	0.90000	1.50200	0.0	0.40000	1.29700	24.19890
4.	7.	0.90000	1.80000	0.0	0.40000	1.29700	20.24579

5.	1.	1.00000	0.01000	0.0	0.40000	1.29700	46.99770
5.	2.	1.00000	0.30800	0.0	0.40000	1.29700	42.38559
5.	3.	1.00000	0.60700	0.0	0.40000	1.29700	37.93100
5.	4.	1.00000	0.90500	0.0	0.40000	1.29700	33.62129
5.	5.	1.00000	1.20300	0.0	0.40000	1.29700	29.44269
5.	6.	1.00000	1.50200	0.0	0.40000	1.29700	25.37920
5.	7.	1.00000	1.80000	0.0	0.40000	1.29700	21.41029
6.	1.	1.10000	0.01000	0.0	0.40000	1.29700	48.09119
6.	2.	1.10000	0.30800	0.0	0.40000	1.29700	43.44890
6.	3.	1.10000	0.60700	0.0	0.40000	1.29700	38.96869
6.	4.	1.10000	0.90500	0.0	0.40000	1.29700	34.63849
6.	5.	1.10000	1.20300	0.0	0.40000	1.29700	30.44550
6.	6.	1.10000	1.50200	0.0	0.40000	1.29700	26.37410
6.	7.	1.10000	1.80000	0.0	0.40000	1.29700	22.40430
7.	1.	1.20000	0.01000	0.0	0.40000	1.29700	48.99280
7.	2.	1.20000	0.30800	0.0	0.40000	1.29700	44.32860
7.	3.	1.20000	0.60700	0.0	0.40000	1.29700	39.82899
7.	4.	1.20000	0.90500	0.0	0.40000	1.29700	35.48199
7.	5.	1.20000	1.20300	0.0	0.40000	1.29700	31.27440
7.	6.	1.20000	1.50200	0.0	0.40000	1.29700	27.19029
7.	7.	1.20000	1.80000	0.0	0.40000	1.29700	23.20789

THE PATTERN SEARCH OPTIMIZATION OF 2ND PLANT SIZE AND TIMING

I	J	ZM(1)	ZM(4)	XS(1)	XS(2)	XS(3)	PRES VAL
1.	1.	0.60000	0.01000	1.26000	0.80000	1.29700	42.73009
1.	2.	0.60000	0.30800	1.20090	0.79000	1.29700	37.02719
1.	3.	0.60000	0.60700	1.20080	0.77000	1.29700	31.60559
1.	4.	0.60000	0.90500	1.20070	0.75010	1.29700	26.44089
1.	5.	0.60000	1.20300	1.02000	0.75000	1.29700	21.54439
1.	6.	0.60000	1.50200	0.62000	0.79000	1.29700	17.02260
1.	7.	0.60000	1.80000	0.0	0.40000	1.29700	15.11440

2.	1.	0.70000	0.01000	1.33000	0.80010	1.29700	46.92200
2.	2.	0.70000	0.30800	1.25000	0.79010	1.29700	40.80710
2.	3.	0.70000	0.60700	1.20060	0.78000	1.29700	35.02570
2.	4.	0.70000	0.90500	1.20050	0.76000	1.29700	29.51990
2.	5.	0.70000	1.20300	1.20010	0.74000	1.29700	24.26649
2.	6.	0.70000	1.50200	0.93000	0.75010	1.29700	19.30330
2.	7.	0.70000	1.80000	0.0	0.40000	1.29700	17.09569
3.	1.	0.80000	0.01000	1.40000	0.79030	1.29700	51.07790
3.	2.	0.80000	0.30800	1.31000	0.79000	1.29700	44.54500
3.	3.	0.80000	0.60700	1.23000	0.78010	1.29700	38.37219
3.	4.	0.80000	0.90500	1.20030	0.77000	1.29700	32.52719
3.	5.	0.80000	1.20300	1.20020	0.75000	1.29700	26.93919
3.	6.	0.80000	1.50200	1.17000	0.73000	1.29700	21.58730
3.	7.	0.80000	1.80000	0.71000	0.79000	1.29700	16.39589
4.	1.	0.90000	0.01000	1.45000	0.79040	1.29700	55.13049
4.	2.	0.90000	0.30800	1.36000	0.79020	1.29700	48.17659
4.	3.	0.90000	0.60700	1.29000	0.78000	1.29700	41.60789
4.	4.	0.90000	0.90500	1.20010	0.78020	1.29700	35.39749
4.	5.	0.90000	1.20300	1.20000	0.76000	1.29700	29.47890
4.	6.	0.90000	1.50200	1.20005	0.74010	1.29700	23.78719
4.	7.	0.90000	1.80000	1.10000	0.74000	1.29700	18.21709
5.	1.	1.00000	0.01000	1.49000	0.79000	1.29700	59.13609
5.	2.	1.00000	0.30800	1.42000	0.78070	1.29700	51.76239
5.	3.	1.00000	0.60700	1.34000	0.78040	1.29700	44.79349
5.	4.	1.00000	0.90500	1.25000	0.78020	1.29700	38.20119
5.	5.	1.00000	1.20300	1.20007	0.77000	1.29700	31.94319
5.	6.	1.00000	1.50200	1.20003	0.75000	1.29700	25.91539
5.	7.	1.00000	1.80000	1.20000	0.73000	1.29700	20.01929
6.	1.	1.10000	0.01000	1.55000	0.78090	1.29700	63.37230
6.	2.	1.10000	0.30800	1.47000	0.78060	1.29700	55.56689
6.	3.	1.10000	0.60700	1.38000	0.78030	1.29700	48.18660
6.	4.	1.10000	0.90500	1.30000	0.78010	1.29700	41.19789

6.	5.	1.10000	1.20300	1.21000	0.78000	1.29700	34.55899
6.	6.	1.10000	1.50200	1.20014	0.77010	1.29700	28.18230
6.	7.	1.10000	1.80000	1.20009	0.75010	1.29700	21.93539
7.	1.	1.20000	0.01000	2.71000	0.66000	1.29700	68.91669
7.	2.	1.20000	0.30800	1.51000	0.82050	1.29700	59.80350
7.	3.	1.20000	0.60700	1.42000	0.82030	1.29700	51.98940
7.	4.	1.20000	0.90500	1.34000	0.82020	1.29700	44.57790
7.	5.	1.20000	1.20300	1.26000	0.82000	1.29700	37.52039
7.	6.	1.20000	1.50200	1.20003	0.81000	1.29700	30.74619
7.	7.	1.20000	1.80000	1.19800	0.80000	1.29700	24.09560

C   FIRST PLANT SIZE = 1297 E6 LBS/YR

THE MONTE CARLO OPTION IS IN EFFECT. SINGLE PLANT CASE

MEAN OF PV = 0.31774E 08 STANDARD DEVIATION OF PV = 0.85259E 07 ITIMES = 500

CUMULATIVE DISTRIBUTION FUNCTION OF PRESENT VALUES

0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.2000	0.6000	1.4000	3.4000	6.4000	10.2000	14.8000
23.0000	31.4000	40.2000	47.8000	54.2000	63.2000	70.9999	78.9999
85.3999	89.7999	93.9999	97.1999	99.1999	99.7999	99.9999	99.9999
99.9999	99.9999	99.9999	99.9999	99.9999	99.9999	99.9999	99.9999

THE MONTE CARLO OPTION IS IN EFFECT. TWO PLANT CASE

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MEAN OF PV = 0.35244E 08 STANDARD DEVIATION OF PV = 0.11384E 08  ITIMES = 500
  CUMULATIVE DISTRIBUTION FUNCTION OF PRESENT VALUES
   0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
   0.0       0.2000    0.6000    1.4000    3.4000    6.2000   10.2000   13.8000
  20.0000   27.2000   33.6000   39.0000   44.4000   50.6000   57.3999   62.9999
  69.3999   76.1999   79.9999   83.7999   87.7999   91.5999   93.5999   95.5999
  97.7999   98.9999   99.3999   99.5999   99.5999   99.7999   99.7999   99.9999

MEAN OF 2ND PLANT = 0.1311E 01 STD DEV OF 2ND PLANT = 0.1482E 00  ITIMES = 500
  NUMBER OF TIMES 2ND PLANT NOT BUILT =    87
  CUMULATIVE DISTRIBUTION FUNCTION OF SECOND PLANT SIZE
   0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
   0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
   0.0       0.0       0.0       0.0       0.0       0.0       0.0      32.6876
  51.0896   61.7433   74.8184   81.5980   90.5569   96.3680   97.3365   97.3365
  97.8208   98.0629   98.3050   98.3050   98.3050   98.5471   98.5471   99.9999

MEAN OF TIMING = 0.78135E 00  STD. DEV. OF TIMING = 0.19125E-01  ITIMES =  500
  CUMULATIVE DISTRIBUTION FUNCTION OF TIMING FACTOR
   0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
   0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
   0.0       0.0       0.0       0.0       1.4528   24.6973   94.1888  100.0000
 100.0000  100.0000  100.0000  100.0000  100.0000  100.0000  100.0000  100.0000
 100.0000  100.0000  100.0000  100.0000  100.0000  100.0000  100.0000  100.0000
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ECONOMIC EVALUATION OF A SINGLE PLANT FOR THE RANGE OF THE MAIN VARIABLES

I	J	ZM(1)	ZM(4)	XS(1)	XS(2)	XS(3)	PRES VAL
1.	1.	0.60000	0.01000	0.0	0.40000	1.39700	38.93349
1.	2.	0.60000	0.30800	0.0	0.40000	1.39700	34.39209
1.	3.	0.60000	0.60700	0.0	0.40000	1.39700	30.01839
1.	4.	0.60000	0.90500	0.0	0.40000	1.39700	25.79880
1.	5.	0.60000	1.20300	0.0	0.40000	1.39700	21.71809
1.	6.	0.60000	1.50200	0.0	0.40000	1.39700	17.75760
1.	7.	0.60000	1.80000	0.0	0.40000	1.39700	13.89060
2.	1.	0.70000	0.01000	0.0	0.40000	1.39700	41.94109
2.	2.	0.70000	0.30800	0.0	0.40000	1.39700	37.26540
2.	3.	0.70000	0.60700	0.0	0.40000	1.39700	32.75919
2.	4.	0.70000	0.90500	0.0	0.40000	1.39700	28.40860
2.	5.	0.70000	1.20300	0.0	0.40000	1.39700	24.19919
2.	6.	0.70000	1.50200	0.0	0.40000	1.39700	20.11240
2.	7.	0.70000	1.80000	0.0	0.40000	1.39700	16.12329
3.	1.	0.80000	0.01000	0.0	0.40000	1.39700	44.64069
3.	2.	0.80000	0.30800	0.0	0.40000	1.39700	39.85529
3.	3.	0.80000	0.60700	0.0	0.40000	1.39700	35.23940
3.	4.	0.80000	0.90500	0.0	0.40000	1.39700	30.77979
3.	5.	0.80000	1.20300	0.0	0.40000	1.39700	26.46089
3.	6.	0.80000	1.50200	0.0	0.40000	1.39700	22.26450
3.	7.	0.80000	1.80000	0.0	0.40000	1.39700	18.16800
4.	1.	0.90000	0.01000	0.0	0.40000	1.39700	46.92470
4.	2.	0.90000	0.30800	0.0	0.40000	1.39700	42.05649
4.	3.	0.90000	0.60700	0.0	0.40000	1.39700	37.35640
4.	4.	0.90000	0.90500	0.0	0.40000	1.39700	32.81059
4.	5.	0.90000	1.20300	0.0	0.40000	1.39700	28.40369
4.	6.	0.90000	1.50200	0.0	0.40000	1.39700	24.11780
4.	7.	0.90000	1.80000	0.0	0.40000	1.39700	19.92899

5.	1.	1.00000	0.01000	0.0	0.40000	1.39700	48.66559
5.	2.	1.00000	0.30800	0.0	0.40000	1.39700	43.74280
5.	3.	1.00000	0.60700	0.0	0.40000	1.39700	38.98499
5.	4.	1.00000	0.90500	0.0	0.40000	1.39700	34.37790
5.	5.	1.00000	1.20300	0.0	0.40000	1.39700	29.90579
5.	6.	1.00000	1.50200	0.0	0.40000	1.39700	25.55019
5.	7.	1.00000	1.80000	0.0	0.40000	1.39700	21.28729
6.	1.	1.10000	0.01000	0.0	0.40000	1.39700	50.01479
6.	2.	1.10000	0.30800	0.0	0.40000	1.39700	45.05128
6.	3.	1.10000	0.60700	0.0	0.40000	1.39700	40.25879
6.	4.	1.10000	0.90500	0.0	0.40000	1.39700	35.62410
6.	5.	1.10000	1.20300	0.0	0.40000	1.39700	31.13249
6.	6.	1.10000	1.50200	0.0	0.40000	1.39700	26.76720
6.	7.	1.10000	1.80000	0.0	0.40000	1.39700	22.50629
7.	1.	1.20000	0.01000	0.0	0.40000	1.39700	51.13390
7.	2.	1.20000	0.30800	0.0	0.40000	1.39700	46.14009
7.	3.	1.20000	0.60700	0.0	0.40000	1.39700	41.32169
7.	4.	1.20000	0.90500	0.0	0.40000	1.39700	36.66579
7.	5.	1.20000	1.20300	0.0	0.40000	1.39700	32.15839
7.	6.	1.20000	1.50200	0.0	0.40000	1.39700	27.78279
7.	7.	1.20000	1.80000	0.0	0.40000	1.39700	23.51689
1.	1.	0.60000	0.01000	1.23000	0.82000	1.39700	42.00220

THE PATTERN SEARCH OPTIMIZATION OF 2ND PLANT SIZE AND TIMING

I	J	ZM(1)	ZM(4)	XS(1)	XS(2)	XS(3)	PRES VAL
1.	2.	0.60000	0.30800	1.20010	0.80000	1.39700	36.21370
1.	3.	0.60000	0.60700	1.19500	0.78000	1.39700	30.70209
1.	4.	0.60000	0.90500	1.20000	0.76000	1.39700	25.45209
1.	5.	0.60000	1.20300	0.92000	0.77000	1.39700	20.50290
1.	6.	0.60000	1.50200	0.0	0.40000	1.39700	17.75760
1.	7.	0.60000	1.80000	0.0	0.40000	1.39700	13.89060

2.	1.	0.70000	0.01000	1.31000	0.81030	1.39700	46.44229
2.	2.	0.70000	0.30800	1.22000	0.81000	1.39700	40.23000
2.	3.	0.70000	0.60700	1.20080	0.79000	1.39700	34.35100
2.	4.	0.70000	0.90500	1.20070	0.77010	1.39700	28.74570
2.	5.	0.70000	1.20300	1.18000	0.75000	1.39700	23.39969
2.	6.	0.70000	1.50200	0.82000	0.77020	1.39700	18.39090
2.	7.	0.70000	1.80000	0.0	0.40000	1.39700	16.12329
3.	1.	0.80000	0.01000	1.38000	0.81010	1.39700	50.87650
3.	2.	0.80000	0.30800	1.30000	0.80030	1.39700	44.23230
3.	3.	0.80000	0.60700	1.21000	0.80010	1.39700	37.95119
3.	4.	0.80000	0.90500	1.20050	0.78000	1.39700	31.99570
3.	5.	0.80000	1.20300	1.20030	0.76000	1.39700	26.30260
3.	6.	0.80000	1.50200	1.12000	0.74000	1.39700	20.86299
3.	7.	0.80000	1.80000	0.70000	0.80000	1.39700	15.65070
4.	1.	0.90000	0.01000	1.44000	0.80050	1.39700	55.24170
4.	2.	0.90000	0.30800	1.36000	0.80030	1.39700	48.16080
4.	3.	0.90000	0.60700	1.28000	0.79010	1.39700	41.46840
4.	4.	0.90000	0.90500	1.20035	0.79000	1.39700	35.14069
4.	5.	0.90000	1.20300	1.20025	0.77000	1.39700	29.10439
4.	6.	0.90000	1.50200	1.20010	0.75000	1.39700	23.30710
4.	7.	0.90000	1.80000	0.88000	0.78000	1.39700	17.64580
5.	1.	1.00000	0.01000	1.50000	0.80000	1.39700	59.45720
5.	2.	1.00000	0.30800	1.42000	0.79009	1.39700	51.94170
5.	3.	1.00000	0.60700	1.33000	0.79050	1.39700	44.83809
5.	4.	1.00000	0.90500	1.24000	0.79030	1.39700	38.11670
5.	5.	1.00000	1.20300	1.20015	0.78010	1.39700	31.73239
5.	6.	1.00000	1.50200	1.20005	0.76000	1.39700	25.58490
5.	7.	1.00000	1.80000	1.18000	0.75000	1.39700	19.57959
6.	1.	1.10000	0.01000	1.55000	0.79060	1.39700	63.72670
6.	2.	1.10000	0.30800	1.47000	0.79040	1.39700	55.77429
6.	3.	1.10000	0.60700	1.38000	0.79020	1.39700	48.25420
6.	4.	1.10000	0.90500	1.29000	0.79010	1.39700	41.13319

6.	5.	1.10000	1.20300	1.20004	0.79000	1.39700	34.37160
6.	6.	1.10000	1.50200	1.19800	0.77000	1.39700	27.87689
6.	7.	1.10000	1.80000	1.19700	0.76000	1.39700	21.52910
7.	1.	1.20000	0.01000	2.75000	0.67000	1.39700	69.23369
7.	2.	1.20000	0.30800	1.51000	0.79070	1.39700	59.88570
7.	3.	1.20000	0.60700	1.43000	0.79009	1.39700	51.93750
7.	4.	1.20000	0.90500	1.34000	0.79030	1.39700	44.40120
7.	5.	1.20000	1.20300	1.26000	0.79017	1.39700	37.22899
7.	6.	1.20000	1.50200	1.20010	0.79001	1.39700	30.34920
7.	7.	1.20000	1.80000	1.20000	0.77000	1.39700	23.61479

C FIRST PLANT SIZE = 1397 E6 LBS/YR

THE MONTE CARLO OPTION IS IN EFFECT. SINGLE PLANT CASE

MEAN OF PV = 0.32296E 08 STANDARD DEVIATION OF PV = 0.93239E 07 ITIMES = 500

CUMULATIVE DISTRIBUTION FUNCTION OF PRESENT VALUES

0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.2000	0.2000	1.0000	2.6000	4.0000	7.0000	11.2000	15.8000
23.2000	31.8000	38.8000	46.4000	51.8000	60.6000	69.0000	74.0000
82.2000	86.5999	91.3999	93.9999	97.1999	98.9999	99.3999	99.7999
99.9999	99.9999	99.9999	99.9999	99.9999	99.9999	99.9999	99.9999

THE MONTE CARLO OPTION IS IN EFFECT. TWO PLANT CASE

MEAN OF PV = 0.35062E 08 STANDARD DEVIATION OF PV = 0.11782E 08 ITIMES = 500

CUMULATIVE DISTRIBUTION FUNCTION OF PRESENT VALUES

0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.2000	0.2000	1.0000	2.6000	4.2000	7.4000	10.8000	15.4000
21.4000	28.6000	35.4000	40.4000	45.6000	51.8000	58.0000	62.8000
69.2000	75.2000	79.2000	83.2000	87.2000	91.3999	92.5999	95.3999
96.9999	98.7999	99.3999	99.3999	99.5999	99.7999	99.7999	99.9999

MEAN OF 2ND PLANT = 0.1316E 01 STD DEV OF 2ND PLANT = 0.1536E 00 ITIMES = 500
NUMBER OF TIMES 2ND PLANT NOT BUILT = 113
CUMULATIVE DISTRIBUTION FUNCTION OF SECOND PLANT SIZE

0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	30.2325
49.8708	60.7235	73.9018	80.3617	88.8888	96.1240	96.8992	97.1576
97.6743	97.9327	98.1911	98.1911	98.1911	98.4495	98.4495	99.9999

MEAN OF TIMING = 0.78593E 00 STD. DEV. OF TIMING = 0.13861E-01 ITIMES = 500
CUMULATIVE DISTRIBUTION FUNCTION OF TIMING FACTOR

0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	1.2920	14.4703	99.7416	100.0000
100.0000	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000
100.0000	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000

Details of the Direct Integration for Evaluating the Present Value of Cash Flows

The original equation (Eq.9 page 33) was used in the work by Twaddle and Malloy.[36] The equation gives the discounted cash flow at time, t_1.

$$DCF = \int_{t_1}^{t_2} CF_1 \; EXP(at) \; EXP(-ct) \; dt \qquad (9)$$

where: DCF = discounted cash flow, dollars

t = time, years

CF_1 = cash flow rate at time, t_1, dollars/year

a = rate of change of cash flow rate at time, t_1

c = cost of capital, fraction per year

Converting the time basis to time equal zero and simplifying the equation:

$$PVCF = \frac{CF_1}{EXP(ct_1)} \int_{t_1}^{t_2} EXP(a(t-t_1)) \; EXP(-c(t-t_1)) \qquad (14)$$

where: PVCF = present value (at t = 0.0) of cash flows from t_1 to t_2.

Integrating Eq. 14 results in:

$$PVCF = \frac{CF_1 \; EXP(t_1(c-a))}{(a-c) \; EXP(ct_1)} \left(EXP(t_2(a-c)) - EXP(t_1(a-c)) \right) \qquad (15)$$

For the general equation used in the computer model let:

$$AC = a-c$$

$$CF(n-1) = CF_1$$

$$t(n-1) = t_1$$

$$t(n) = t_2$$

Substituting into Eq. 15 results in Eq. 10 page 33:

$$PVCF = \frac{CF(n-1)}{AC} \; \frac{EXP(-AC\ t(n-1))}{EXP(t(n-1)\ c)} \left(EXP(t(n)AC) - EXP(t(n-1)AC) \right) \quad (10)$$

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OPTIMIZATION OF MULTIPLE INVESTMENTS WITH RISK ANALYSIS

by

Stephen Paul Sims

ABSTRACT

The increasing amounts of initial capital investments in the chemical and petroleum industry are making accurate and realistic economic analyses a necessity. The purpose of this investigation was to develop a general economic evaluation model which was an improvement over previous analysis techniques. The new aspect of this model is its capability of analysing multiple investments with a comprehensive risk analysis and with a short computer running time. Significant features of the analysis technique include: (1) A general and flexible computer model which can easily be applied to a wide range of capital investment decisions, (2) The use of present value for a consistent and realistic economic evaluation criterion, (3) Consideration of the future economic environment through the capability of predicting the time-dependent changes of the main variables, (4) Monte Carlo risk analysis to determine the effect of uncertainty in the 14 main variables, (5) Two-plant analysis with the advantage of a delayed decision on the second plant, and (6) Execution in a relatively short computer running time (six minutes on IBM 360, 65).