UMR-MEC Conference on Energy

12 Oct 1976

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Recommended Citation

Findley, Marshall E., "Process Energy Evaluations and Optimization in International Projects" (1976). *UMR-MEC Conference on Energy*. 124.
https://scholarsmine.mst.edu/umr-mec/124

PROCESS ENERGY EVALUATIONS AND OPTIMIZATION IN INTERNATIONAL PROJECTS

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Abstract

A discussion is presented of some of the factors which enter into the economic evaluations and optimizations of energy consuming or producing processes with special emphasis on international projects with multiple national and financial interests involved. In such analyses the objectives and the prices of energy and other factors used have an important effect.

1. INTRODUCTION

Critical factors in technical development of processing industries throughout the world include investment, material, energy and manpower requirements. The combination of these factors into an economically feasible production process usually requires a number of evaluations of alternatives and some efforts at optimizing the process variables to achieve the best operating conditions. In order to evaluate and optimize processes it is necessary to establish criteria for determining the "best" of two or more alternatives, and these criteria should be based on the objectives of those responsible for the project.

The increasing scarcity and costs of high quality fuels has increased the relative importance of energy requirements in process economics, but it has not eliminated the importance of the other factors. The supply of energy is largely international in nature and increases the importance of international aspects and operations in the process industries. In an international project, the criteria and objectives may be much more complex than those involved in a single organization in a single country. A capital-exporting country, a capital-importing country of location, an international lender, and a owner may be involved, each with their own objectives and criteria. Although the owner is normally the responsible party, it may be necessary to obtain approvals or meet the requirements of a number of parties involved to achieve a successful project. In addition to the goals of profit, other objectives of a partially political nature may be important, including energy independence, foreign currency flows, employment, national prestige, and other non-monetary benefits. These not-completely-for-profit objectives vary widely from one nation to another, with the possibility that any given factor will vary from high to low priority.

It is the purpose of this paper to present some possible methods for including energy considerations, international factors, and the coordination of various input factors into the engineering economics, evaluations, and optimizations of processing industries.

2. PROCESS ENERGY AND ECONOMICS

The problem of conserving energy or reducing the costs of energy involves complex relationships. It is obvious that certain methods can be used to conserve energy, such as increased insulation, increased sizes of heat exchangers, and improved operating procedures. However, since all these methods increase non-energy costs, they cannot be used without limit. If a process was designed to use the minimum amount of energy it would probably require infinite insulation thickness and possibly infinite heat exchanger size, and lead to ridiculous capital costs and possibly very high operating costs for materials or labor. Thus the objective in a process design must be minimum total cost or maximum total profit or similar objectives related to benefits produced.

In general, in optimizing profit or cost related variables, the higher the energy cost per unit, the more the optimum conditions will be shifted towards lower energy consumption. Conversely the lower labor or material costs are, the more the optimum conditions will be shifted towards higher labor or material consumption to reduce other costs, including energy. Also, the lower depreciation rate and the return required on capital, the more process conditions should be shifted toward increased capital with savings in non-capital costs. Thus, in a process design or in optimizing process operations, increased energy costs will result in lower energy consumption with increased capital, material, or labor consumption, the amounts depending on the costs of these items relative to energy and each other. Actually in a profit or cost optimization it will cost exactly as much to save the last BTU of energy as the price used for energy. The appropriate price in the optimization should then be the amount those responsible are willing to pay for a BTU of energy saved. Appropriate prices for an optimization could be present prices with some modification based on how the costs of investment energy, material, and labor are apt to vary in the future operations. In addition, the prices used, the objective function optimized, and the limiting conditions may vary depending on government policies.

In some ways, international projects may be much more sensitive to energy costs and policies than projects involving a single nation. Costs in general may be more variable and it may be more difficult to compare future operating costs and sales over many years with present requirements for cash investment. Future policies with regard to energy imports or exports may be difficult to estimate, and limitations may be complex on capital and currency flows. However, in most countries it is probably safe to assume that local products and local labor will be available for energy or other import cost savings for some time. In addition, most projects which can be shown to decrease energy, import, or foreign currency requirements, or to increase exports, will probably be welcome. The evaluation and optimization of processes for international operations should give some consideration to the various objectives that might be involved.

3. METHODS OF EVALUATING INVESTMENTS

A number of criteria have been developed over the years for evaluating investments on the basis of profit for commercial enterprises. The basis for most of these methods is some sort of equivalent interest rate to which the profit or return rate is compared. This return rate to which investments are compared may vary widely for various countries (Chaykowski and English, 1975, Fleischer, 1972, Dasgupta, et al., 1972). The interest rate or rate of return required for a given investment should be based on at least three factors. First, since money, capital, or investment funds have value, the use of this value over a given period of time has value for which the lender or investor expects compensation. Second, inflation or deflation will change the value of a given quantity of money over a period of time and the investor will consider this in evaluating the monetary return for his investment as it occurs with time. Third, the potential risk of losing all or part of invested funds should be compensated for by the interest or return rate as a sort of insurance premium in addition to a risk-free expected return or as a payment for the investor's risk. The overall return rate will be approximately the sum of the amounts expected for all three considerations, and perhaps others. In international projects these factors may vary widely from nation to nation and an appropriate interest or return rate may be difficult to estimate. Also, actual interest rates may vary from very low concession rates to very high rates.

For this discussion let r equal the required continuously compounded rate of return required with time, as a fraction of the investment per year. The following 3 equations can then be used to convert an amount of currency I_{t_1} at time t_1 to the equivalent amount I_{t_2} at time t_2, or vice versa, and a uniform continuous flow of R, in currency per year, from t_1 to t_2 to an equivalent amount I_{t_1} at time t_1 or I_{t_2} at time t_2, where t is in years.

$$I_{t_2} = I_{t_1} e^{r(t_2-t_1)} \qquad (1)$$

$$I_{t_2} = \frac{R(e^{r(t_2-t_1)} - 1)}{r} \qquad (2)$$

$$I_{t_1} = \frac{R(e^{r(t_2-t_1)} - 1)}{r\, e^{r(t_2-t_1)}} \qquad (3)$$

Table I summarizes methods for calculating a number of variables useful in evaluating processes or process alternatives. All equations are based on constant continuous yearly flows over the life of an investment and continuous interest or return. This discussion will be restricted to these methods and assumptions. Evaluation variables are also important as objective functions for optimizing design, operating, or control variables. These variables have been discussed adequately by Jelen (1970), Peters and Timerhaus (1968), Rudd and Watson (1968), Perry (1973), Dasgupta, et al., (1972), and Fleischer (1972). Maximizing venture worth is probably the best method of maximizing profit above a certain required rate of return.

TABLE I

Engineering Economic Evaluation Calculations

Original Investment Costs

I_F = Fixed Investment in Plant and Equipment, \$

I_L = Investment in Land, \$

I_W = Investment in Working Capital, \$

I_T = Total Investment = $I_F + I_L + I_W$

Yearly Flows of Monetary Values

S = Cash Receipts from sales and services, \$/year

C_T = Total yearly cash costs, not including depreciation, \$/year

D = Yearly depreciation, assume straight line depreciation for this paper = $(I_F - I_S)/N$

C_{FBT} = Cash flow before taxes = $S - C_T$, \$/year

P_{BT} = Profit before taxes = $S - C_T - D$, \$/year
= $C_{FBT} - D$

T_X = Tax on Income = $T_{XF}P_{BT}$

P_{AT} = Profit after tax = $P_{BT} - T_X = (1 - T_{XF})P_{BT}$

C_{FAT} = Cash flow after taxes = $C_{FBT} - T_X$
= $C_{FBT} - T_{XF}P_{BT} = C_{FBT}(1 - T_{XF}) + T_{XF}D$
= $P_{AT} + D$

Other Variables of Importance

I_S = Salvage value of original I_F after N years

N = Life of plant and equipment in years based on physical conditions, obsolescence, and market changes.

TABLE I (cont.)

r = Required rate of return after tax as a fraction or % of investment/yr, equivalent to interest rate after tax

T_{XF} = Income tax as a fraction of income before tax

Measures of Profitability

R_{OI} = Return on Investment

$$= \frac{P_{AT}}{I_F + I_L + I_W} 100, \text{ \%/year}$$

P_{OT} = Pay Out Time

$$= \frac{I_F}{C_{FAT}}, \text{ years}$$

V_P = Venture Profit (simplified)

$$= P_{AT} - rI_T, \text{ \$/year}$$

V_W = Venture Worth or Present Worth

$$= -I_T + \frac{C_{FAT}(e^{Nr} - 1)}{r\, e^{Nr}} + (I_L + I_W + I_S)/e^{rN}, \text{ \$}$$

D_{CF} = Value of r that will make $V_W = 0$, fraction or % per year.

C_{BR} = Cost-Benefit Ratio

$$= \frac{\text{Value of all Costs converted to 0 time}}{\text{Value of all Benefits converted to 0 time}}$$

It is also possible to modify all the variables used in Table I, according to specific desired criteria. For example, a country short of foreign currency could consider all of the variables defined in terms of foreign currency required for investment and costs (including depreciation of imported equipment) and foreign currency income. Another way of evaluating the flows of benefits and costs for a government would be to consider the profits to the government plus domestic owners. This would be the profit before tax minus any exported profits or interest. Another method of evaluating national benefits from a production facility would be to subtract from gross income only the costs lost by the national economy to this facility. Surplus labor or material inputs would not be considered as costs. The value of products replaced should be subtracted and their replaced costs added if useful and available to the national economy. The resulting quantity could be called "Change in Gross National Economic Benefit" (GB herein), or something similar. For example, fuel usage to dry grain, replacing sun and air dried grain, would result in a GB of DRY GRAIN VALUE - SUN-AIR DRY GRAIN VALUE - COST OF FUEL DRYING LOST TO ECONOMY + SUN-AIR DRYING COSTS MADE AVAILABLE AND USEFUL TO ECONOMY (if any). For foreign currency flows or gross national economic benefits, it might be desirable to subtract a fraction of all labor costs based on the average fraction of labor earnings spent on imported goods requiring foreign currency, but imported goods are benefits to the nation.

It is important to emphasize that measures of specific types of partial flows of currency or values are not suitable variables for optimization unless no other variables are changing, because these flows do not include all costs. Thus a project based on maximizing foreign currency inflow (or minimizing outflow) might indicate a use of a ridiculously large labor force, or a use of all the country's timber, or similar excessive local costs. The same might be true of a gross benefit optimization. However, even though not suitable for optimization, such calculations may be useful in demonstrating public benefits for governmental purposes or for understanding how an investment might influence a country's economy. Such calculations could also indicate the types of process modifications most likely to obtain governmental approval for licensing, foreign currency exchange, export of profits, etc.

A very hypothetical example of the optimization of a process variable and the effect of this variable on various economic measures is given in Table II and the results are shown in Figure 1.

The plots shown in Figure 1 show how the various measures of profitability change with the insulation thickness of the refrigerated space. In this case the optimum of R_{OI}, P_{OT}, and CBR all fall at 6 cm of insulation. The optimum of V_P and V_W fall at 9 cm of insulation thickness, and this is probably the most appropriate optimum, since it best represents the maximum profit above the desired rate of return after tax. The maximum venture worth of gross benefits is slightly higher at 10 cm, the venture worth to owner and government is at 11 cm, and the venture worth of foreign currency involved does not reach a maximum up to 15 cm of thickness (primarily because insulation has zero foreign currency cost). Minimum energy consumption would be at an infinite thickness, and infinite investment.

This example illustrates that optimum design conditions can depend upon the objective function which is maximized or minimized, and the choice of objective function is important in the design of a production process. In a complex multivariable design and optimization it would not be feasible to optimize with respect to several objective functions and it would be more important to select the appropriate measure of profitability or benefits prior to optimization.

TABLE II

Economic Study in a Fish Freezing System

Purpose of System: Increase efficiency, utilization, and profit from a remote fishing industry.

Process variable studied: Insulation thickness, x, centimeters.

Life of Facilities: 20 years.

Income Tax Rate: 40% of income before tax.

Fraction of domestic labor costs spent on foreign products: 5%

Fraction of domestic operating cash costs lost to economy: 10%

Maintenance costs: 5% of fixed capital per year.

Depreciation: 5% of fixed capital per year.

Other Costs: 5% of fixed capital, none in foreign currency.

Required rate of return after tax: 15%/year

Interest Rate on Borrowed Foreign Currency: 12%/year

Products Replaced: None

Lump Sum Investment Required

	Total in Domestic Currency Units	Foreign Currency in Equivalent Units
Plant and Refrigeration	215,000 + 45,000/(1.2 + x)	13,500 + 40,500/(1.2 + x)
Insulation	2000X	0
Working Capital	10,000	2000
Land	0	0
Total	225,000 + 45,000/(1.2 + x) + 2000X	15,500 + 40,500/(1.2 + x)
Salvage Value of Facilities	0	0

Income and Expenses per Year (+ income, - cost)

	Total currency units/year	Foreign, equiv. units/year
Increased Sales	+ 540,000	+ 108,000
Labor	- 250,000	- 0
Utilities (50% Energy)	-(16,000 + 60,000/(1.2 + x))	-(8,000 + 30,000/(1.2 + x))
Maintenance	-(10,750 + 2,250/(1.2 + x) + 100X)	-(675 + 2,075/(1.2 + x))
Depreciation	-(10,750 + 2,250/(1.2 + x) + 100X)	-(675 + 2,075/(1.2 + x))
Other	-(10,750 + 2,250/(1.2 + x) + 100X)	-0

The most satisfactory approach to a problem involving multiple criteria for approval would be to optimize according to the desired criteria of the responsible party (the owner), but at least at the optimum on this basis or at a number of conditions, calculate the profit or benefit measurement criteria for the other parties who must approve (governments, lenders). If the optimum for the owner did not meet government or lender criteria adjustments in design conditions

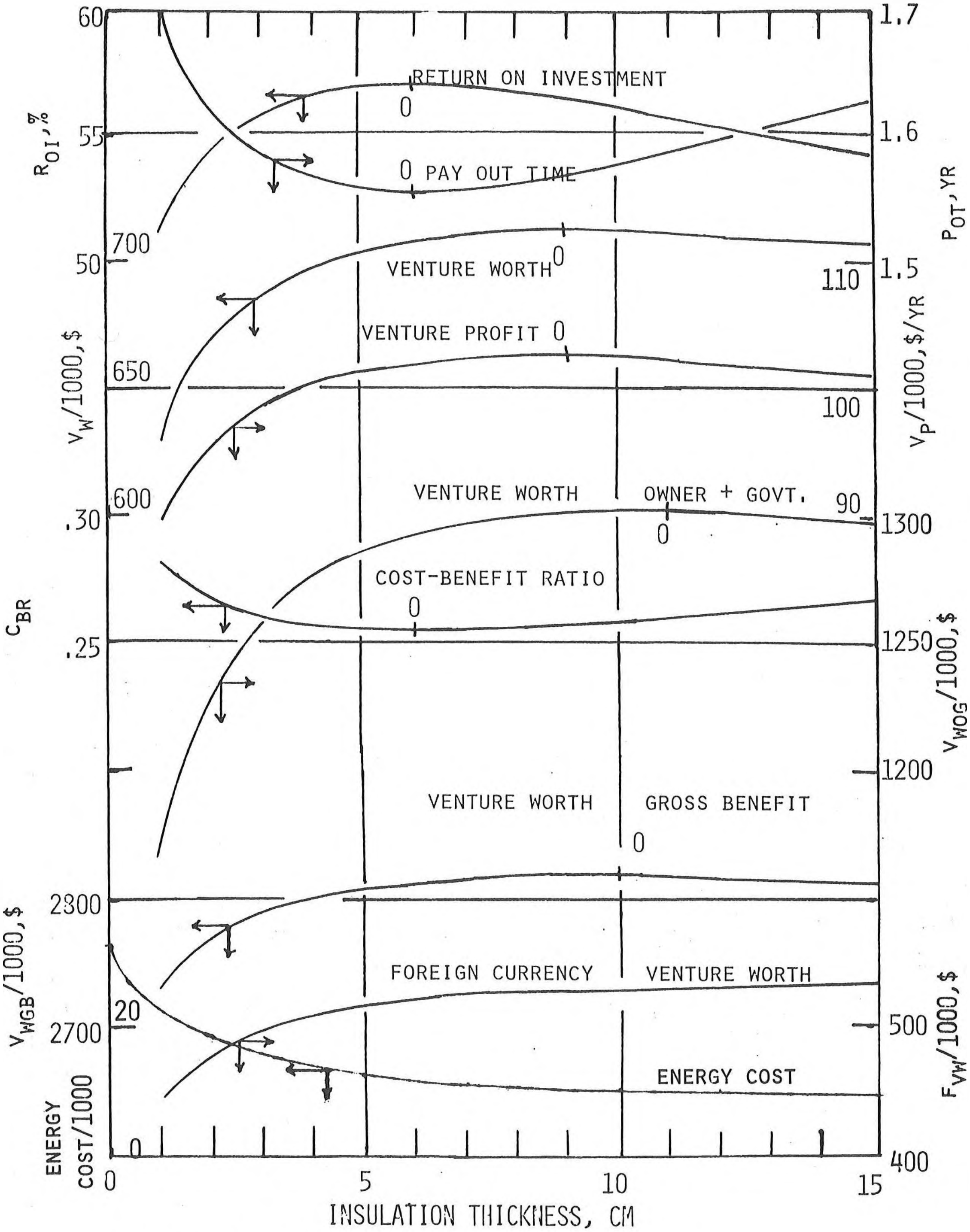

Figure 1. Various Economic Measures in Example 0 = Optimum Point

could be made to meet the requirements for approval. One way this could be done would be to add a constraint equation to the optimization problem to make certain the requirements were met. For example, in the above problem, if the government required a foreign currency venture worth of 520,000 (because a fish canning operation could produce this much), the inequality constraint $F_{VW} > 520,000$ could be used in the optimization procedure to discard all insulation thicknesses that produced F_{VW} values less than 520,000. Such a condition might result when an alternate investment could produce a certain value, and the two investments were mutally exclusive.

For the example presented in Figure 1, a table such as Table III could be used to show the effects of various financing arrangements on the criteria of various parties that might be involved.

TABLE III

Optimized Results, Fish Freezing Plant

All Cases*: Optimum X (Basis V_W, $r = .15$) = 9 cm

$R_{OI} = 56.4\%/yr$, $P_{OT} = 1.57$, $C_{BR} = 0.258$,

$V_P{}^{**} = 102,390$ \$/yr, $V_W{}^{**}(\max) = 712,000$ \$,

Energy Cost = 10, 941 \$/yr

Criteria	100% Local Investment	50% Foreign Borrowed at 12%	50% Foreign Owned
$V_{WOG}{}^{**}$, Venture Worth Domestic Owners and Government	1,301,100	1,324,700	945,150
$V_{WGB}{}^{**}$, V.W. of Gross Benefits	2,816,700	2,840,200	2,460,700
$F_{VW}{}^{**}$, V.W. of Foreign Currency Flow	528,200	428,100	48,840
Lenders Interest	-	12%	-
$V_W{}^{**}$ of Foreign Ownership	-	-	356,000

*Based on Total Investment (owners & borrowed)
**Basis r = 15%/year

4. COORDINATING INVESTMENT COSTS AND PRODUCTION IN AN INTERNATIONAL ECONOMY

A small country or a developing country must participate in the international economy in order to obtain many of the benefits of large-scale production and modern technology. Also a multinational company derives advantages from operating on an international scale by use of large scale production and coordination of operations. In each case there is the problem of coordinating many operations and sources of supply in an approximately overall optimum manner. For example certain nations may have to import either food, fertilizer, or energy to produce fertilizer, or any suitable combination. Overall optimization could be so complex that by the time an optimization program, results, and implementation are obtained the optimization assumptions might be obsolete.

Rudd and Watson (1968) present a chapter on "Multi-Level Attack on Very Large Problems" which may be helpful in arriving at approximately optimum conditions. One approach to this type of problem proposed by Lasdon (1964) is to adjust the transfer prices between the various operations to produce the overall optimum, assuming each of the individual operations is operating under optimum conditions. The assumptions of optimum individual plant operation is often incorrect, but a least in commercial or industrial units, the goal is optimum operation and conditions should move toward the optimum.

This procedure can be applied to an optimization of a national economy or to operations of a large corporation with a number of production units including units in various countries. For a simple example, let Figure 2 represent a large organization with production units A, B, and C, each of which may involve many subunits. If it is assumed each of the units has the responsibility and capability to optimize its supply and production rate of major inputs and outputs, stream rates S in Figure 2, then the equations representing optimum production should apply for each unit. If it is also assumed that the overall objective is to provide income from sales minus costs to and from external sources, overall optimum equations can be derived. It should be noted that this may not be the objective of a national economy since it may be more important to develop high internal flows of production to satisfy domestic needs rather than make profits on foreign trade. However, in most cases ability to export at a profit indicates a stronger domestic economy, and export income is directly related to ability to import needs, including energy, for the domestic economy. At any rate, this analysis will be based on optimizing overall income from external sources, primarily as an example of this type of analysis. Other objectives can be chosen if they can be adequately measured and related to supply and production rates and prices.

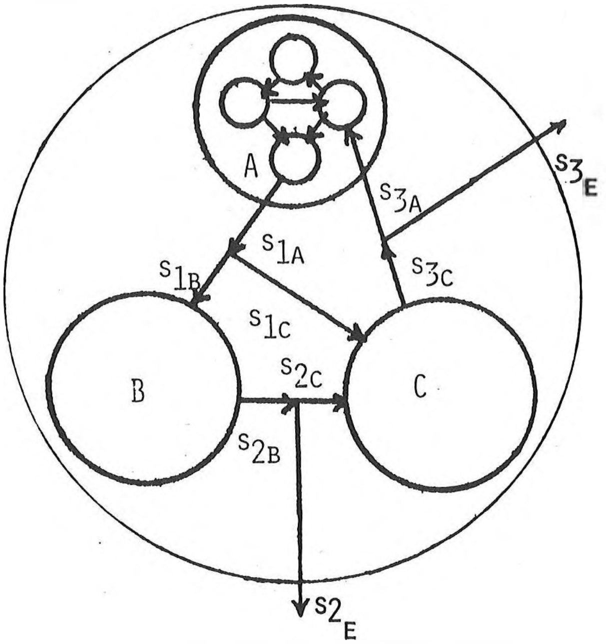

Figure 2. Example of Very Large Economic System with Individual Production Units and Subunits

If optimal equations are obtainable for each unit relating production rates to prices then these equations can be used with the overall optimum equations to determine the optimum relationships of the prices of various streams. Assuming external prices are fixed by external market conditions (the international market for a country, the market from or to which supplies or products move in the case of a corporation), and are beyond the influence of the system, then internal prices can be related to external prices. A country exporting scarce products, such as energy, may be able to control prices, but internal prices should still be related to external prices.

If the objective function U for each unit is related to stream flows, S, prices, P, and all other costs, F, a function of the unit and rates, and the objective functions are defined proportionally to inflow minus outflow of monetary value, then the following equations apply:

U = sales-cost supplies-other costs

$$U_A = S_{1B}\,P_{1B} + S_{1C}\,P_{1C} - S_{3A}\,P_{3A} - F(A)$$

$$U_B = S_{2C}\,P_{2C} + S_{2E}\,P_{2E} - S_{1B}\,P_{1B} - F(B)$$

$$U_C = S_{3A}\,P_{3A} + S_{3E}\,P_{3E} - S_{2C}\,P_{2C} - F(C)$$

$$U_E = S_{3E}\,P_{3E} + S_{2E}\,P_{2E} - F(A) - F(B) - F(C)$$

At the optimum conditions for the overall system with respect to external flows,

$$\frac{\partial U_E}{\partial S_{3E}} = 0 = P_{3E} - \frac{\partial F(A)}{\partial S_{3E}} - \frac{\partial F(B)}{\partial S_{3E}} - \frac{\partial F(C)}{\partial S_{3E}}$$

since S_{3E} has no direct effect on A or B,

$$\frac{\partial F(A)}{\partial S_{3E}} = 0 \qquad \frac{\partial F(B)}{\partial S_{3E}} = 0$$

and since $S_{3C} = S_{3A} + S_{3E}$, or $\frac{\partial S_{3C}}{\partial S_{3E}} = 1$,

$$\frac{\partial U_E}{\partial S_{3E}} = P_{3E} - \frac{\partial F(C)}{\partial S_{3E}} = P_{3E} - \frac{\partial F(C)}{\partial S_{3C}} = 0 \tag{4}$$

similarly,

$$\frac{\partial U_E}{\partial S_{2E}} = P_{2E} - \frac{\partial F(B)}{\partial S_{2B}} = 0 \tag{5}$$

If unit B is operating at its optimum rates, then in similar derivations as equation (4),

$$\frac{\partial U_B}{\partial S_{2C}} = P_{2C} - \frac{\partial F(B)}{\partial S_{2B}} = 0 \tag{6}$$

$$\frac{\partial U_B}{\partial S_{2E}} = P_{2E} - \frac{\partial F(B)}{\partial S_{2B}} = 0 \qquad (7)$$

$$\frac{\partial U_B}{\partial S_{1B}} = -P_{1B} - \frac{\partial F(B)}{\partial S_{1B}} = 0 \qquad (8)$$

Also on unit C at optimum,

$$\frac{\partial U_C}{\partial S_{2C}} = -P_{2C} - \frac{\partial F(C)}{\partial S_{2C}} = 0 \qquad (9)$$

$$\frac{\partial U_C}{\partial S_{3E}} = P_{3E} - \frac{\partial F(C)}{\partial S_{3C}} = 0 \qquad (10)$$

$$\frac{\partial U_C}{\partial S_{3A}} = P_{3A} - \frac{\partial F(C)}{\partial S_{3C}} = 0 \qquad (11)$$

$$\frac{\partial U_C}{\partial S_{1C}} = -P_{1C} - \frac{\partial F(C)}{\partial S_{1C}} = 0 \qquad (12)$$

From these and similar equations on Unit A and sufficient information on F(A), F(B), and F(C) and knowledge of the external prices at various production rates, it would be theoretically possible to calculate optimum prices and stream flows. However, a simpler approach is possible.

Equation (4) and (10) are identical as are (5) and (7) indicating that unit optimization meets the requirements of overall optimization for external streams. Equations (6) and (7) show that P_{2C} = P_{2E} for optimum stream flows. Similarly it can be shown that P_{3A} should equal P_{3E} from (10) and (11), and from an analysis of U_A it can be shown that P_{1C} should equal P_{1B}. Any or all of the streams shown in the diagram could be reversed to give negative flows and the relationships derived would still be the same. Thus, whether bought or sold, imported or exported, internal prices within a large system should be equal to external prices for the same product, allowing for transportation. In addition, all internal prices for the same product should be equal for optimum conditions. The analysis up to this point indicates that prices should be set so that when each unit is operating at optimum for the given set of prices, all the supplies should balance all demands. Completely internal supplies and demands should balance at the optimum price. This is what would happen in a theoretical free market system, with supply and demand determining prices.

It should be emphasized that the above simplified analysis applies to only those processes and operations which are operating at optimum or near optimum conditions and can adjust conditions and rates of production readily toward changing optimums. It does not consider the dynamics with changing conditions.

Such an analysis could be applied to energy and other imports or exports. Although hypothetically the same analysis could be applied to the supply and demand of labor, the assumption of optimum production or supply of labor based on price is completely false and the production of human labor supply by birthrate seems to be the reverse of optimization (the more the surplus and lower the price, the more is produced and vice versa). This is probably a very important factor in economic stability. This type analysis could also be applied to the supply and demand of investment funds and their price (interest), and this could include foreign currency.

The reasonable implications of this analysis are that it is not necessary to control or fix prices for industries which are capable and willing to operate at near optimum conditions in a free market economy (including free export and import capability). In addition, units of production not capable of operating in a free market with no non-monetary benefits are probably not contributing to the system. The analysis implies also that monopolistic practices, highly centralized management, administrative, or control structures over very large systems may be unnecessary or undesirable in achieving optimum economic performance. It is more important for each of the units involved to be capable of optimization and for free market prices to exist between units and between units and external suppliers and customers.

Another important consideration for administration of economic systems is that an improper fixing of prices will help some units but hurt other units and their contributions toward the optimum production condition. Excessive bureaucratic controls can very easily create almost impossible barriers in the technical improvement of small industries, even when the improvements could be economically justified and benefical to many local people. Under such conditions the contribution of small-scale industry would not be optimum and probably not even near optimum.

On the other hand, a conflict of interest between the central administration and a large unit could lead to improper price conditions for the large unit and less than optimum production. In a small country such a conflict might exist between a monopolistic industry and governmental control of prices, where neither situation would provide the optimum conditions. One important aspect of this analysis seems to be that under free market prices the objectives of the individual production units will probably be consistent with national objectives.

Since a single processing operation should be prepared to operate feasibly in an international market, evaluations and optimizations using international prices would be worthwhile for information purposes even if decisions are to be based on a restricted pricing system. In this way there would be some idea of what would be required for optimal conditions in the international economy.

5. CONCLUSIONS

This study makes no conclusions or recommendations concerning the management of a country's economy, an international corporation, or an energy policy. However, it does suggest that for specific projects, engineering economic calculations can be made to appropriately estimate desired objectives of the various parties involved in an international project. It is suggested, that for optimizing process variables, the owner's criteria be used, with the necessary contraints on the optimization or calculations to satisfy other parties such as governments or lenders. This study also indicates that optimization of individual units under appropriate price conditions may reduce or possibly eliminate the need for overall optimization of all units within a system, and that at least in some cases, the appropriate prices are the free-market prices.

6. REFERENCES

Chaykowski, J. E., and English, J. M., "What Discount Rate Should be Used for Evaluating Development Projects," paper prepared for World Congress on Educating Engineers for World Development, ASEE, (1975).

Dasgupta, P., Sen, A., Marglin, S., "Guidelines For Project Evaluation," UNIDO, United Nations, N.Y. (1972).

Fleischer, G. A., "Engineering Economic Analysis in Developing Countries," TECHNOS, 1, No. 1, (Jan.-March, 1972).

Jelen, F. C., Ed., "Cost and Optimization Engineering," McGraw-Hill, N.Y., (1970).

Lasdon, L., "A Multilevel Technique for Optimization," Systems Research Center report, SRC50-C-64-19, Case Institute of Technology, Cleveland, Ohio, (1964).

Perry, R. H., and Chilton, C. H., "Chemical Engineers Handbook," 5th ed., McGraw-Hill, N.Y., (1973).

Peters, M. S., and Timerhaus, K. D., "Plant Design and Economics for Chemical Engineers," 2nd ed., McGraw-Hill, N.Y., (1968).

Rudd, D. F., and Watson, C. C., "Strategy of Process Engineering," Wiley, N.Y. (1968).