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PREFACE

Industrial development can be seen as the process of changing the production structure by means of investment over the course of time. To control this development to the benefit of society while maintaining the profitability of the industry, decision makers must learn how socioeconomic changes and market conditions affect the static and dynamic properties of the production structure. This paper reports on the progress of collaborative research into the design of tools which could help decision makers to control development in the chemical industry.

The basic approach is to formulate a model of the equilibrium state of the industry or, in the case considered here, of a particular subsector of the industry. The development process is initially described by a static multiobjective optimization problem, from which a dynamic multiobjective optimization problem is then derived. An example illustrating the use of this method for the pesticide-producing sector is given.

The optimization problem and method for controlling industrial development put forward in this paper were worked out as part of the research program on Growth Strategy Optimization Systems (GSOS), sponsored by the Ministry of the Chemical Industry in Poland. This program is actually carried out at the Institute for Control and Systems Engineering (ICSE), part of the Academy of Mining and Metallurgy (AMM) in Cracow.

The multiobjective optimization method for generating efficient alternatives and the related software were developed by the System and Decision Sciences Area at IIASA.

This collaborative research was carried out within the framework of the agreement on scientific cooperation cosigned by IIASA and the AMM in June 1980.

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1. INTRODUCTION

Development in the chemical industry, as in other industries, can be considered as the process of changing the production structure by means of investment over the course of time. Both socioeconomic conditions, e.g., changes in the commodity and raw materials markets, and environmental factors constrain this process, but also stimulate it to occur. The main objective is to control industrial development to the benefit of society, with due regard for the need to keep the industry itself profitable.

In practice this task is extremely complicated, largely because it deals with problems and areas which are very difficult to quantify and can hardly be compared on the same terms. One approach to this problem is therefore to use the concept of a production-distribution network as a model of the inflows and outflows of the basic resources involved in production, distribution, and development processes. This model of the chemical industry provides the planner or decision maker with basic information about the industry in terms of products, intermediate products, raw materials, production levels and capacities, prices, foreign exchange, investment required for new plants, etc.

On the basis of this model, static and dynamic states of the production-distribution network can be defined to correspond to the tasks of planning and programming development, respectively.

This paper describes the control of the development process as a multicriterion decision problem. The results given here were obtained through collaboration between IIASA and the Institute for Control and Systems Engineering, part of the Academy of Mining and Metallurgy (ICSE-AMM) in Cracow, Poland. They are closely related to the research program sponsored by the Ministry of the Chemical Industry in Poland and carried out by the ICSE-AMM.

Our description of the problem area illustrates the characteristic features of the chemical industry, and also introduces the concept of a sector within the industry, called here a Production-Distribution Area (PDA). The static and dynamic decision problems are formulated as programming problems in sector development. The multiobjective optimization approach is then discussed, starting with an outline of the relevant theory and continuing with a presentation of the software used in our analysis. Some methodological aspects of the application of this software are also discussed. This is followed by a brief presentation of the results obtained from the application of the method to the relatively small area responsible for the production and supply of a fairly limited range of pesticides (80 products and 30 processes). We then report on the research progress that we expect to make and evaluate the results obtained so far.

2. PROBLEM AREA

Our objective is to find a method for generating efficient alternatives for structural development in the chemical industry.

The first step is to identify those features of the chemical industry which should be included in a model describing the development of the industry. This model could then be used to devise a method for generating alternatives - which is precisely the objective of this study.

We shall therefore start with a brief description of the chemical industry.

Chemical production is basically a sequence of processes that change the input compounds into other compounds - this means that the end product is quantitatively (physico-chemically) different from the input material. This flow of material can be considered to be continuous even in the case of periodic reactions. Each particular product (compound) can be obtained in a number of ways. Final products are in most cases obtained not from a single reaction but from a chain of reactions. The same substrates may be used for a number of reactions in the chain under consideration and may also be used in other chains - this is why such chains form a network. The substrates going into reactions in the middle of chains or obtained from them are called semiproducts or intermediates. There is a very large and natural market within the chemical industry for this kind of exchange between companies, frequently on a world scale.

Thus, the industry, by its very nature, is composed of a great number of elements that are very strongly interdependent. In practice, there are many ways in which this interdependence can be created, both from the technological and from the market point of view.

Moving along the process chains toward the commodity market, it can be perceived that a small number of natural raw materials, which includes crude oil, gas, salt, and sulfur, yields thousands of semiproducts and tens of thousands of final products. The chemical industry has a vast individual consumer market but its products are also vital as raw materials (and semiproducts) in practically every industry, including construction, shipbuilding, light industry, electronics, and telecommunications.

One may ask how the boundaries to this production-distribution network should be marked. Are organizational or corporate boundaries the only way of limiting the system?

Our aim is to find a way of generating alternatives for the development of this system, and to control the changes in the production structure through investment. How should we decide what should be produced and what can be supplied from outside?

Well-established chemical companies evolve (from the historical point of view) by diversifying their production, i.e., by selling some of their plants and buying or investing in the construction of other new installations in order to maximize their overall efficiency.

It often happens that each of the large companies covers a certain peripheral area of chemical production and distribution, supplying the other companies with related products according to their needs. It would be rather impractical to attempt to handle such a large system as a whole simply because all of the elements under construction (plants, products) belong to one corporation or are supervised by the same management.

Industry is organized by enterprises which have developed over the years - this organization is based on previous experience, and recognizes the need to deal with the impact of changes in the economic, political, and social environments. So the industrial system evolves with the years, usually with a certain delay before the best possible structure is attained. We may describe this as a learning process in which the industry tries to invest in such a way that its structure is adapted to the changing operational conditions with the maximum possible efficiency.

We conclude that a special need manifests itself at this point: the need for a theory which would provide better understanding and consequently better handling of the process of structural change in the industry.

As a first step in this direction we shall adopt the idea of dividing the production-distribution network into selected areas or PDAs. There must be a certain amount of freedom in selecting or marking the PDA boundaries, although the relative density of technological connection is perhaps one of the most important factors here. Others include organizational factors and market, labor, maintenance, transport, and supply conditions. The idea of such a sector or area should become even clearer after the presentation of the simplified mathematical model. The model, however, represents only the "hard", well-defined part of reality - and by introducing the model we cannot cut off the "soft" part of reality. The term "soft" as used here does not mean "ill-defined": it covers all factors which may be significant in a particular situation in a particular region, country, company or even the whole industry itself. It is up to decision makers to weigh the importance of these factors.

Let us summarize what we mean by a production-distribution area. A PDA is any part of the production-distribution network which it is practicable to manage in terms of controlling its development.

We should now perhaps throw some more light onto our "hard" or model representation of the PDA; using this representation we can compare the setting up of the PDA boundaries with drawing the borders of the potentially most fertile field. This model should also be helpful in making an objective judgment on the attainability of goals.

3. GENERAL MODEL

3.1 Principles and Assumptions

In the above, brief description of the chemical industry it has been observed that the industry can be modeled as a production-distribution network. The model should include the following basic features (elements):

- the processing and flow of chemicals within the PDA;
- the flow of chemicals into and out of other areas; this represents the marketing or business activity of the PDA;
- the flow of investment, revenue and other resources such as energy, manpower, etc.

Pollution can also be treated as a special kind of flow which may be distinguished from the flow of chemicals necessary for the network to perform its functions. (This flow can be evaluated in terms of the capacity of the environment to absorb each form of pollution.)

The natural way of managing existing production sites is to maximize their economic efficiency, measured over a given period of time.

This efficiency depends directly upon the rates of flow. Therefore, we may redefine the problem of production planning as a search for the most efficient (in the sense of a given performance function) rates of flow over a period of time. The rates of flow must balance in the sense of network connections (technological recipes and production capacities) and are limited by certain exogenous constraints (such as the availability of raw materials).

The effects which can be achieved by planning are limited by the existing network. Factors of two kinds may influence these effects by changing the conditions which determine the solution of the planning problem. Firstly, there are the factors that mainly influence the parameters of the network - these include the development of new technologies and products. Secondly, there are factors which cause changes in the environment of the network. The latter cannot usually be influenced directly by the industry itself.

The obvious planning period would therefore be a period in which major changes in the above-mentioned factors would not occur. We shall regard this planning period as a basic time increment, and in practice it is usually one year.

By differentiating between the factors which influence the performance of the network, we can differentiate between two planning situations: static and dynamic. The static case is limited to the situation in which the optimum balance of the network can be obtained for a given state of the environment within the limits of change of the technological parameters. However, changes in market and supply conditions as well as changes in cooperation require that the flows should be readjusted regularly. This leads to the problem of dynamic planning, which must be done within the limits of the parameters of existing production sites. In an extreme case this may lead to the closing-down of a particularly inefficient plant, but it cannot result in new investment.

The process of adjustment to a changing environment and the technological development that leads to a transformation of the network structure through investment is a different problem altogether - a problem that we shall call programming of development.

The above-mentioned transformation of network structure causes a disturbance from the point of view of planning in that a planning task would be triggered each time such a disturbance occurs. This feature of the network makes it possible to treat it as a discrete system, the equilibrium state of which is defined by the planning problem, and consequently development programming may be formulated as a dynamic optimization problem.

It is useful, however, to define a subsidiary problem. If we consider a particular time increment (e.g., a year) in the future, for which we can assume a particular amount of investment and other resources to be available and for which we can forecast the market conditions and available technologies, then we may ask what the optimum equilibrium state for this time increment would be. Since the answer involves a change in the technological structure of the network we shall call such a case a static programming problem.

Then, assuming that the accepted solution of this subsidiary problem is a goal to be achieved by the network, we may try to solve the problem of development programming in the dynamic case.

3.2 Model of an Equilibrium State

We shall now formulate a model representing the equilibrium state of a PDA in the chemical industry. Before describing the production-distribution network of the PDA, we shall first define its links with its environment (Figure 1).

From Figure 1, we can write the following equation describing the outflow of any chemical j:

$$y_j = y_j^{ms} - y_j^{mp} + y_j^{cs} - y_j^{cp} \quad , \qquad j \in J \qquad (1)$$

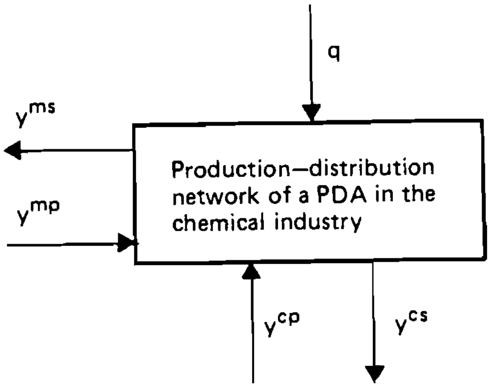

Figure 1. Links between the production-distribution network of a PDA and its environment.

where

y_j^{ms} - market sale of chemical j

y_j^{mp} - market purchase of chemical j

y_j^{cs} - coordinated sale of chemical j

y_j^{cp} - coordinated purchase of chemical j

J - set of indices of all chemicals under consideration

Here we introduce the concept of a coordinated flow, where the coordination is achieved through the buying and selling of chemicals among PDAs. This makes it possible to define the coordination between PDAs. (The coordination referred to here cannot be achieved by the formal decomposition of a larger problem containing a number of areas. However, decomposition algorithms may be helpful in this procedure.)

A typical situation involving coordinated flows arises when the source of a semiproduct is located in an area covered by another enterprise. This enterprise may not be willing to disclose all the data that would be necessary for optimization at a higher level.

Resources other than chemicals required for network activities are denoted in Figure 1 by q, and include inputs such as energy, labor, and water.

The performance measure (or economic efficiency) is described in terms of the variables defined above; the constraints on q and y model the conditions imposed on the area by the environment.

The particular form of the performance function depends on the strategy and policy adopted by the industry and does not influence our considerations until we are ready to solve the algorithm.

It is already clear at this stage that such complex goals and such a variety of resources will inevitably lead to a multiobjective problem.

Now let us briefly look at the form of the production-distribution network. The network is formed by two types of elements:

- process elements, which represent chemical processing;
- balance nodes, which represent the total flow of any chemical j.

We shall denote by J^* the set of indices describing chemical processes taking place in the area under consideration. It is clear that J^* must be related to J.

The way in which the network is constructed ensures that all of the above considerations concerning links to and from the environment are taken into account, regardless of the number of process elements and balance nodes.

Let us consider a process element PE_k, $k \in J^*$ (see Figure 2).

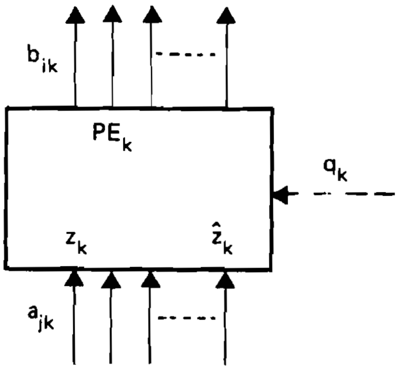

Figure 2. A process element PE_k and its inflows and outflows.

The variables used in Figure 2 may be defined as follows:

z_k - production level of PE_k

$\hat{z}_k$ - production capacity of PE_k

$a_{jk}z_k$ - quantity of chemical j consumed by PE_k

$b_{ik}z_k$ - quantity of chemical i produced by PE_k

$q_k(z_k)$ - necessary resources

For the balance nodes we may write an equation of the following type:

$$y_j = x_j^+ - x_j^- \tag{2}$$

for each chemical j, where

y_j - total outflow of j

x_j^+ - total production of j

x_j^- - total technological consumption of j

The network is constructed from both kinds of elements in a way that reflects all of the technological connections occurring within the industry. Of course, a process element may be connected to other process elements only through balance nodes.

Once we have defined the network we may formulate the following equations:

- total production of chemical j:

$$x_j^+ = \sum_{k \in J^*} b_{jk} z_k \quad , \quad j \in J \tag{3}$$

- total technological consumption of chemical j:

$$x_j^- = \sum_{k \in J^*} a_{jk} z_k \quad , \quad j \in J \tag{4}$$

By substitution of (3) and (4) into (2) and combining the result with (1), we obtain:

$$y^{ms} - y^{mp} + y^{cs} - y^{cp} = (B - A)z \tag{5}$$

To complete this somewhat simplified description of the network, we have to add the constraints imposed by production capacity. The form of these constraints will depend on the type of chemical process concerned, and may, for example, include a number of alternative technologies.

The model that we have developed in our research describes all possible variations of production in any process industry - these variations include alternative technologies, alternative ranges of products made at a given installation, recycling of semiproducts, and coupled production of a number of chemicals at one installation.

4. MULTIOBJECTIVE APPROACH

4.1 Problem Formulation

As we have already stated, our aim is to generate efficient alternatives for the development of a given area of an industry (described as a PDA in the model presented here).

This basically means that we are interested in maximizing economic efficiency (or revenue) while minimizing investment, energy, and labor. Our problem can therefore be stated as the following multiobjective optimization problem:

$$
\begin{aligned}
Q_{rev} &= \sum_{j \in J} c_j^s (y^{ms} + y^{cs}) - c_j^p (y^{mp} + y^{cp}) \rightarrow \max \\
Q_{ener} &= \sum_{k \in J^*} e_k z_k \rightarrow \min \\
Q_{inv} &= \sum_{k \in J^+} n_k z_k \rightarrow \min \\
Q_{labor} &= \sum_{k \in J^*} l_k z_k \rightarrow \min
\end{aligned}
$$

with constraints given by market conditions and production capacities. We use the following notation:

c_j^s, c_j^p - sale price and purchase price, respectively (for simplicity, market and coordination prices are assumed to be the same)

e_k, n_k, l_k - coefficients representing consumption of energy, investment, and labor, respectively

J^+ - set of newly available technologies, where $J^+ \subset J^*$. This is a very important feature of the model since it opens the way to technological change in the structure of the area and in practice makes its boundaries even more flexible

Having formulated the multiobjective optimization problem we can look at it from the point of view of a decision maker. He focuses on the problem of the design and control of the development of a PDA through global resource allocation and selection of the appropriate technologies.

In industrial terms, as we have mentioned, this is called development programming. Even a rough description of the managerial procedures and the related data processing involved in this process would be beyond the scope of this paper (for more information see H. Gorecki et al., 1978) and so we will limit the discussion to the conceptual model at its core.

Any feasible approach to a multiobjective problem of this type must involve an analysis of two specific areas:

1. Resources of a global kind which we may wish to use in the development of a particular PDA.
2. The structure of this PDA and the constraints imposed on the variables of the model by market conditions and production capacity.

It is very difficult to evaluate the relative worth of resources such as investment, energy, and labor, and to determine what level of economic efficiency (or revenue) would be satisfactory. We should not make our evaluations simply in monetary terms because we would then lose the informative potential of the multiobjective approach. A decision maker should try to identify the relative scarcity or availability of the resources. He should try to determine outcomes that would satisfy him, and decide what should or should not be accepted within the PDA in terms of the consumption of various resources.

This means that it is necessary to develop a practical method, based on evaluation and reference techniques, capable of finding an "acceptable" area in resource space - this is the area containing feasible solutions.

With this in mind, it is necessary to think simultaneously in terms of the structure of the PDA under consideration. What technologies and products should be included and why? What new technologies could be considered and when? What would be the limitations imposed by the coordinated flows to and from the other PDAs? What would be the terms of trade for the PDA?

Both parts of the analysis would, of course, have to be carried out with a strong mutual feedback.

This analysis should be carried out interactively and therefore the simulation of the multiobjective problem is of particular importance, calling for appropriate methodology. Before describing the methodology that we have adopted we should provide some background to our approach to multiobjective optimization. Our basic aim is to formulate the problem in such a way that it includes a reference point representing the aspirations of a decision maker (DM). His wishes bring a subjective factor into the problem and one of the goals of a good methodology should be to bring about the convergence of the objectives of the PDA and the wishes of the decision maker. We should say at this point that we hope to exclude any wishful thinking!

4.2 Philosophy of Problem Solution

As stated in the previous sections, it is difficult to describe in a general way all aspects of the system under consideration in terms of one objective function; it must be regarded as a multiple-criteria problem. But from the practical point of view this is not a complete answer to our question. It is possible to utilize the Pareto approach to "solve" the problem, but in this case there is usually a great number of solutions which can be regarded in some sense as the "best". However, in real life they are not equivalent to the experienced decision maker (DM), who can distinguish between solutions on the basis of his own overall performance criteria. Unfortunately these criteria cannot be utilized directly in the optimization process - there is simply no way in which they can be formalized.

Because of this, the decision maker must play an active role in the optimization process: he should analyze and evaluate the solution obtained from the computer and, perhaps on the basis of his analysis of previous solutions, modify his preferences and increase his knowledge about the system.

This means that there must be an interaction between the computer and the DM: the computer accumulates information about the goals and solutions desired by the DM and, in turn, the DM "learns" from the computer about the behavior of the system.

There are several approaches to interactive decision making. In the authors' opinion, however, the reference point approach developed by Wierzbicki is one of the most useful. This method is a generalization of the goal programming and displaced ideal approaches (see, e.g., Hwong and Masud, 1980) and combines their advantages, simultaneously eliminating their weak points. The reference point approach has already been successfully applied to a number of problems (see Kallio et al., 1980; Kindler et al., 1980).

The experience of the authors in the programming of industrial development has led to the application of this method to the analysis of development strategies for the chemical industry, and this application will be discussed in more detail later in this paper.

The basic idea of the method is quite simple: it assumes that the DM can express his preferences in terms of aspiration levels. In other words, the DM should be able to specify the values required for individual objectives. Our experience shows that it is relatively convenient and fairly easy for him to think in these terms, compared with other approaches in which he is required to estimate trade-off coefficients or utilities.

The following two situations can occur:

- the DM overestimates the possibilities - his reference level is too high and cannot be achieved by the system (the aspiration level is not attainable);
- the DM underestimates the possibilities (the aspiration level is attainable).

There is also a theoretical possibility of a third situation in which the aspiration level is a point in the Pareto set. In this case the solution offered by the method may differ slightly from the aspiration level. However, the probability of such a case arising is very low.

The computer has a clear course of action in each of these two situations:

- when the aspiration level is not attainable it reports this fact to the DM and calculates the "nearest" point in the Pareto set (see Figure 3);
- when the aspiration level is attainable it finds the point in the Pareto set which is simultaneously as far from the aspiration level as possible and not worse than the aspiration level in terms of the values of the criteria (see Figure 4. Note that this figure illustrates the max,max type of problem, and is slightly different in other cases.)

The second situation is especially interesting for the DM because the response given by the computer can be interpreted: "you have underestimated the possibilities, I suggest a new solution which is in accordance with your wishes, but which also improves the value of every objective".

The suggested solution is presented to the DM and he decides whether to accept it. If it is not acceptable he must propose a new, improved (from his point of view) aspiration level. This process is repeated until the DM finally accepts the solution. Experience shows that this generally takes 10-20 iterations.

Special software has been developed at IIASA for the solution of such problems (Lewandowski, 1982). This has made easy interaction with the computer possible even for decision makers who know little about computers. A short description of this software is given in the Appendix.

5. METHODOLOGY FOR GENERATING EFFICIENT ALTERNATIVES

It has already been pointed out that there is a need for methodology which would make it possible to find efficient alternatives for development in the chemical industry. The methodology discussed here deals with the somewhat narrower area limited to a particular PDA, The core of this methodology is a multiobjective approach utilizing the idea of reference points. The methodology will be described in a rather general way for the sake of simplicity. In practice, each stage in the design of development alternatives for the PDA usually involves a number of very laborious tasks which have to be performed by a specially

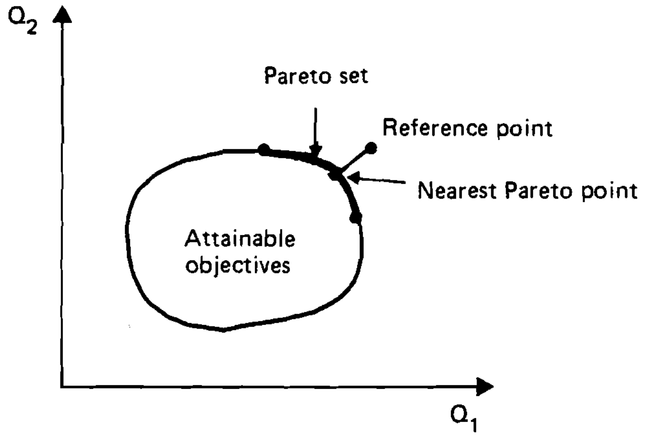

Figure 3. Situation in which the aspiration level is not attainable.

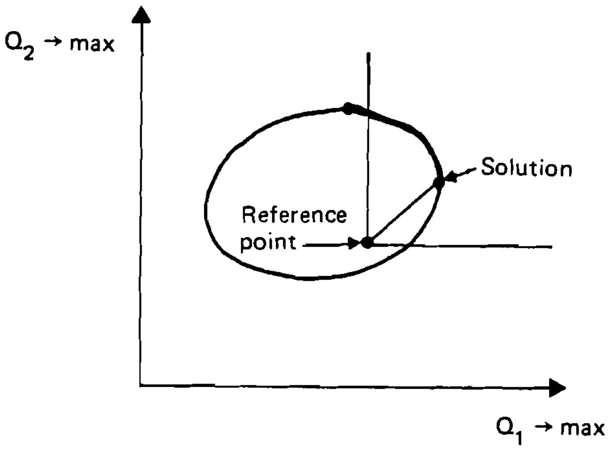

Figure 4. Situation in which the aspiration level is attainable.

chosen staff taken from different fields. This whole process has to be embedded in the management system, or rather in that part of the management system which is responsible for development (Borek et al., 1978).

It is assumed that the DM (and his staff) have access to all the relevant information. This implies that a preparatory analysis has already been carried out. As mentioned above, this analysis falls into two main areas. The first deals with goals and global resources such as capital investment, energy, labor, and so on. This part of the analysis should enable the DM to evaluate the "initial conditions" for programming the development of the PDA in terms of global resources. These can be used to set up the a priori reference points in the multiobjective optimization. The other part of the analysis should yield all kinds of market information, supply forecasts and the like, a specific example being the coordination variables describing the coordinated sale and purchase of chemicals between various PDAs. This kind of information is included in the general model described in the previous sections in the form of constraints. The technological analysis furnishes forecasts concerning the processes expected to be available, when they are expected to be available, and what their capacities, efficiencies, and so on will be.

We shall now illustrate the use of the proposed methodology by describing how it is applied to the problem of finding efficient alternatives for the development of a given PDA over a given period T.

In practical terms the procedure can be divided into the following five stages:

1. Set up the final state of PDA at time $t = T$, i.e., generate the goal state of the PDA. This necessitates:
   - the formulation of the static multiobjective problem (as described in the section on problem formulation).
   - the simulation of the various alternatives for the final state of the PDA by solving the static multiobjective problem at time $t = T$. This is done using the reference point approach.

  - the choice of an efficient or acceptable final or goal state using the simulations described above.

2. Find the reference trajectory from the present time ($t = 0$) to the time $t = T$ by repeating the procedure described in stage 1 for different increments of the time $t < T$.
3. Formulate the dynamic multiobjective problem.
4. Simulate the various alternatives for the optimum dynamic trajectory of the PDA using the reference trajectory derived in stage 2.
5. Choose an efficient or acceptable development alternative for the PDA.

The reference trajectory which the DM is supposed to find in stage 2 has a purely practical function. It helps the DM to set his aspiration levels for the whole programming period and is characterized by the fact that it lies entirely within the nonattainable zone, so that it does not switch between attainable and nonattainable values. The DM is of course free to modify the reference trajectory if he wishes but he should have a good reason for doing so.

Instead of discussing these five stages in more detail, we shall illustrate the approach by examining the loop performed when either the static or dynamic multiobjective problem is solved (a more detailed description of the dynamic problem will be given in our next report). This loop is illustrated in Figure 5.

Step A in this figure represents an analysis which results in a general model of the PDA. This means that we now have some basic knowledge about the range of available resources (energy, manpower, capital, etc.) and the goals that the decision maker intends to achieve. Information about technological possibilities and market conditions are also included in this general model.

Step B reflects the formulation of the multiobjective problem and is shown explicitly to underline the solution sequence.

Step C contains the operations already described in the section dealing with the reference point approach.

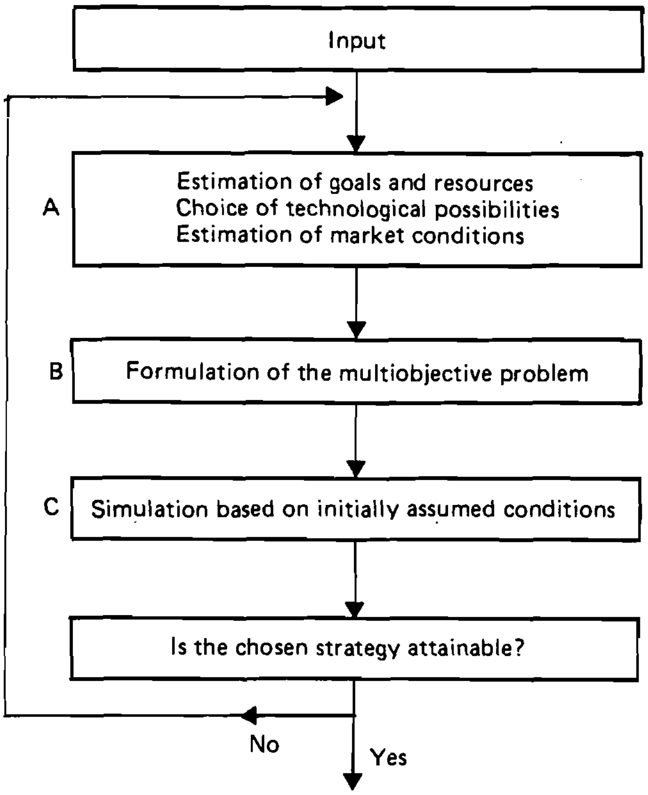

Figure 5. Loop of operations performed when either the static or dynamic multiobjective problem is solved.

Using the general loop given in Figure 5 we can explain the proposed methodology in the form displayed in Figure 6.

This loop must be initiated whenever a change which could affect the solution occurs, i.e., any change which could alter the development program of the PDA. This type of programming must therefore be carried out continuously.

The results presented in the next section provide an illustration based on a series of experiments performed on a fairly small PDA.

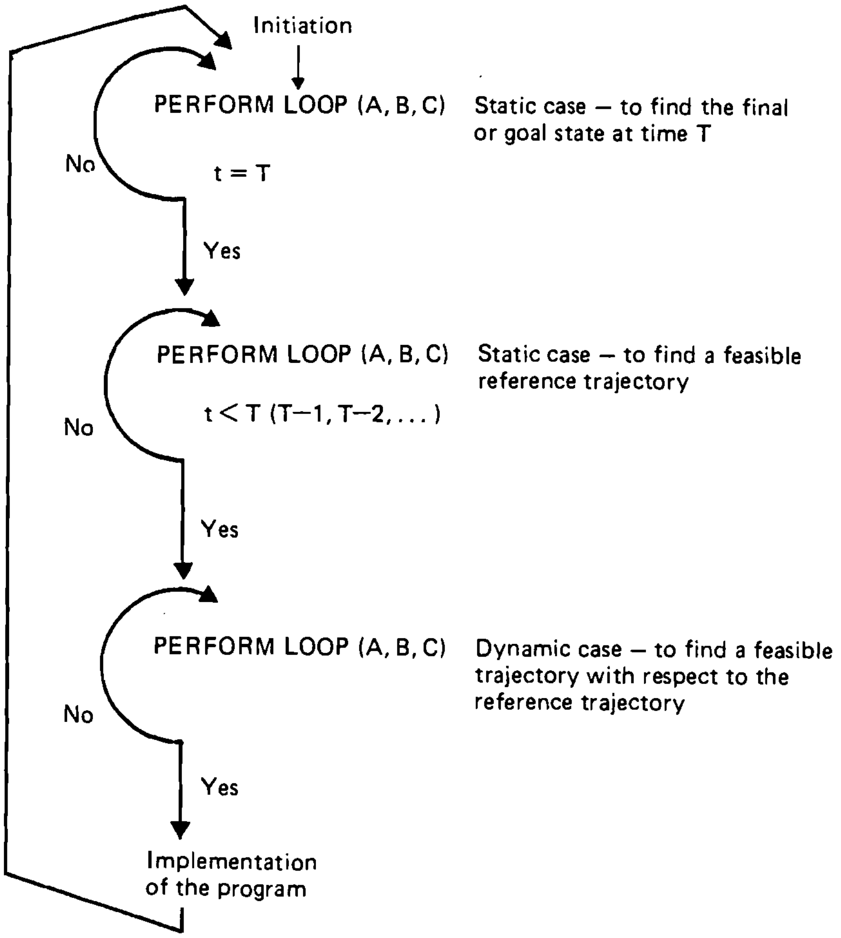

Figure 6. Outline of the proposed methodology (see also Figure 5).

6. ILLUSTRATIVE EXAMPLE

The PDA considered here covers the relatively small area responsible for the production of a fairly limited range of pesticides and is concerned with about 80 products and some 30 processes. The results presented here were obtained from the static multiobjective problem which was solved in order to find a range of efficient alternatives for the final or goal state of the PDA under consideration. There are four criteria: revenue/ year, energy, capital investment, and labor. Figure 7 shows the trade-offs between pairs of resources in criteria space and illustrates the relation between the global resources which must be utilized to achieve a particular state in the development of the PDA. The state corresponding to a given configuration of

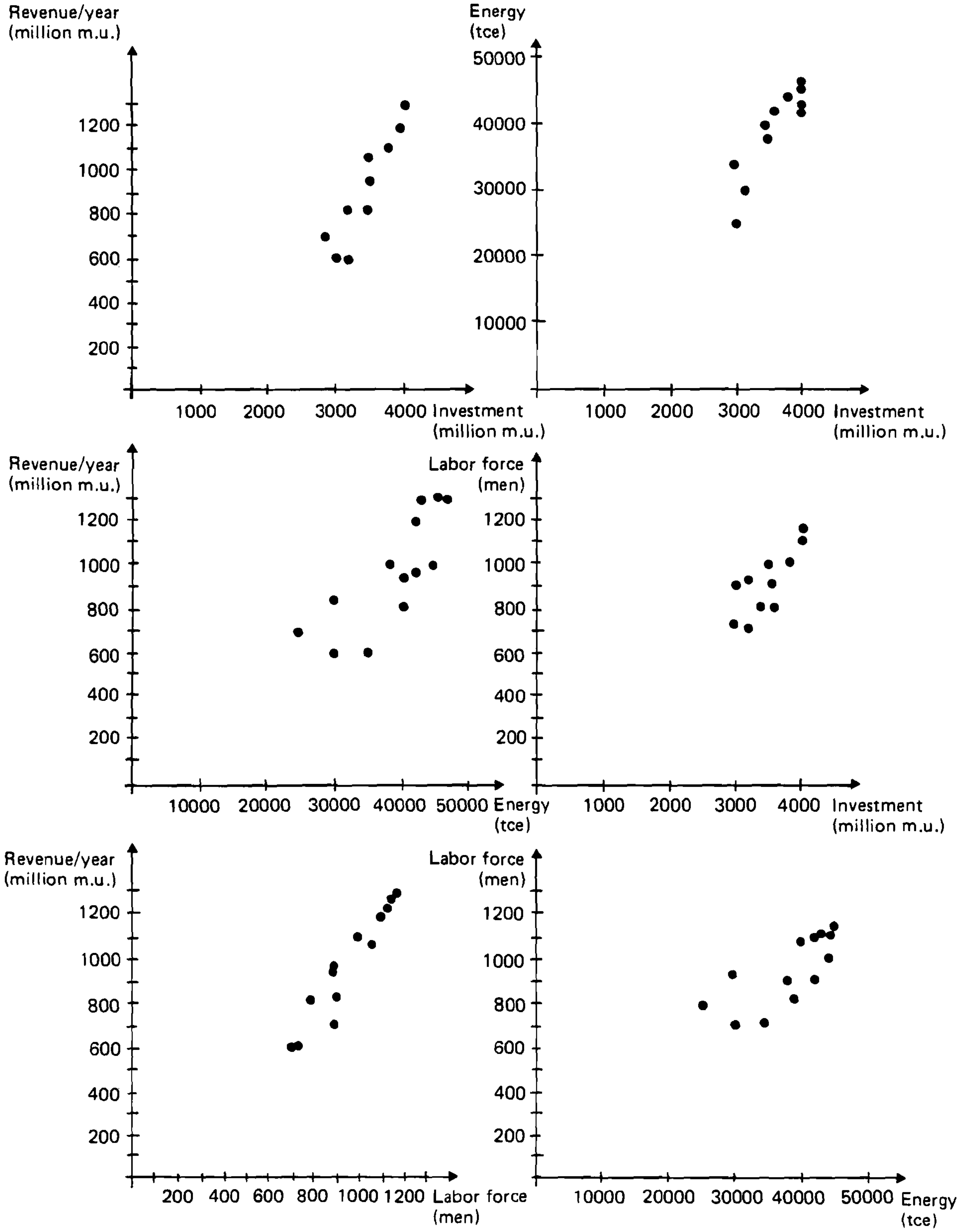

Figure 7. Tradeoffs between pairs of resources in criteria space (tce - tons of coal equivalent; m.u. - monetary units).

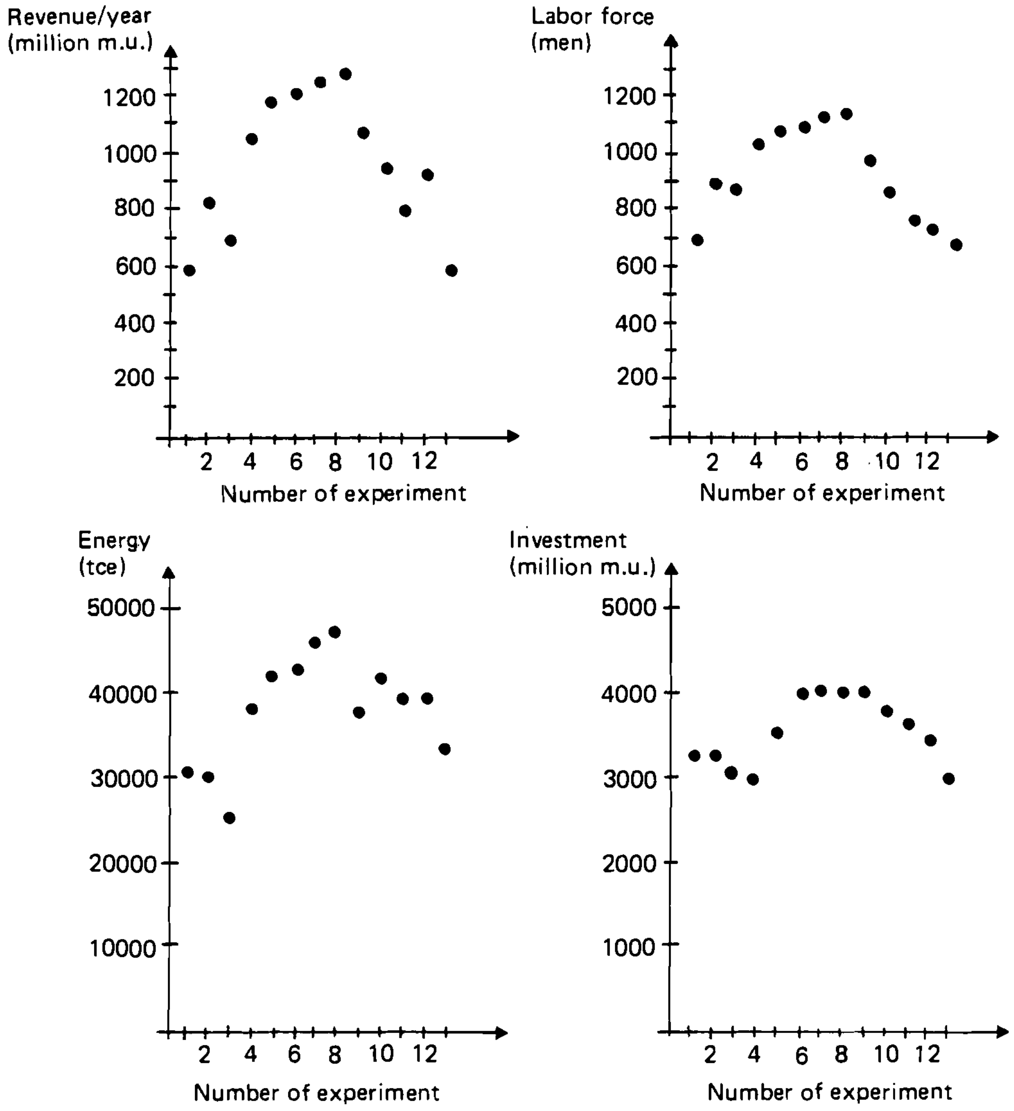

Figure 8. Values obtained for each criterion in thirteen consecutive experiments.

these resources is described by the model of the PDA which, as we recall, contains all "active" technologies, their level of utilization, and the volumes of the flows. Figure 8 is a complementary illustration which simply shows the value for each criterion obtained in a sequence of 13 experiments. All four parts of the figure should be viewed in conjunction. It can be seen that there are clearly distinguishable zones in resource space, e.g., experiments 1-6 or 7 (Figure 8) show a tendency towards growing interdependence between resources while in experiments 6 or 7-13 this interdependence is decreasing, giving some sort of maximum for experiments 5-10. This last series of experiments shows that the PDA is very sensitive to changes of the reference point within this zone and consequently the interdependence of resources is very strong. Since the reference point represents the expectations of the DM, the fact that the response of the PDA is especially sensitive in this zone means that the development of the PDA may be unstable if any of the predictions are inaccurate.

These results show how simple and at the same time how rich is the information resulting from experiments based on the model of the PDA

SUMMARY

The aim of this paper was to present a method for generating efficient development alternatives for the chemical industry. The problem was narrowed down to the PDA or Production-Distribution Area which was described in the paper as a specific area of the chemical industry. The significance of the PDA concept in programming the development of the chemical industry was discussed - the whole methodological concept is in fact based on the general model of the PDA. The multiobjective approach was adopted in this model. The reference point approach for solving multiobjective problems has been shown to be useful in practice and was therefore embedded in the proposed methodology.

The methodology for programming PDA development was worked out specifically for this application. A more extensive report which will also include a detailed description of the dynamic multiobjective problem is in preparation. This report will include a discussion of experimental data, and an analysis of the internal structure of the PDA, showing how the assumed attainability of the global resources can influence its structure.

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APPENDIX: SOFTWARE FOR LINEAR REFERENCE POINT OPTIMIZATION

A special software package based on the ideas presented in Section 5 has been developed. For a theoretical background, see Wierzbicki (1979, 1980); a technical description can found in Lewandowski (1982). The system works in conjunction with the MINOS LP package (Murtagh and Saunders, 1980) and consists of three programs:

- lpmod, which enables the user to define the components of the reference point;
- lpmulti, which converts the standard problem description in MPSX format (multiple-objective case) into its single-objective equivalent;
- lpsol, which calculates the solution of the multiple-criteria problem on the basis of the solution obtained by the MINOS system.

The general structure of the package is presented in Figure A1.

The system is written in FORTRAN and is highly portable. The only restriction is that the LP system with which it is used must accept the problem description in MPSX format.

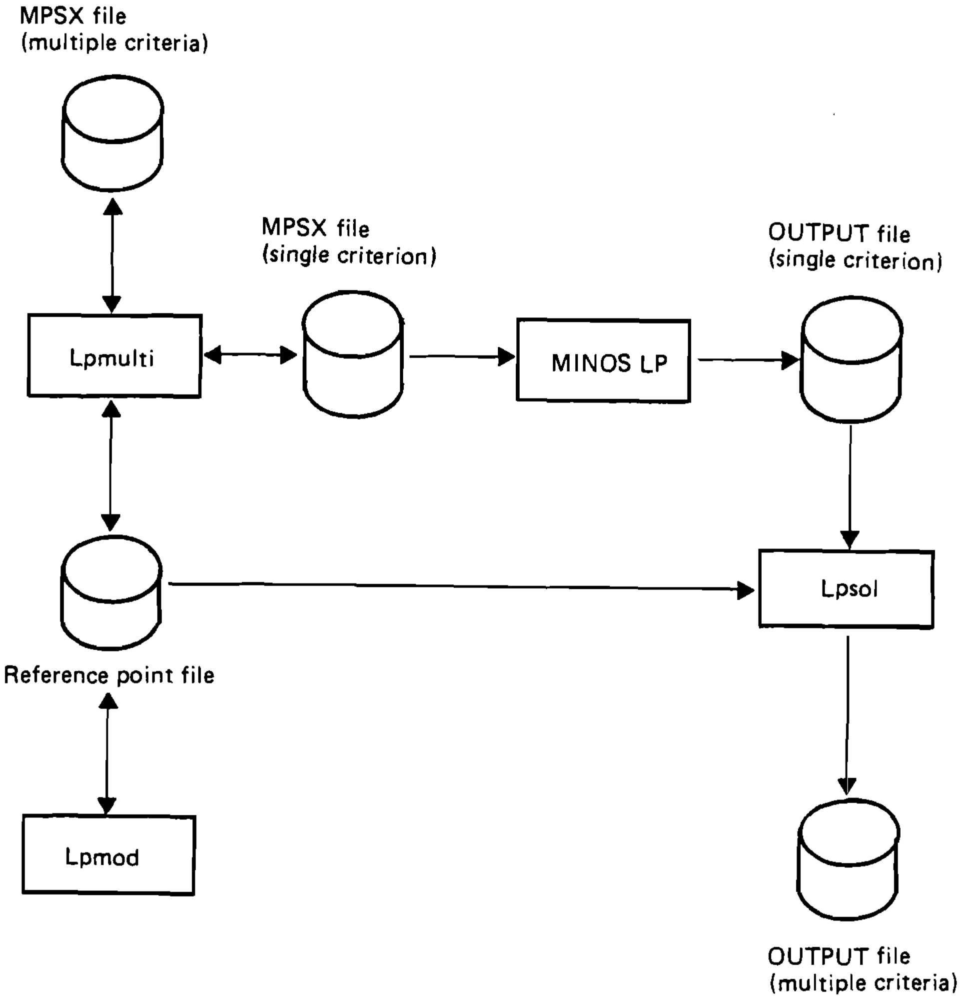

Figure A1. The general structure of the multiple-criteria LP package.

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