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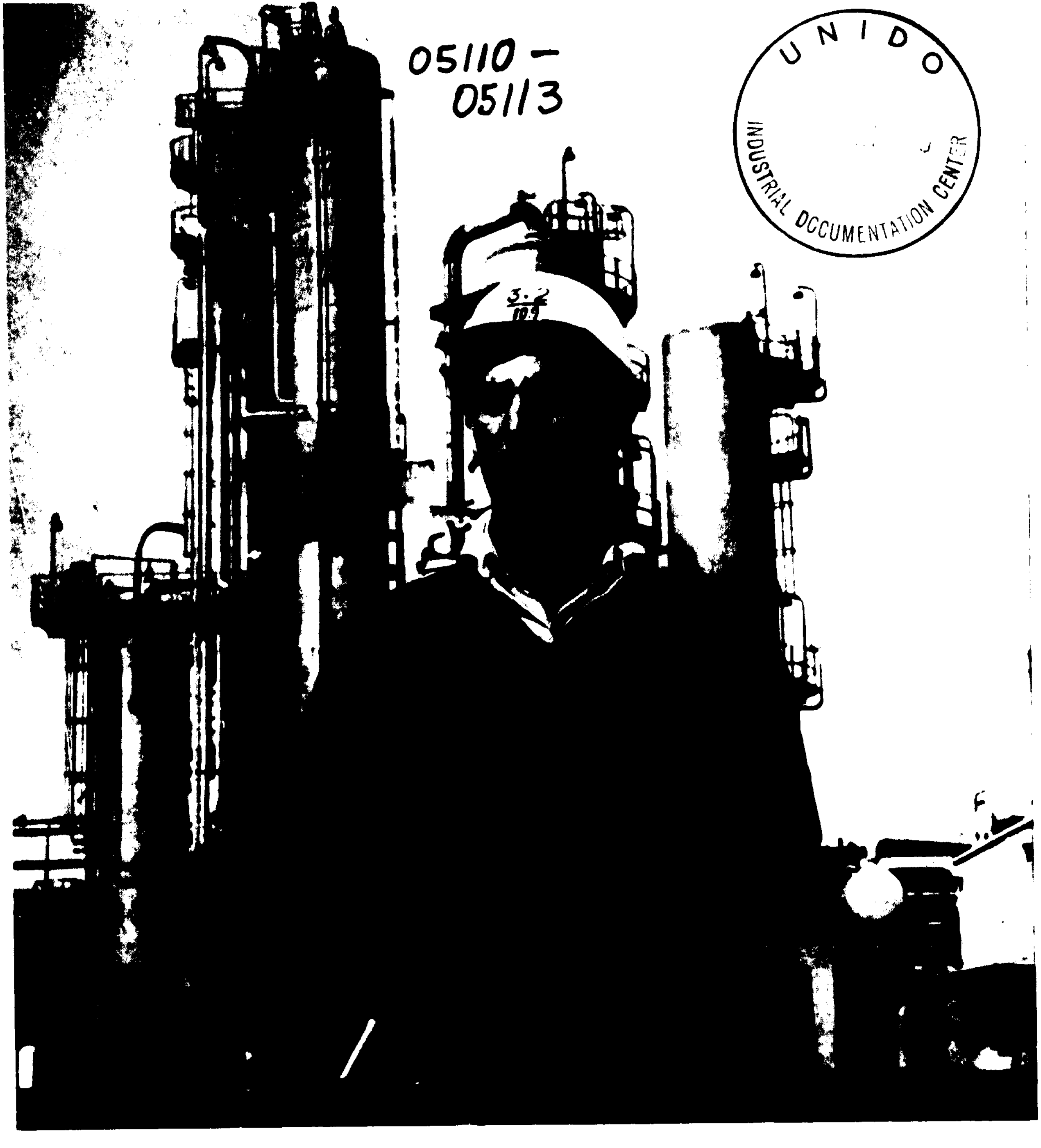

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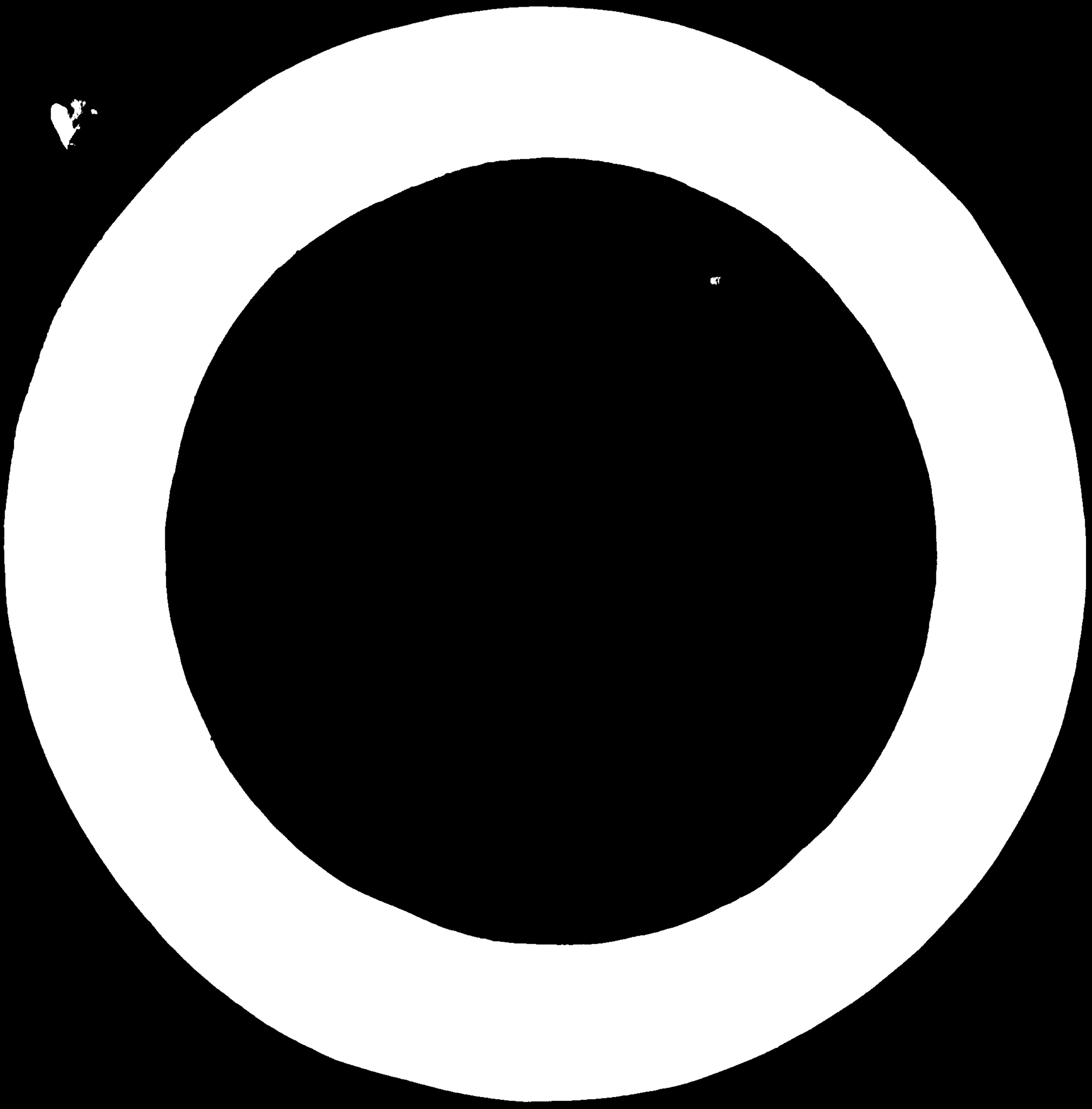

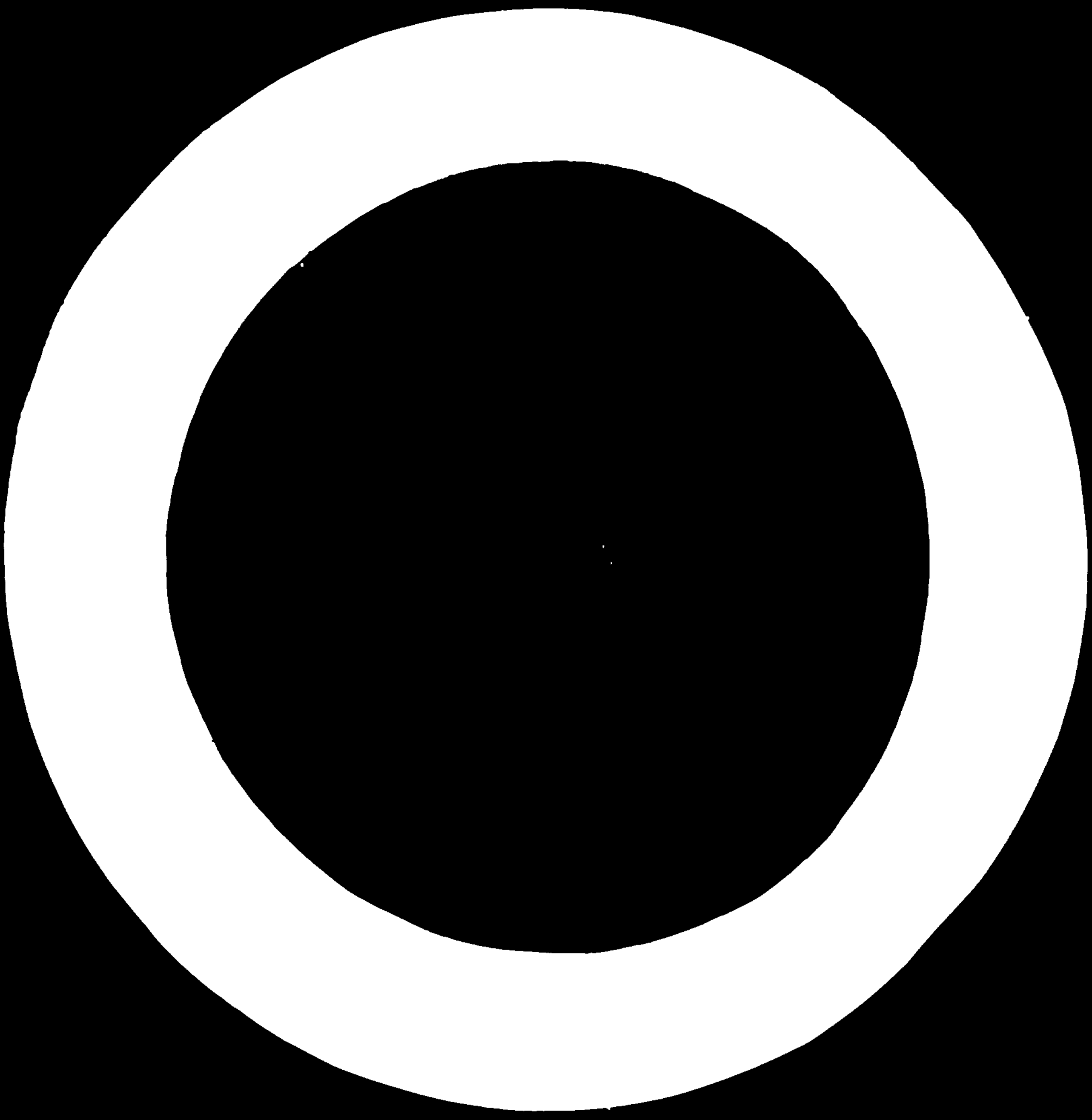

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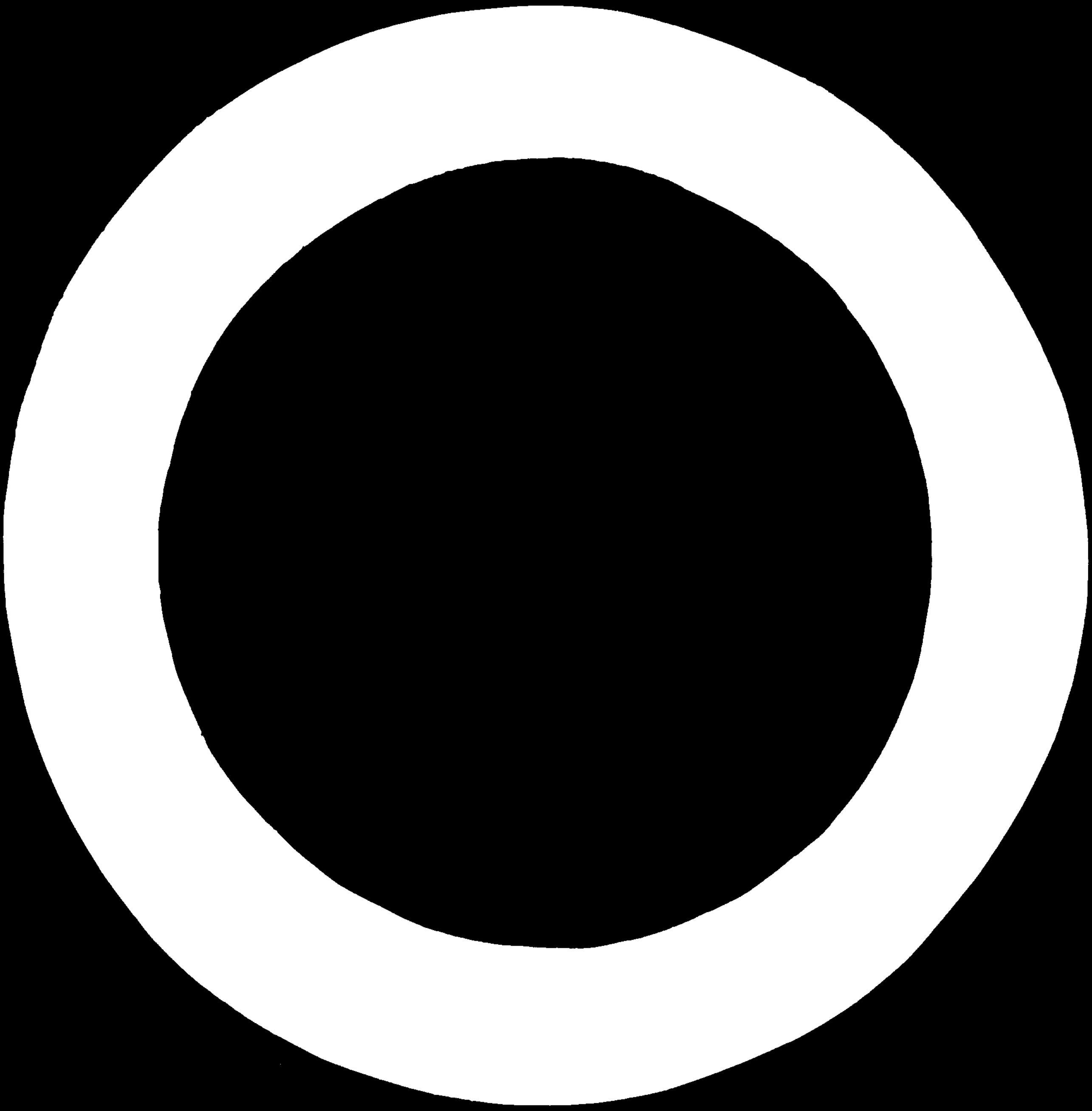

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Cover illustration: Mechanic at work at the Daura oil refinery in Iraq. Several articles in this issue are concerned with investment planning and project evaluation, with special reference to the chemical, petroleum refining and petrochemical industries

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Preface

THIS ISSUE OF the *Industrialization and Productivity Bulletin* is mainly devoted to industrial development programming and, in particular, to programming data for the chemical and petroleum industries.

In the first article, Professor Victorisz summarizes a body of technological and economic information on heavy chemical production processes, to be used in programming the development of the chemical industry in the developing countries. This information should prove especially valuable in the preselection of promising lines of chemical development, as an aid in preparing more detailed feasibility studies and for use in interindustry analysis.

In the second article, Professor Manne presents programming data to be used in planning investments in the petroleum refining industry, in such a way as to allow for a wide variety of process alternatives and product-mix options. These data are also intended for preliminary project evaluation and interindustry economic analyses, although they should be supplemented with specific information on local conditions.

The third article, written by Professor Pronikov, deals with problems of maintenance and repair of machine tools in developing countries. Since most developing countries are handicapped by a shortage of industrial equipment and machinery, they must import various kinds of equipment while they set up their own industries to produce these goods. As the existing stock of machinery in the developing countries increases, problems of repair and maintenance become more urgent. This article offers solutions to some of these problems.

This issue of the *Bulletin* concludes with two notes prepared by the Policies and Programming Division of the Centre for Industrial Development, Department of Economic and Social Affairs. The first summarizes the report of an interregional conference on the development of petrochemical industries in the developing countries, held in Tehran in November 1964; and the second is a succinct account of an interregional symposium on industrial project evaluation, held in Prague in October 1965.

Levelling a mound of ammonium sulphate in a plant in Pittsburgh, United States

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Programming Data Summary for the Chemical Industry

By THOMAS VIETORISZ

THE ORIGINAL VERSION *of the present paper was written for the meeting of the Expert Working Group on Industrial Development Programming Data, held at United Nations Headquarters from 17 to 19 May 1961. The numerical data included in that version were taken from the unpublished interim report of the Latin American chemical industry study (Vietorisz and Szabo, 1959). The first phase of the study, initiated and supervised by the present author, was undertaken by a joint working party of the United Nations Economic Commission for Latin America (ECLA) and the Chilean Development Corporation. The data that had been incorporated in the study originated, in turn, in earlier work reported upon in several books and articles (Isard and Schooler, 1955; Isard and Vietorisz, 1955; Vietorisz, 1956; Isard, Schooler and Vietorisz, 1959, and Airov, 1959; see the list of references at the end of this article).*

In the course of this earlier work, the author initiated a card file on individual technical processes which was meant for use in studies of the kind represented by the Latin American chemical industry study. The format of the file was especially suited to keeping up to date and expanding this type of information which by its very nature is in constant flux. The file was considerably revised and expanded in the course of the first phase of the Latin American study. The technological information fixed upon for the purposes of numerical computations represented the status of this file approximately as of 1958. These were the data that appeared in the first version of the present Programming Data Summary.

In the meantime, the Latin American chemical industry study entered its second phase, which involved a thoroughgoing revision of all materials, including technology. The present author did not participate in the second phase. The final report of the study has recently been published in Spanish in United Nations, La Industria Quimica en América Latina (*Sales No.: 64.II.G.7*)*; an English translation is in the process of preparation. This document contains a detailed discussion of technology (annex XIV with ninety technical data tables, and annex XVIII with further data on economies of scale).*

Recently, the author has been asked to revise his 1961 Pre-investment Data Summary for publication in the Bulletin. *The body of the discussion in this 1961 document is largely complementary to the material contained in the recently published ECLA report rather than overlapping with it; the numerical data and some aspects of their presentation (for example, accounting cost items) have, however, been superseded by the very extensive revisions to which the entire technological material has been subjected by ECLA during the second phase of the study. This poses a dilemma: to publish the 1961 coefficients now would certainly be futile in view of the fact that they have been superseded; to publish a discussion without explicit reference to a particular set of coefficients would, on the other hand, serve the user poorly. Therefore the author has decided to replace his 1961 tabulation of data in the "Pre-Investment Data Summary for the Chemical Industry" by the technological*

DR. THOMAS VIETORISZ, Professor of Economics at The New School for Social Research, New York, U.S.A., has been associated with the United Nations as a regional expert in industrial development programming with the Economic Commission for Latin America (ECLA). He already contributed to this *Bulletin* a "Preliminary Bibliography for Industrial Development Programming", published in Nos. 5 and 6 of the *Bulletin*. Dr. Vietorisz has also prepared studies for several United Nations meetings, including the Interregional Conference on the Development of Petrochemical Industries in Developing Countries held in Tehran, Iran, in November 1964, and the Interregional Symposium on Industrial Project Evaluation held in Prague, Czechoslovakia, in October 1965. His article is a revised edition of a paper which he submitted to an Expert Working Group on Industrial Development Programming Data at United Nations Headquarters in May 1961.

annex XIV of the ECLA document, complemented by a short section from annex XVIII of the same source, and to make reference to this numerical information consistent with the presentation of ECLA.

It is obvious that the revised ECLA materials will in due course of time suffer the same obsolescence as the superseded 1961 coefficients. It would therefore be urgent to establish the material in the form of a punched-card file that permits periodic updating, expansion and printing of the revised version with a minimum of effort. The maintenance and continuous updating and expansion of a punched-card pre-investment data file for a well-studied industry, such as the chemical or petroleum refining industry, by a small staff including two or three engineers and economists should by now be well within the realm of possibility. The best way of defining the exact contents and format of a file, the exact procedures to be used in its updating and expansion, the organization of such an effort and the ways of establishing satisfactory communications between the users of the information and the central staff require urgent professional discussion.

GENERAL SURVEY OF PROBLEMS

Introduction

Planning objectives

This paper embodies a summary of technological and economic information relating to a number of heavy chemical production processes. This information is meant to be used in connexion with programming problems of the chemical industry in under-developed countries.

Data such as presented here are intended for use in the preselection of promising lines of chemical development, as an aid in the preparation of more detailed feasibility studies and as a source of information for use in inter-industry analysis.

In connexion with the task of *preselection* it should be noted that detailed engineering surveys of individual industrial branches or feasibility studies relating to individual projects typically represent outlays in the five-figure range: thus it is not feasible to submit hundreds of potential lines of development to such a detailed analysis. In general, industrial economists without detailed specialized knowledge will have to make preliminary evaluations of those lines of development which merit the investment of the considerable sums of money needed to carry the preliminary proposals to the stage of detailed feasibility studies. For preselection purposes, an approximate description of technological alternatives, such as can be achieved with the aid of data summaries like the present one, appears entirely satisfactory. At this stage, a wide coverage is essential in order to insure against the risk of overlooking potentially attractive projects. Technical specialists are generally not required for the preselection stage, but an effort should be made to include in the data summary technical information of a critical nature which, if overlooked, might invalidate the conclusions, such as, for example, purity requirements or specifications of raw materials. Nevertheless, even in the absence of such technical specifications, the data summaries can be useful in that they help to discard all obviously uneconomical alternatives.

At the next stage, the preparation of detailed *feasibility studies*, any process which should have appeared unduly advantageous owing to neglect of the limitations on purity or other factors of a detailed technical nature will be discovered and discarded. At this stage of feasibility study preparation, the participation of technical specialists is essential. Recent experience in Latin America has indicated that, in the preparation of a development plan for the chemical industry of one country, the technical experts and the information summarized in the present draft have played complementary roles in the formulation of feasibility studies. Thus, it can be confidently asserted that while the data presented here are not enough in themselves for preparing such studies, they are of great value in systematizing and speeding up the work of the experts and in aiding the process of communication (which is often very difficult) between these experts and the general industrial development planner.

In the progression from the conception of an idea to a concrete project the stage following the preparation of feasibility studies is detailed project engineering. It should be stressed that the programming data summaries are *not meant* for this task.

The present programming data are also intended, finally, for use in connexion with interindustry and resourse-balance studies. For this purpose, they will have to be aggregated or will have to be integrated with other types of information, usually of a statistical nature. As a typical example, if a projection is to be prepared for the industrial sector of a developing country which has not had significant amount of chemical activity at the time the base historical data for the industrial sector had been collected, data summaries such as these can greatly facilitate the indispensable modification of historical coefficients.

Purpose of the present data summaries

The data included here can be accepted for tentative use in concrete planning problems, but considering their preliminary nature, caution is indicated. This caution would be most properly exercised by recurring to a larger measure of advice and assistance from technical experts even at the preselection stage than would be the case with data which had already undergone a more extensive process of testing in concrete applications. The data represent recent technological practice; however, no matter how carefully such data are revised at a given moment of time, they become rapidly obsolete soon after publication. One of the objectives of presenting them in this paper is to provide a background for the appraisal of the methodological problems connected with the collection, organization, presentation and application of such programming data for the chemical industries.

A *caveat* is in order concerning the place of origin of these data. Largely, they represent United States and western European practice; the problems arising in transferring such data from one country to another will be discussed further under "Transferability of the data between countries".

In the following pages, a brief description will first be given of the organization and use of the present data summary; thereafter, some of the main questions raised by the methodology which has been followed will be explored.

ORGANIZATION AND USE OF THE DATA SUMMARY

Coverage

The focus of attention for this programming data summary has been on the production of a representative number of homogeneous chemical commodities, such as ammonia, acids, alkalis, chlorine, fertilizers, plastics, detergents and organic intermediate products.

The field of the chemical industry can be defined to comprise, besides the production of chemicals proper, a number of other related industrial branches. On the one hand, the production of certain raw materials which the chemical industry uses can be classed as parts of the chemical industry; thus, the production of salt from sea water or brine, the separation of certain constituents of natural gas and the like can be classified as chemical industries. On the other hand, many so-called "chemical end-products" are logically thought of as belonging to the chemical industry, such as plastic materials, rubber, fertilizers, insecticides and phamaceuticals.[1] In addition to these, there are a number of important industries and industrial branches in which chemical-type processes predominate and which are closely related to the chemical industry. These industries are often referred to as the chemical process industries: for example, chemical metallurgy, pulp and paper, or petroleum refining.

The principal raw materials of the chemical industry, chemical end-products, chemical process industries and the most important chemical-using industries are listed below.

PRINCIPAL RAW MATERIALS OF THE CHEMICAL INDUSTRIES

Hydrocarbons	Petroleum, natural gas, liquefied petroleum gases, fuel oil
Carbon	Coal, lignite, graphite, coke, petroleum coke
Other minerals	Sulphur, salt, limestone, phosphate rock, potassium salts, fluorspar, sand, pigment materials
Raw materials of organic origin	Cellulose, fats and oils, waxes, naval stores, bones and hides, molasses, agricultural wastes
Other	Metals

PRINCIPAL CHEMICAL END-PRODUCTS

Inorganic	Fertilizers, copper sulphate, pigments
Organic	Solvents, dyes, pharmaceuticals, insecticides, pesticides, herbicides, detergents, essential oils, cosmetics, perfumes, explosives, tetraethyl lead
Organic polymers ..	Plastics and resins, synthetic fibres, rubber, adhesives, glue and gelatine, gums
Compounded and miscellaneous products..........	Paint and varnish; oils, fats and waxes; photosensitive surfaces (film etc.)

CHEMICAL PROCESS INDUSTRIES

Chemicals
Chemical end-products
Thermo-electric power generation
Water purification and waste water treatment
Coking of coal
Petroleum refining, including topping, cracking, visbreaking, coking, polymerization, alkylation, reforming, hydrogen treating, desulphurizing etc.
Cement, lime, gypsum and magnesium products
Ceramics and glass
Chemical metallurgy of ferrous and non-ferrous metals
Electrothermal products; abrasives
Leather tanning
Textile dyeing and finishing
Pulp and paper

PRINCIPAL CHEMICAL-USING INDUSTRIES

Agriculture (fertilizers, insecticides, pesticides, herbicides)
Battery manufacture (acid, lead sulphate, additives)
Construction (plastics, paint and varnish, adhesives)
Food processing (acids, perservatives, cleaning fluids, disinfectants)
Glass (sodium sulphate additives)
Leather (tanning agents)
Metal fabrication industries (pickling acid, plastics, paint and varnish, rubber)
Pulp and paper (pulping chemicals, bleaches, adhesives)
Soap (alkalis)
Textiles (alkalis, detergents, dyes, bleaches, resins and adhesives for sizing)
Wood preserving (creosote, tar acids, inorganic salts).
Wood products (resins and adhesives, paint and varnish, waxes, bleaches)
Electrical industries (plastics and resins)

In the present programming data summary, only a limited number of chemical commodities have been included. The selection of these was based on a recent study of the chemical industries in the Latin American region performed by the United Nations Economic Commission

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[1] *See* the definition of the chemical industry in United Nations, *International Standard Industrial Classification of All Economic Activities* (Sales No.: 58.XVII.7).

for Latin America (ECLA).[2] For the first phase of this study, a total of seventy intermediate and final products were selected, regarded as the most important in the United States, either from the point of view of annual tonnage or annual value of production. The initial list was narrowed down by excluding from further consideration those products for which the total market in the Latin American region in the foreseeable future did obviously not justify the establishment of a plant of minimum size. Of course, the size of the smallest economical unit of production itself depends on local cost and price considerations and cannot be accurately determined without an extended analysis; nevertheless, for the purpose of setting orders of magnitude, it was deemed satisfactory to rely on estimates of the minimum economical plant size in the United States.

Outline of planning methodology

The study of the development of the chemical industry in a given country can be carried out in the following stages:

(*a*) First, in a market analysis, the magnitude and diversity of the existing demand for chemicals is examined. On the basis of this information, the demand is projected for a target year in the future.

(*b*) The technological problems connected with the productive processes used for making these chemicals are then considered, the corresponding manufactures being grouped into industrial complexes in order to allow for the economies of scale obtainable in the production of intermediate chemicals.

(*c*) On the basis of these technological data, the needs for intermediate products and raw materials are worked out which correspond to the projected demand for the final goods that are considered.

(*d*) Taking into account the information obtained on raw material requirements and a detailed inquiry into their availability, the localities likely to be best suited for the establishment of chemical industries are selected.

(*e*) The next stage is to determine the typical costs of raw materials, services and labour, taking into account the current prices of these inputs and their opportunity costs. At the same time, the market prices of the chemical studies and the transport costs of raw materials and finished articles are compiled.

(*f*) Using all this material, an analysis is made of the profitabilities and the social benefits of the manufacturing processes studied at the locations selected.[3]

The foregoing outline refers to the sectoral study of chemical production. While isolated sectoral studies are entirely feasible and at the present stage of the art constitute an important forward step in almost any under-developed country, the methodology is conceived so as to allow fitting of the sectoral study, in turn, into the over-all structural study or development plan for an economy as a whole. It is not the purpose of this paper to explore the conditions under which this integration can be achieved most advantageously. Thus, it is only briefly noted that an iterative process is envisaged between the over-all structural studies for the economy and individual sectoral studies. In other words, an interindustry model containing perhaps up to fifty sectors is proposed for the economy as a whole, which is constructed in such a way that it should yield approximate social accounting prices (or opportunity costs) for the most important strategic resources of development. Initially, this interindustry model is to be based principally on historical data derived from statistical sources. The social accounting prices estimated by the use of this model can be complemented or, in case of extreme data scarcity, can even be replaced by social accounting prices based on simpler estimating techniques (such as the consideration of marginal resource-using activities). Given the social accounting prices, together with the observed market prices, individual sectors—among others, the chemical sector—can be studied by methods such as the one proposed above. The criterion for including or excluding a productive activity in the development programme for the sector is some combination of the private profitability and social benefit criteria based, respectively, on market prices and on social accounting prices. The programme selected for each sector becomes the basis, in the next step, for the modification of the historically derived structural coefficients of the economy-wide model. The social accounting prices are then estimated again on the basis of the altered model, and the procedures of sectoral evaluation are repeated in order to determine if the change in social accounting prices does or does not lead to significant modifications of the previous development programme for the sector. The iterative procedure is

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[2] *See* United Nations, *La Industria Química en América Latina* (Sales No.: 64.II.G.7), and T. Vietorisz and Z. Szabo, *The Common Market and the Development of the Chemical Industry in Latin America* (1959), unpublished interim report (Spanish) of the Latin American chemical industry study undertaken by a joint working party of ECLA and the Chilean Development Corporation, at the conclusion of its first phase. The version published in 1964 is based on a thorough revision of this material by a study group of experts who visited a number of Latin American countries to verify and refine the preliminary information and calculations. The published version does not include, however, much detailed information that had been included in the interim report. Since the present author did not participate in the second phase of the study, he has not had access to the revised versions of the detailed unpublished materials referred to above. Consequently, materials will at times be cited from the *1959* reference if they are not available in the *1964* report. Such materials are cited on the sole reponsibility of the present author and should in no way be construed as committing any other individuals or organizations to particular points of view that may be advanced here.

[3] In connexion with the comparative study of profitability levels, it should be pointed out that an analysis designed to determine the optimum geographical distribution of production produces slightly different results according to whether it is based on (*a*) a comparison of costs, which is tantamount to presupposing that the internal price structure is determined by the interaction of production costs in the country with world prices or (*b*) on a comparison of profitability levels calculated exclusively on the basis of the world price structure. For the purposes of most studies, the latter hypothesis can be adopted as being simpler and more realistic. Results will also differ to some extent between studies that are concerned primarily with a given target year and dynamic (multi-period) studies.

repeated until the discrepancies between rounds are reduced to a tolerable level.[4]

Principles of organization of the programming data

The information embodied in this data summary is intended, in accordance with the foregoing section, to be used for making profitability and social benefit estimates. The summary does not, however, contain information of a local nature, but only information that is believed to have a general applicability. Accordingly, all information relating to markets, the availability of raw materials and other resources in individual countries, as well as all price-type information is excluded from the summary. The focus is rather on the presentation of technological data which are intended for world-wide application.

Cost and profitability estimation relating to chemical processes is widely used in the investment decisions of private firms. The simple idea underlying the preparation of such estimates can, however, be elaborated in a way that transforms it into a powerful tool of economic development programming.

(*a*) First of all, programming the chemical sector in an under-developed country implies investigating a large number of processes and an even larger number of process combinations, owing to such factors as plant integration and competition between alternative processes and raw materials; moreover, the evaluation for each process or process combination has to be performed repeatedly in order to explore the effects of partial variations in the price structure or the effects of replacing market prices by social accounting prices. Therefore, it is essential to *systematize all computations in such a way that they can be undertaken quickly and mechanically* on the basis of a condensed set of reference data, either by computing clerks or potentially by modern high-speed electronic computing machines.

In order to achieve this systematization, it is necessary to *separate the technological data from pricing information.* In so far as possible, all inputs and outputs of a given process are to be expressed in physical or engineering units (tons, cubic metres, kilowatt-hours, man-hours etc.); then the appropriate local price can be applied to each input or output item. When the physical amount of such an input or output item is multiplied by its price, the total value of the cost or revenue contribution due to that item is obtained. The sum of all revenue items minus the sum of all cost items gives the net revenue (or loss) for the process. This net revenue (or loss) or its ratio to some normalizing quantity, for example, investment, can be used as the criterion for evaluating the attractiveness of individual processes.

The separation of technological coefficients from pricing information achieves several essential objectives:

(i) It permits the investigation of how the technological coefficients vary between different localities or different countries. In many cases, it will be found that these coefficients are transferable from one country to another without a significant distortion of reality, whereas the money values of individual inputs or outputs can vary widely for the same processes due to the variation of local prices. If the technological coefficients are transferable, this facilitates greatly the programming tasks in developing countries, as it permits the use of data derived from sources in more highly industrialized countries.

(ii) If the technological coefficients are invariant between locations, alternate local prices can be applied in a mechanical fashion to the same technological skeleton, thereby permitting a great simplification and systematization of computations connected with locational studies.

(iii) Computations can be performed on the basis of a given set of technological coefficients, using alternately either market prices (to estimate private profit) or social accounting prices (to estimate social benefit, usually in the form of the direct plus indirect contribution to national income). The use of social accounting prices has received considerable attention in recent years and improved methods are now becoming available for estimating them.[5] As indicated previously these prices cannot be derived for any one industry or sector in isolation, since they express the value of resources, such as labour, capital, foreign exchange and invididual commodities in function of the interaction of all sectors and the resulting over-all structure of the economy. The need for using social accounting prices in the process of programming gives additional emphasis to the separation of technological coefficients from pricing information because all statistically derived value data for individual input or output items contain implicit market prices which must be replaced by the appropriate social accounting prices for this type of analysis. This can be done only if the technological coefficients are known in physical (engineering) units.

(iv) Price projections for future years in connexion with industrial development programming are always difficult and uncertain. Under such conditions, it is not enough to evaluate alternate lines of development under a single set of prices, but it is essential to test the sensitivity of the conclusions to variations in the price parameters. Sensitivity analysis involves the repeated computation of solutions for different values of the price parameters and makes it all the more essential to set up the calculations systematically. The separation of technological coefficients from pricing data is again a basic prerequisite for achieving this end.

(*b*) The technological data pertaining to related processes have to be organized in such a fashion as to *permit defining quickly and efficiently the more important process combinations or*

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[4] *See*, for example, United Nations, *Programming Techniques for Economic Development* (Sales No.: 60.II.F.3) and *Formulating Industrial Development Programmes* (Sales No.: 61.II.F.7), chapter 2; as well as T. Vietorisz, "Sector Studies in Economic Development Planning by Means of Process Analysis Models" in A. S. Manne and H. M. Markowitz *eds.*, *Studies in Process Analysis—Economy-Wide Production Capabilities* (New York, 1963) and *Planning of the Chemical Industries at the National Level*, United Nations Interregional Conference on the Development of Petrochemical Industries in Developing Countries, 16 to 30 November 1964, Tehran.

[5] *See* references cited in foot-note 4.

"*complexes*" which have to be subjected to evaluation.[6] Processes can be related (i) through the common use of some important scarce resource, such as the input of a raw material or an intermediate product; (ii) through the production of the same output; (iii) in sequence, that is, when an output of a given process forms an input to another process. Complexes built up out of related processes have a great practical importance in that such complexes often turn out to be economical even when they are composed of processes which are individually not attractive. For example, several processes using ethylene as an intermediate-product input can jointly render possible the production of ethylene on a large enough scale to result in a substantial lowering of its production cost; this lowering of the cost of ethylene, in turn, can reduce the production costs of these ethylene-using processes to the point where they become economically attractive.

In order to permit the quick and easy definition and evaluation of many different alternative complexes, the technological data pertaining to individual processes have to be standardized in presentation and grouped into larger units which can be handled by mechanical computing routines. The development programme for the chemical industry of a country consists of a collection of such complexes. Ideally, it would be desired to select the best combination of processes for each complex and the best combination of complexes for the industry, in other words, to select an optimum development programme for the industry. In practice, the aim often has to be more modest and typically consists in the definition of a reasonable number of alternative programmes which appear *a priori* attractive, the spelling out of their implications in detail with the aid of the programming data which are available and the selection of the best alternative based on this limited sample. It is, of course, of advantage to organize the programming data in such a fashion that, while relying on the practical procedure outlined above for the immediate future, these data should also lend themselves eventually to analysis by more sophisticated mathematical models, that is, of the "process analysis" type, whenever these models become powerful enough to handle large concrete programming situations.[7] For the time being, the importance of economies of scale in the chemical industry poses an obstacle to the use of conventional optimizing models because it introduces a "non-convexity" into the mathematical formulation which cannot yet be routinely handled; however, new techniques which are currently being developed, especially integer programming,[8] show enough promise to suggest that the organization of the data in conformity with the needs of mathematical models, should be given considerable weight. In defining chemical complexes, the objective is to create an intermediate level of analysis half-way between the unit activity and the over-all development programme of the chemical industry. The attempt is made to group together activities in such a way that each complex may be analysed as a more or less self-contained unit, permitting the compilation of a development programme for the industry from these complexes as building blocks. In other words, it is desired to enclose all the strong interactions between individual activities within the confines of a single complex, leaving only weak links between activities that are grouped in separate complexes. This attempt cannot be entirely successful, as a few major links always remain between complexes; nevertheless, the concept of a complex is a very useful one for practical purposes, since it permits focusing attention on a limited number of activities at a time. The major connexions remaining between complexes are sufficiently few in number so that, when the independent analysis of individual complexes leads to discrepancies in the development programme for the industry as a whole, one or two iterations will reduce them to tolerable levels.

The complexes given in figures I through VII are built around acetylene, sodium-chloride electrolysis, phosphoric acid, ammonia, ethylene, benzene, and propane-butane, respectively.[9] As indicated previously, the grouping of activities into complexes has been based on technical criteria; however, there is a sufficient element of flexibility in the delimitation of individual complexes to make it worth while to adjust them to the specific programming task in hand. The complexes as given here have been adjusted to the needs of the ECLA chemical industry study; other applications might be better served by different groupings.

It should be noted that the definition of complexes is a matter of convenience rather than of necessity. It would be possible to pass from unit activities directly to industry programmes, especially if the selection of an optimum programme could be undertaken by mathematical methods. There are, however, strong indications that even in the latter case it would be convenient to have complexes as intermediate-level units of analysis in order to facilitate the testing and adjustment of industry programmes.

Description of technology[10]

(*a*) The technological data can be best organized by employing the "activity vector" concept of mathematical programming in a generalized form. The use of actual

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[6] See W. Isard, E. W. Schooler and T. Vietorisz, *Industrial Complex Analysis and Regional Development* (New York, 1959).

[7] See A. S. Manne and H. M. Markowitz, op. cit.

[8] See T. Vietorisz, *Industrial Development Planning Models with Economies of Scale and Indivisibilities* (1964).

[9] These figures are taken from Vietorisz and Szabo, op. cit., 1959. Similar diagrams are also given in United Nations, op. cit., 1964, annex XIV, pages 251, 254 and 255, and 259 to 261, as well as in Isard, Schooler and Vietorisz, op. cit., pages 72 to 77.

[10] The table of technical data in the first version (1961) of this data summary has been replaced by material from annexes XIV and XVIII of United Nations, op. cit., 1964. In addition to standardized tables covering ninety production processes, these annexes give a detailed discussion of many problems of technology and methodology. References to these annexes will henceforth be given in the form "ECLA, annex XIV" or "ECLA, annex XVIII" with page numbers referring to the Spanish edition (the only one available at present).

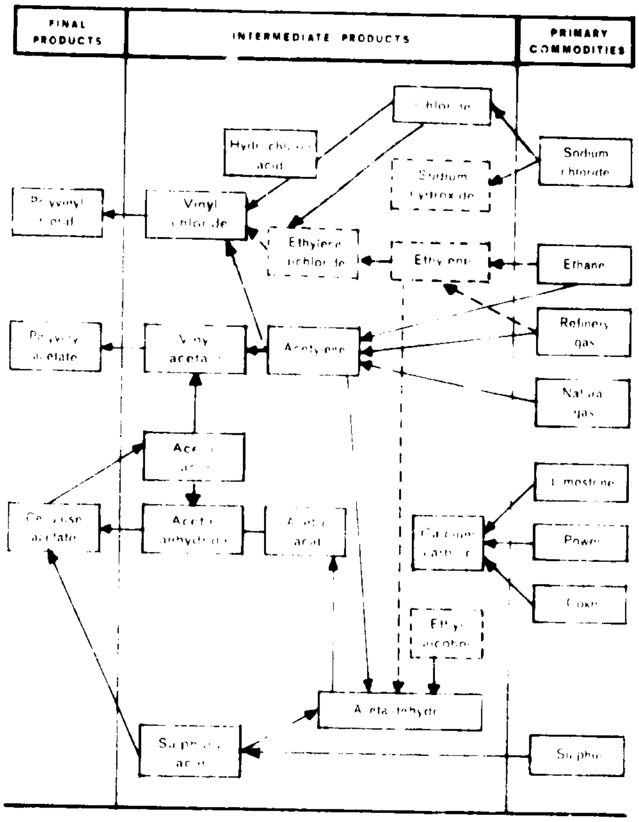

Figure I

ACETYLENE COMPLEX: FLOWSHEET OF PRINCIPAL COMMODITIES

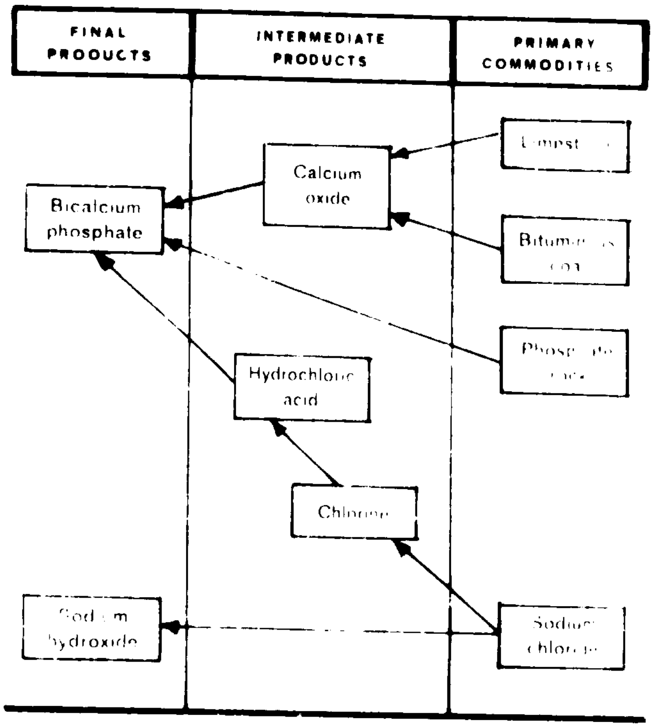

Figure II

SODIUM-CHLORIDE COMPLEX: FLOWSHEET OF PRINCIPAL COMMODITIES

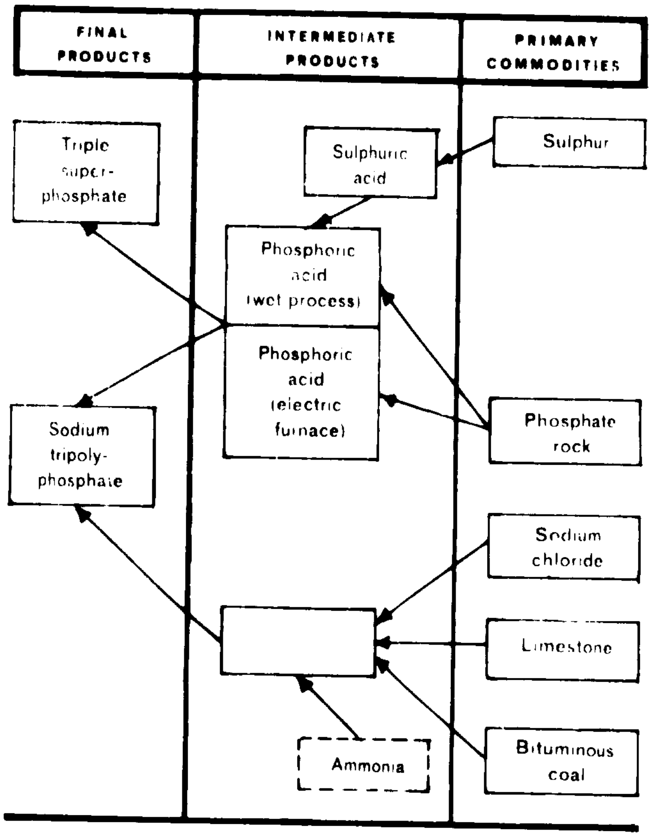

Figure III

PHOSPHORIC ACID COMPLEX: FLOWSHEET OF PRINCIPAL COMMODITIES

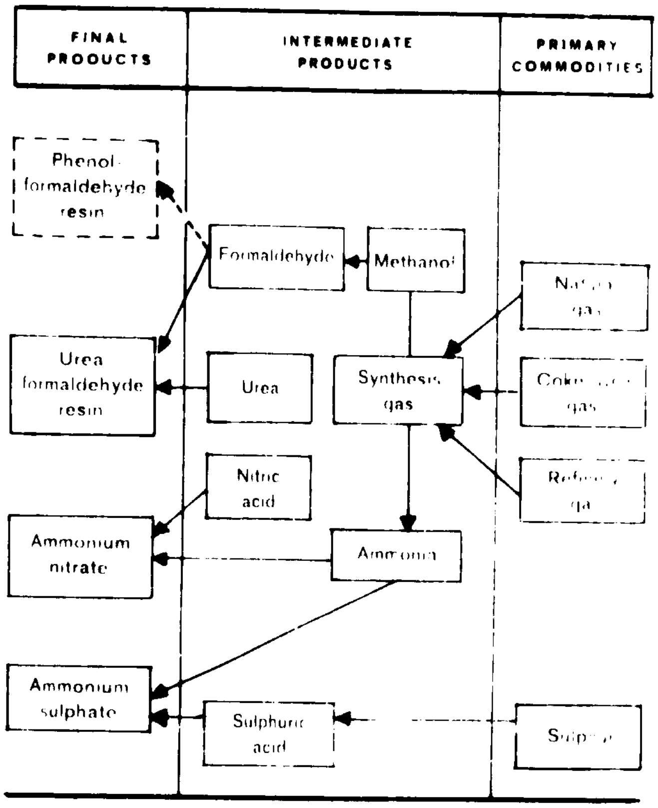

Figure IV

SYNTHESIS GAS COMPLEX: FLOWSHEET OF PRINCIPAL COMMODITIES

[a] Coke oven gas appears here as an intermediate product, as it is produced in another complex.

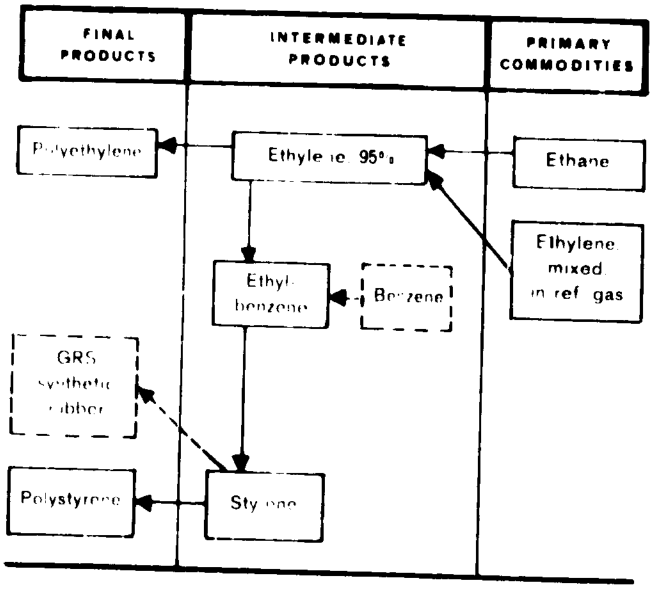

Figure I

ETHYLENE COMPLEX: FLOWSHEET OF PRINCIPAL COMMODITIES

programming models is, however, often extraordinarily difficult owing to the presence of economies of scale and the resulting mathematical problem of nonconvexity that has been indicated in the previous section. The retention of the activity-vector concept is justified under these circumstances by two considerations:

(i) While formal programming models employing, for example, integer programming might often not be justified for the analysis of a given problem owing to the experimental nature of such models and the unusually heavy requirements they pose in regard to computing ability, there are a number of approximative methods which make it possible to obtain fairly good solutions together with bounds on possible further improvement by relatively simple methods.[11]

(ii) In the absence of an optimizing model, the activity-vector concept is still highly attractive as an auxiliary method of summarizing technological information, since it permits the exploration of many potential process combinations under different assumed parameter values in a rapid and systematic fashion.

For the present purpose, a *generalized activity* is defined as the basic technological element of the integrated industrial complexes, that is, a process of chemical transformation with inputs and products which are easily identifiable and unique. While an ordinary activity is conventionally represented by a column (vector) of figures, in a generalized activity the same representation covers only those inputs and products that are proportional to the scale of production; the latter have to be supplemented by additional parameters referring to inputs whose variation with scale is nonlinear.

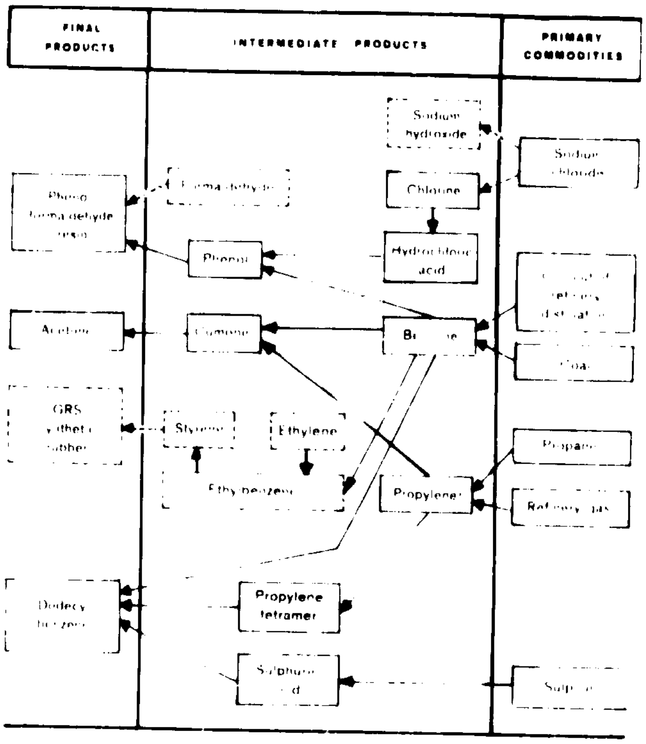

Figure II

BENZENE COMPLEX: FLOWSHEET OF PRINCIPAL COMMODITIES

[a] Propylene appears here as a primary commodity, as its production has been left outside the complex; it is a refinery operation

For example, the process for producing ammonia from natural gas may be represented by the following figures referring to the *linear* inputs and products:[12]

AMMONIA FROM NATURAL GAS: LINEAR INPUTS

Product	
Ammonia	1 metric ton
Inputs	
Natural gas	1,500 m³
Caustic soda	0·004 metric ton
Catalysers, chemicals and royalties	$2 per metric ton
Electric power	120 kWh
Water	25 m³

Mathematically the elements of these vectors represent quotients strictly determined between the inputs and products of a specific technical process.[13] It is also assumed that such quotients are constant. When a technical process allows a variable composition of raw materials and a variable distribution of products, the whole series of variations must be expressed by means of an adequate number of vectors of individual activities.

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[11] Near-optimum solutions can often be obtained by the so-called "steepest-ascent, one-move algorithm", and bounds on further improvement are furnished by linear programming solutions to the dual problem, ignoring integrality constraints. See Victorisz, op. cit., foot-note 8.

[12] ECLA, annex XIV, activity No. 10, page 266.

[13] The inputs of steam, water and fuel gas are not, strictly speaking, proportional to scale in the chemical industry. However, in general studies (though not in the preparation of individual projects) they may be considered as such with an allowable margin of error. See Isard, Schooler and Victorisz, op. cit., page 51; W. Isard and E. W. Schooler, *Location Factors in the Petrochemical Industry with Special Reference to Future Expansion in the Arkansas White-Red River Basins* (Washington D.C., 1955), pages 21 to 23 and references there cited, and ECLA, annex XIV, page 246.)

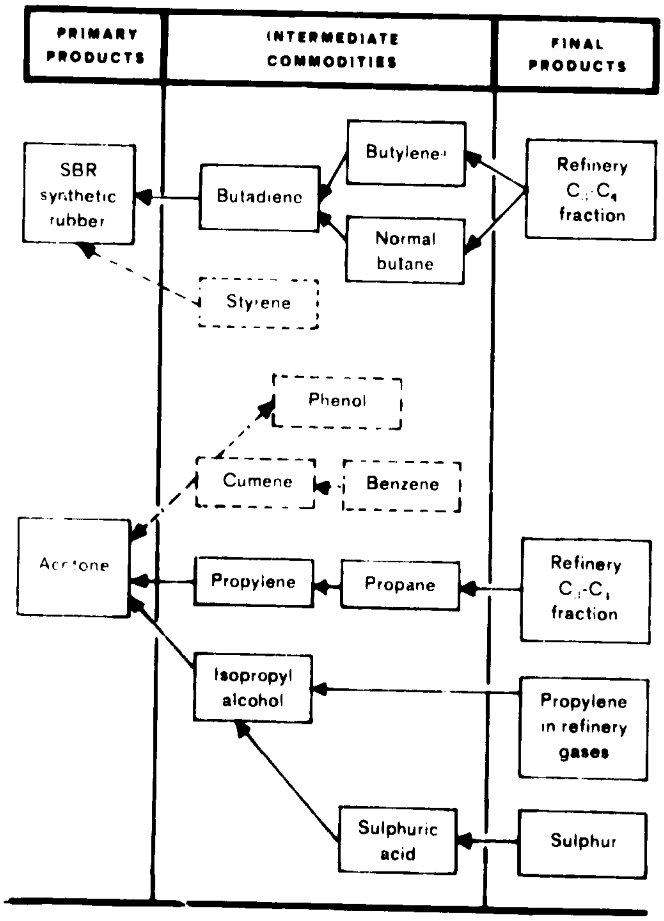

Figure VII

PROPANE-BUTANE COMPLEX: FLOWSHEET OF PRINCIPAL COMMODITIES

[a] Butylene, propylene and butane appear here as primary commodities, because their separation from refinery fractions has not been included in this complex.

The components of the above vector are expressed in physical units, except for the item "catalysers, chemicals and royalties", which is given as a value total. The use of the latter representation suffers from the shortcomings discussed earlier, but the error committed will be small when the items are of minor importance (like auxiliary chemicals used in small amounts) or stable in price (like royalties that are independent of location).

(*b*) The vector described above includes the breakdown of those inputs which expand proportionally as production grows. Certain inputs vary in a *nonlinear* fashion. The most important of these are: fixed capital investment in buildings and equipment (referred to hereafter simply as "investment") and direct operating labour (referred to hereafter simply as "labour").

In considering this latter point, it can be assumed that the ratio between investment or labour inputs on the one hand and plant size on the other can be expressed in the following equation:

$$X/X_0 = (S/S_0)^f$$

where X_0 is the input of the productive factor at the base production scale (reference scale) S_0; X is the input of the labour or investment factor which is to be estimated for the production scale S, and f is an empirical exponential coefficient which may fluctuate numerically between the limits 0 and 1.

The exponential coefficients f being known for each process—on the basis of practical experience in the chemical industry—the economies in unit investment and labour requirements resulting from any increase in production scales may be measured, always provided that basic information is available on investment and labour inputs for one given plant capacity. These coefficients, together with the technological coefficient relating to the inputs which increase linearly as production rises, must be known in advance and can then be incorporated into a "technology matrix" for the chemical industries. In the case of ammonia, the basic data pertaining to the nonlinear labour and investment requirements are the following:[14]

AMMONIA: NONLINEAR INPUTS

	Plant capacity (tons per day)	*Input*
Labour		
Workers per shift	100	–
	200	10
	300	12
	500	15
Supervisors per shift	50 to 200	2
	Over 200	4
	(tons per year)	
Investment		
Millions of dollars	36,000	5
	108,000	11
	180,000	16

These data specify given input levels for stated plant capacities. The conversion from daily to yearly capacity is undertaken in this case on the assumption of 360 operating days per year.[15] The data have been plotted on double logarithmic co-ordinates in figure VIII. It can be seen that both the labour and the capital inputs follow very closely a straight line correlation such as corresponds to the formula given above. The f exponent can be obtained from the figure by calculating the slope of the correlating line: to the accuracy of the drawing and with the correlating lines plotted visually, the exponent for labour is 0·472; for investment, 0·764. A similar plot, based on the lower points of the ranges for supervision, gives an exponent of 0·500.

In ECLA, annex XVIII (page 295) the value of the investment exponent is given as 0·73; no exponents are shown for labour and supervision. One other important item of information to be found in the latter locus gives the range of scales (18,000 to 180,000 tons/year for ammonia) within which the constant-exponent function can be assumed to approximate adequately the nonlinear input relationship. Below this range, the application of the function is highly questionable; there are indications that the exponent tends to fall, that is, there are *stronger* nonlinearities than described by the function. Above the upper limit of the range,

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[14] Foot-note 12, loc. cit.

[15] This conversion factor is found in ECLA, annex XIV, page 247; it varies between processes.

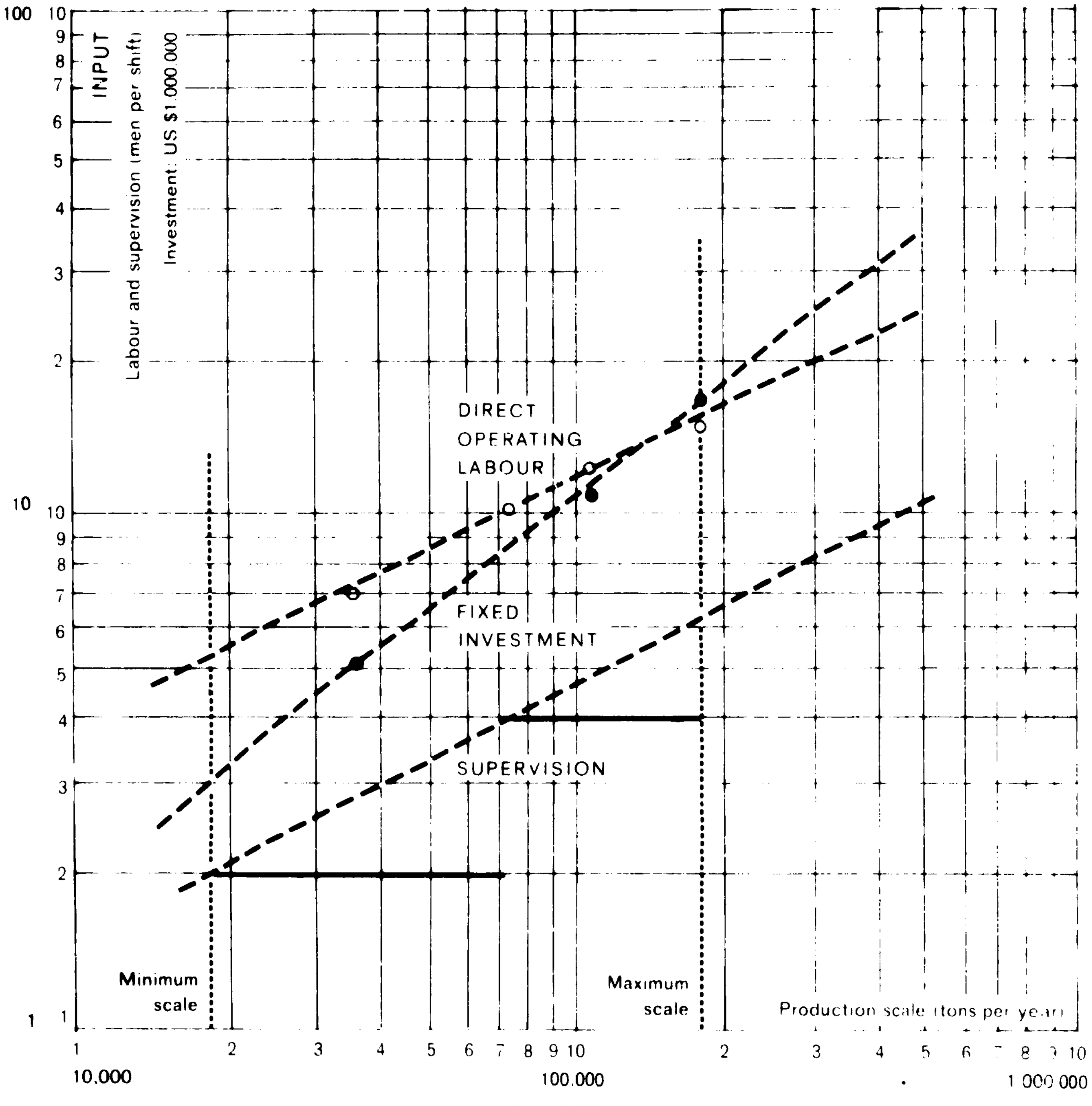

Figure VIII

AMMONIA: ECONOMIES OF SCALE

the economies of scale tend to weaken and the exponent approaches values of the order of 0·88 to 0·92.[16]

(*c*) The calculation of investment and labour inputs required for various plant sizes permits the estimation of certain accounting costs which may be expressed as percentages of these two items. Following the established practice in the United States chemical industry, costs such as supervision, payroll overhead, plant maintenance, equipment and operating supplies, indirect production cost, general office expenditure, insurance, capital charges and depreciation may be calculated by expressing them as suitable percentages of investment and/or labour. In ECLA, annex XIV, *supervision* is given in detail for several scales similarly to direct operating labour (this has already been included in the small labour and investment table for ammonia above), *maintenance* and *depreciation* are given in percentages of fixed investment; and "*general expenses*", meant to include primarily indirect production cost and general office overhead, are given as percentages of the sum of direct operating labour and supervision. For ammonia, these items are:[17]

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[16] *See* ECLA, annex XIV, page 248.

[17] ECLA, annex XIV, loc. cit.

Pharmaceutical industries in several countries. TOP LEFT: *Laboratory technician performs quality control test in vaccine production in a plant in Venezuela.* TOP RIGHT: *Packaging line in a pharmaceuticals factory in Toluca, Mexico.* BOTTOM LEFT: *Filling terramycin intravenous solution ampoules in a plant in Kobe, Japan.* BOTTOM RIGHT: *Labelling tablet containers at a plant in Moreno, Argentina*

Maintenance	3 per cent
Depreciation	8 per cent
General expenses	100 per cent for 50 to 250 tons per day 80 per cent for over 250 tons per day.

As can be seen, maintenance and depreciation follows the economies of scale characterizing fixed investment, since they are proportional to this item; while general expenses, in addition to following the economies of scale of direct operating labour and supervision, show further economies of scale in relation to the latter.

(*d*) Finally, the needs for working capital must be added to the needs for fixed capital in figuring accounting charges on the total investment embodied in the process. The basis for estimation of the latter is total out-of-pocket expense during a stated period of time that may vary between one and three months.[18] Process-by-process data, while apparently available during the second phase of the ECLA Latin American chemical industry study, have not been published.

Examples and practical applications

(*a*) The over-all approach to the representation of technology in the chemical industries which is given here was first developed by Isard and Schooler (op. cit.) for the case of some three dozen individual production processes and simple sequences of such processes. A number of concrete calculations are given in this publication in connexion with the exploration of the locational advantages of establishing manufacturing facilities near the raw material sources as against the markets of petrochemicals in the United States.

The study is based on the concept of *locational cost differences*. The location of a given process or of a simple processing sequence is analysed by itself, independently of the influence of other locational decisions pertaining to the same region or the same industry. A model based on locational cost or cost-benefit differences between two geographical points is the simplest formulation of the problem of locational choice: only two alternative locations are considered at one time, and the productive process is assumed to be identical in regard to scale and structure at both locations. Under these assumptions, it is possible to compare the profit or the net social benefit levels at the two locations without reference to the absolute magnitudes of the cost or benefit contributions by individual input or output items, since it is enough to know the cost or benefit *differences* due to each item. These are obtained by multiplying the physical amount of each input or output by the difference between its local prices at the two locations. This method has two powerful advantages over more complex techniques of analysis: first, geographical price differentials tend to be easier to determine and more stable than absolute price levels; and second, *no technological parameters need to be determined for items associated with near-zero price differentials*. The nonconvex labour and capital input functions do not create a difficulty in this model, since the scale of production is a constant.

View of a nylon intermediates unit of a chemical plant in Texas, United States

(*b*) As a next step, the consideration of larger complexes of activities was tackled in a subsequent study dedicated to the exploration of the locational advantages of chemical industries in Puerto Rico.[19] In this study, calculations have been performed for refinery-petrochemical-fertilizer-synthetic fibre complexes, exploring a number of variants and evaluating their advantages and disadvantages for different points of view.

The study maintains the methods of locational cost-benefit differentials as the foundation of the analysis, even though a set of secondary corrections are adopted to deal with major disparities between the structure or scale of production at the competing locations. The model comprises about six dozen activities, including some for petroleum refining and synthetic fibre production. The important advance of this study is in the simultaneous consideration of complexes of interrelated activities. This permits the analysis of the economies of scale which result from the simultaneous demand of several processes for a given intermediate product, the transport cost savings ob-

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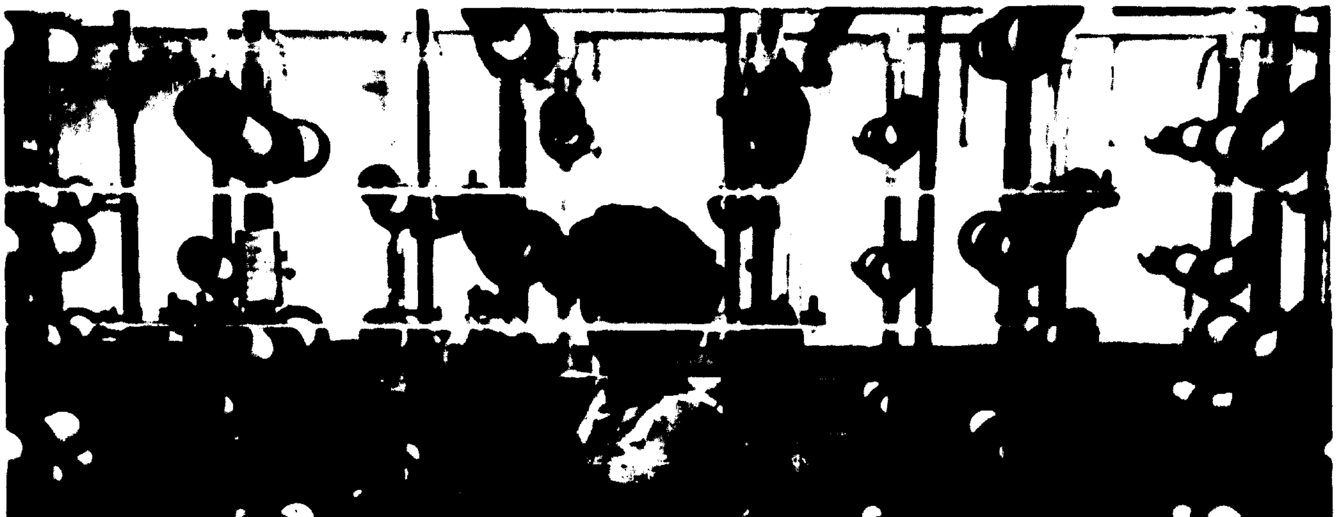
[18] ECLA, annex XVIII, page 295; *see also* annex XIII, page 244.

[19] See Isard, Schooler and Victorisz, op. cit. *See also* J. Airov, *The Location of the Synthetic Fiber Industry* (New York, 1959).

tained at a given location when successive links of a processing chain are operated jointly, the joint demand of several processes for raw materials, services and transport facilities, and other problems of mutual locational influences between individual processes. The nonconvex labour and capital input functions characteristic of chemical processes do not permit the application of the usual linear programming techniques to this locational study, but the data are organized and presented with the aid of the concepts of mathematical programming which include generalized activity vectors, resource balances and limitations, and feasible programmes. The quantitative investigation consists in the detailed exploration of more than thirty programmes, selected on the basis of process combinations which appear *a priori* attractive, but without an analytical attempt to arrive at an optimum programme.

(*c*) The first phase of the Latin American chemical industry study (Vietorisz and Szabo, op. cit., 1959)[20] was based on the experience of this earlier work; it was directed explicitly at the estimation of *absolute costs* rather than of cost differences, for a variety of chemical production processes, complexes composed of these processes and alternate over-all programmes to satisfy the demands for major chemical products in all regional markets in Latin America. The abandonment of the severe limitations of the locational cost-benefit difference approach and the dealing instead with absolute price levels has permitted the exploration of locational equilibrium for key production sites in five countries, twelve market areas covering the entire region and over sixty production activities. Owing to the nonconvex nature of the labour and capital input functions, formal optimization has again been avoided; instead, a number of alternative programmes which appeared *a priori* attractive in the course of the investigation have been explored by means of detailed computations.

The industrial complex approach[21] initiated by the study mentioned under (*b*) above has been carried further by this study. In addition to taking into account the interactions between productive activities within the complexes and thus obtaining realistic estimates of potential economies of scale, the individual complexes have been used here as a means of decomposing the over-all programming problem into a number of reasonably self-contained subproblems. In regard to locational choice, each complex is taken to behave as a unit, very much as though it were a single activity rather than a combination of several



Checking the automatic distribution of synthetic yarns in one of the largest chemical plants in Colombia

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[20] *See* the introductory note to this article and foot-note 2. *See* (*g*) below for the second phase.

[21] *See also* the preceding discussion of complexes under "Principles of organization of the programming data".

Machine filling of urea bags in a factory in China (Taiwan)

activities. The internal structure of the complex, nevertheless, can be adjusted to the local requirements of each geographical production site. The over-all programme for the industry serving the entire region can then be pieced together from the complexes which are used as building blocks, rather than from individual productive processes. This leads to a great economy of effort and to the ready identification of programmes that can be regarded as *a priori* attractive, since it makes it possible to focus attention on a limited number of activities at a time.

The quantitative exploration of alternative programmes is greatly facilitated in this study by a fortuitous relationship between the parameters characterizing the economies of scale, product demands and transport costs. It so happens that the economies of scale obtainable by serving additional markets from a single plant generally dominate transport costs in the entire range of demands which are of interest; in other words, it is more efficient to serve all markets from one plant than to split up the markets between two or more plants, given the assumptions of the particular model chosen for analytical purposes.[22] This is plausible when it is noted that the total market projection for 1965 for a given chemical product in Latin America (in the group of chemicals that have been considered in this study) is generally of the order of magnitude of a single very large-sized modern plant. Thus, the analytical problem is reduced to selecting the best *single* plant location from among several alternative locations. A simple way of doing this is to trace profits as a function of plant size for each productive location individually as markets are added one by one in the sequence of their profitabilities.[23] If the relationship between the parameters of the model were a different one, however, this simple method would no longer be applicable and a more powerful method would be needed.

In selecting alternative programmes for detailed computation, it is generally assumed that the production of intermediate products is integrated with that of final products. This is an excellent *a priori* supposition as long as the relationship between the parameters of the model favours single plant locations over split locations. In this regard, it is noted that, apart from economies of scale and transport costs, the dominant locational forces in the model are fuel costs (which also define petrochemical raw material costs) and capital costs. The influence of the latter two factors on intermediate products is likely to run parallel to their influence on final products: thus, it is unlikely that the transport cost savings afforded by an integrated operation would be outweighed by the possible disadvantage which arises when an intermediate product has to be produced, not at it own best location, but at the best location of a given final product. When other than *single* locations may occur, however, the force of this argument is greatly reduced, because a split location for the final product has to be considered separately from a split location for the intermediate product.

In a few cases, a major intermediate product forms a strong link between different complexes[24] whose optimum locations differ. These cases are handled in the study by also considering each of the alternative locations as possible sites of a combined plant serving both complexes.

(*d*) The methods and technological data developed in the course of the foregoing study have been given a practical test in connexion with the preparation of a chemical industry development plan by the Government of Chile. This plan constitutes an integral part of the over-all industrial and economic development plans for this country. The chemical industry development plan was prepared with the participation of national and international technical experts in industrial chemistry and chemical engineering. One of the sources for the preparation of this plan was the information gathered in connexion with the first phase of the ECLA chemical industry study which had been

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[22] One exception noted was that of (simple) superphosphate fertilizer.

[23] This sequence usually coincides with the sequence of geographical proximity: thus the sequence is different for each alternative plant location.

[24] For example, styrene based on the intermediate product ethylene forms a link between the ethylene complex and the propane-butane-synthetic rubber complex, since GRS synthetic rubber is produced from butadiene and styrene. Thus, a possible joint location of the ethylene and propane-butane complexes is of interest.

Production of antibiotics in the sterile area of a plant in Istanbul, Turkey

undertaken by a working group jointly with the Economic Development Corporation of the Chilean Government.[25]

(*e*) The methodology of chemical industry studies was carried a step further by the detailed investigation of the role of nonconvexities in one part of the Latin American regional market problem. In a paper by Vietorisz and Manne, "*Chemical Processes, Plant Locations and Economies of Scale*", in Manne and Markowitz (op. cit.), the production of nitrogenous fertilizers was selected for more detailed investigation. The complex to be studied comprised the production of ammonia, nitric acid, sulphuric acid, ammonium nitrate and ammonium sulphate; technological, price and demand data were taken from Vietorisz and Szabo (op. cit., 1959). Two major simplifications were introduced to make the computational problem more manageable. *First*, the five separate activities of the complex were reduced to just two stages, the production of ammonia from a hydrocarbon feed stream and the production of mixed fertilizer (ammonium nitrate and ammonium sulphate in fixed proportions) from ammonia. The amount of fertilizer produced was measured in ammonia equivalent units, that is, in the weight of ammonia input required to produce the given amount of fertilizer. *Second*, the nonproportional cost items in the production of ammonia and fertilizer were approximated by a fixed cost and a linear variable cost. By means of these simple devices, the two-stage production of fertilizer and its distribution to the different markets could be made formally equivalent to the two-stage transportation of ammonia from the ammonia plants to the fertilizer plants and from the fertilizer plants to the markets. The transport costs from ammonia plants to fertilizer plants and from fertilizer plants to markets were increased by the amount of unit production cost at each location of origin, and thus production did not have to be formally considered as a process distinct from transport. A given ammonia or fertilizer plant location could, however, be considered as an origin for the respective transport activity only if the fixed cost associated with that productive location has already been incurred. Thus the chemical plant location problem was formally reduced to what is known as a two-stage "fixed charge transport problem".

The purpose of formulating this model was to verify the assumption that the production of intermediate commodities (like ammonia) could be integrated into a complex with the production of final commodities (like, fertilizer) without a significant distortion of reality, and, in particular, that the locational pattern obtained by an optimum solution to the reformulated problem would coincide with the locational pattern arrived at heuristically. It was further of great interest to investigate the distribution of near-optimum solutions and to obtain some indication of whether there was a reasonable chance of finding some such near-optimum solution in the course of a heuristic investigation. The method of attack was a complete enumeration of all locational alternatives, in this case of 1,024 zero-one combinations of fixed charges at individual ammonia and fertilizer locations. The results confirmed the validity of the heuristic approach for this case and indicated further that there were a great many near-optimum solutions, in other words, that the optimum to the nonlinear-nonconvex programming problem in this case was a flat rather than a sharp one.

(*f*) The same selected problem was also investigated by means of integer programming and by linear-programming and steepest ascent approximations. The integer programming formulation yielded only lower bounds on the total cost rather than actual solution values; these bounds were, however, quite close (Vietorisz, op. cit., 1964). In the same study, the static cost-minimization approach for a selected target year was generalized to a multi-period formulation that attempts to define not only the best location of productive units at a given moment of time, but also the best time-space pattern of capacity expansion. One particularly interesting preliminary indication that showed up in this study concerns the advantages of time phasing the expansion of capacity at more than one supply point in

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[25] The Chilean development plan referred to here has appeared in mimeographed form in the version whose summary volume bears the date January 1961. *See* the list of references at the end of this article, under Chile. The present author does not know whether this version was later revised or not, nor has he any knowledge of the data on which any revisions may have been based.

such a way that whenever a deficit occurs at one point there is a surplus at the other. With sufficiently low transport costs, such time phasing and the making good of temporary deficits by mutual exports can be substantially cheaper than independent growth of capacity at both locations. This result goes beyond the verification of the heuristically obtained results of the Latin American chemical industry study and points the way to a potentially attractive institutional arrangement within the Latin American Common Market.

(*e*) The final report of the Latin American chemical industry study whose first phase was described under (*c*) above was recently published by the United Nations (op. cit., 1964). During the second phase of the study, the empirical materials were thoroughly revised and greatly expanded by a working group which visited the key countries covered by the report.

While the emphasis of the interim report (Victorisz and Szabo, op. cit., 1959) was on an attempt to determine the fundamental features of locational equilibrium for the industry covering the entire Latin American region, deliberately cutting across fortuitous institutional features which stand in the way of joint supranational planning of this industry within a common market, the final report has been directed toward the more immediate needs of development within this industry, taking as a basis present-day institutional realities within the region, together with such changes as can be reasonably anticipated within the time horizon of the study. As a result of this difference in emphasis, the description of the present status of the industry, the details of demand projection, the survey of resource availabilities and prices, and the representation of technology have been greatly improved for inclusion in the final report; at the same time, the presentation of the extensive analytical contents of the interim report pertaining to locational equilibrium within the region has been dropped and the results are only most sparingly referred to. The final report concentrates on a detailed presentation of all background materials, leading up to an analysis of production costs for ninety chemical processes considered individually or in complexes, at production sites within seven countries of the region. The scales of production correspond either to the needs of these individual countries or they are determined by possible integrations between selected countries; however, the optimum division of markets between alternative production sites as a function of the interaction of production and transport costs is not taken up in any significant detail. It is, nevertheless, indicated that economies of scale tend to weaken consider-

Laboratory examination and testing of finished yarn in a nylon factory at Berazategui, Argentina ably near scales of production corresponding to the integration of the seven countries studied and even near the scales corresponding to the three largest individual countries; as a result, near these scales the balance between economies of scale and additional transport costs, as the market of a given production site is expanded, tends to lead to a flat optimum and to a lack of marked cost differences between alternative programmes embodying a greater or lesser degree of integration. This conclusion is entirely in line with the results of the quantitative investigation of sub-optimum programmes in the study discussed under (c) above.

(*h*) The idea of time phasing has recently been applied to the planning of chemical industries in India (A. S. Manne, *The Caustic Soda Industry*, Cambridge, Mass., 1964). This report is the latest example of the systematic application of programming data to the study of this industry in the context of a practical planning situation. The technological information has in this case been taken from Indian sources, but these have been double-checked against the data contained in the Latin American chemical industry study, and the two sources have been found to be consistent.

(*i*) Of the many quantitative programming studies of the chemical industry which are undoubtedly being undertaken in countries with centrally planned economies, this author has had an opportunity to review to date only one (J. Kornai and others, *Mathematical Programming of the Development of Hungarian Synthetic Fiber Production*, Budapest, 1963). Of the studies discussed, this one is probably the closest to operational planning; for this reason, it is very interesting that the basic conceptual framework of the model used and the description of technology incorporated in this study are completely consonant with the other studies discussed so far. In particular, the description of economies of scale is undertaken by means of the fractional-power function discussed under "Description of technology" (*h*) above. The model focuses on the exploration of greater or lesser degrees of autarchy in synthetic fibre and chemical-intermediate production *versus* participation in international trade in the products of this sector under different assumptions. The sensitivity of the conclusions to various parameters, particularly to the foreign exchange rate, the future price levels of individual chemical products and possible correlations between changes of the latter, as well as to capital, labour and material coefficients is carefully analysed. The mathematical method employed for improving the solutions of the model does not guarantee that the optimum solution is actually reached, but it makes the attainment of a near-optimum solution highly probable.[26]

In the following section, a number of conceptual and practical problems connected with the compilation and use of the programming data summary will be discussed.

Critique

It is believed that the data and methods presented in this paper are of immediate practical value for industrial development planning in the less developed areas. The information presented here has, as mentioned above, already been relied on to some extent in the preparation of at least one chemical industry development plan in a Latin American country; in addition, information of a partly different origin but organized in the same format—see (*i*) above—is being applied directly as a background for practical planning decisions.

The materials pertaining to the chemical industry have been collected and subjected to testing in a long series of research studies conducted at different institutions. Some of these studies have been briefly discussed above.[27] As a result of this accumulation of materials, it is probably true that the chemical industry is at present better explored from the point of view of industrial development planning than most other industries of comparable breadth.

In addition, other chemical process type industries have also been studied by methods which are closely related to the one described in this paper. Among these are petroleum refining, cement and the chemical metallurgy of steel-making.[28]

In view of the foregoing, the methodology employed in regard to the chemical industry (and the related chemical process industries) may serve in many ways as a prototype for the organization of data pertaining to other industries. Therefore, it is necessary to subject this entire methodology to careful scrutiny in order to disclose its limitations and weak spots and to indicate lines of needed improvement.

The following discussion will be organized around five central topics: the vector concept, capital investment, ancillary process, transferability of the data between countries and practical application.

The vector concept

(*a*) The concept of a generalized activity vector as defined in this paper, that is, allowing for nonlinear labour

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[26] This mathematical method is of interest for its own sake. While the nonconvex programming methods cited earlier have been based on the approximation of the fractional-power cost function by means of a fixed cost and a linear variable cost, the nonlinear objective functions are retained in the last study as they are originally formulated, and their values are calculated at extreme points of the polyhedron of feasible solutions. A local optimum can always be attained by a path moving over neighbouring vertices. Once a local optimum is attained, a method is offered for testing if this is also an over-all optimum. The test is based on increasing the curvature of the objective function, whereby the current vertex is often rendered sub-optimum, and a move to other vertices is originated. By appropriate changes of curvature restricted to different subspaces, a variety of new paths are generated, some of which may include vertices that have objective-function values below the former local optimum.

[27] See *also* the reports of the Commissariat général du plan de modernisation et d'équipement, commission de modernisation des industries chimiques (Government of France); as well as United Nations, *Studies in Economics of Industry: Cement, Nitrogenous Fertilizers Based on Natural Gas*; and *Bulletin on Industrialization and Productivity*, No. 6 (Sales No.: 63.II.B.1), pages 67 to 77.

[28] *See* Manne and Markowitz, op. cit., and Manne, "Programming Data for the Petroleum Refining Industry" in this issue of the *Bulletin*.

and capital inputs, is central to the organization of all technological information in this data summary. It should be pointed out that the powerful simplification underlying this concept consists in the idea of *replacing an n-dimensional production function by $(n-1)$ two-dimensional functions.*[29] It is always easier to think in two dimensions than in many dimensions: two-dimensional functions can be represented in the plane of the graph paper and their significance can often be grasped at a glance. For example, the activity vector relating to ammonia production, under "Description of technology" (*a*) lists six commodities; in addition, the nonlinear part given under (*b*) and (*c*) adds six more items: labour, capital, supervision, maintenance, depreciation and general expenses. These twelve resources are interrelated by a functional relationship which, in its most general form, would require twelve dimensions to describe. Nevertheless, it is an acceptable simplification to assume that among the twelve variables of the production function, not eleven are independent but only one. We can choose the quantity of any one of the twelve resources as the independent variable and call it the "scale of production". In this paper, the output of ammonia has been chosen to fix the scale: it is convenient to use as a scale indicator one of the commodities which vary in proportion to each other.

Given the scale, every one of the eleven remaining commodities can be related to it, without the need of taking the other ten commodities into account. The first important assumption relating to activity vectors is that this can be done without a significant distortion of reality.

The second assumption is that all inputs and outputs except labour and capital and accounting items depending upon these vary proportionally to scale. In the case of fuel, power and steam inputs, deviations from proportionality are known to occur but they are generally small enough to be tolerable. There is some evidence, however, that under unusually small scales of operations, such as are likely to be encountered under certain conditions in developing countries, the inputs of some commodities, especially auxiliary chemicals, can become abnormally high owing to poor recovery.[30]

The third assumption relates to the fractional-power labour and capital input functions discussed under "Descriptions of technology" (*b*). There is a good deal of supporting evidence concerning the general shape of the relationship,[31] but large deviations are known to occur. These are in part related to the vague definition of the inputs, for example, the lack of differentiation between direct and indirect labour, or between investment in new plants and additions to existing plants. A closely related reason for these deviations may lie in the inexact delimitation of the process to be characterized, that is, the lack of definition of what, if any, ancillary processes are included (this issue will be discussed later in more detail). In addition to deviations from the function, there is the question of suitable upper and lower limits to the fractional-power variation. The upper limit is usually estimated by reference to the largest existing installation, but new plants are constantly breaking the existing records of size. Above this limit many unit inputs remain constant, but in fact the limit is not sharp. Different pieces of equipment have individual size limits, and this results in a gradual rather than an abrupt transition from equipment-size increase to duplication, with a consequent effect on investment and operating labour inputs. In addition, economies in design, engineering and common ancillary facilities (see below) tend to continue beyond the upper limit of the range; as a result, the economies-of-scale exponent for capital approaches about 0·9 rather than unity.[32] At the lower limit the uncertainties are even more critical. There is no good way of defining minimum economic plant size, except by reference to a concrete price constellation. Sometimes technical minima can be found, for example, as given by the smallest size of standard equipment that can be purchased or the technical deterioration of the process below a certain plant size. Nevertheless such minima can often be regarded as more apparent than real, since the sizing of standard equipment as well as its design can be taken to be adjusted to the conditions typical of the more industrialized countries, and consequently changes in design objectives could introduce an element of flexibility even with regard to the "technical minimum" plant size. There is some evidence which indicates that below the lower limit of the approximating range the exponent of the economies-of-scale function tends to fall.[33]

With known values of the exponents in the nonlinear input functions *the generalized activity vectors can be represented by a column of pairs of numbers* in which the first number denotes the coefficient (input or output) corresponding

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[29] Another key concept pertaining to vectors is *additivity*, to be discussed later.

[30] See *also* O. P. Michelsen, "Chemical Development in Colombia", *Chemical Engineering Progress* (New York), June 1960, pages 46 to 49.

[31] See C. H. Chilton, "Six-tenths Factor Applies to Complete Plant Costs", *Chemical Engineering* (New York), April 1950, pages 112 to 114; B. P. Schofield, "How Plant Costs Vary with Size", *Chemical Engineering*, October 1955; Isard and Schooler, op. cit., pages 21 to 23 and references there cited; T. Vietorisz, *Regional Programming Models and the Case Study of a Refinery, Petrochemical, Synthetic Fiber Industrial Complex for Puerto Rico*, Massachusetts Institute of Technology, Cambridge, Mass., 1956 (doctoral dissertation), pages 173 to 184 and references there cited; Isard, Schooler and Vietorisz, op. cit., pages 52 to 58; F. T. Moore, "Economies of Scale: Some Statistical Evidence", *Quarterly Journal of Economics* (Harvard University Press, Cambridge, Mass.), May 1959, pages 232 to 245; J. Haldi, *Economies of Scale in Economic Development* (Stanford University, Calif.), November 1960; ECLA, annex XIV, pages 247 and 248, and ECLA, annex XVIII, pages 293 to 295.

[32] In order to take into account the slackening off of economies of scale beyond the upper limit of the approximating range, a hyperbolic function is proposed in Kornai and others, op. cit., page 135, which is asymptotic to a line of proportional variation at very large scales. In view of the fact that at such large scales an exponent of approximately 0·9 is more appropriate than an exponent of unity, the function could be redefined so that it would be asymptotic to a function with the above exponent.

[33] See ECLA, annex XIV, page 248.

to unit scale and the second number denotes the exponent applicable to the resource in question. For proportional inputs or outputs this exponent is equal to unity. When a process is represented in this form, it is convenient to choose the reference scale in such a way that it falls within the range of the nonlinear approximating function. Thus, in the case of ammonia, it is not convenient to choose one ton of ammonia output to fix the reference scales of the process, since the production scale of one ton per year is totally meaningless except in the formal mathematical sense. It is far more sensible to choose instead the lower or upper limit of the range, or some round number within the the range. For ammonia, 36,000 tons per year has been chosen as the reference scale;[34] the generalized activity vector based on this choice is shown in the table entitled "Illustrative generalized activity vector."

Illustrative generalized activity vector

(Process: Ammonia from natural gas)

Resource	*Unit*	*Coefficient*	*Exponent*
Ammonia	Thousands of metric tons per year	36	1
Natural gas	Millions of m³ per year	54	1
Caustic soda	Thousands of metric tons per year	0·144	1
Catalysers, chemicals and royalties	Thousands of dollars per year	72	1
Electric power	Millions of kWh per year	4·32	1
Water	Millions of m³ per year	0·9	1
Direct operating labour (staff)	Men	28	0·47
Fixed capital investment	Millions of dollars	5	0·73

Source: ECLA, annex XIV, activity No. 10, page 266. Linear inputs per ton of ammonia have been recalculated for a yearly output of 36,000 tons. The labour input corresponds to the production scale of 100 tons per day, converted to a yearly basis by the factor of 360 operating days per year; this factor is taken from ECLA, annex XIV, page 247. The datum appearing for this production scale is 7 men per shift. This is converted to the given staff requirement on the basis of 4 man-shifts per day, on the following considerations: a 44-hour week, 50 weeks per year, 5 paid holidays (40 hours) deducted from yearly working hours figured on former basis; complete coverage of all hours of the year (365 × 24 hours): this yields 8,760 ÷ 2,160 = 4·055 man-shifts per day. The labour exponent is taken from figure VIII, the capital input from activity No. 10 and the capital exponent from ECLA, annex XVIII, table A, page 295.

The inputs and outputs corresponding to any other scale within the approximating range can be obtained from such a generalized activity vector by means of the formula:

$$X_{i,j}/a_{i,j} = (X_{1,j}/a_{1,j})^{f_{i,j}}$$

where the subscript j indentifies the activity in question and i identifies the resource (input or output); $a_{i,j}$ is the input or output coefficient of the i-th resource and $a_{1,j}$ is the input or output coefficient of the scale-determining resource (in this case, ammonia); $X_{i,j}$ and $X_{1,j}$ are the total inputs or outputs of the corresponding resources at a different scale, and $f_{i,j}$ is the constant exponent characterizing the resource i within the activity j. When tables of generalized activities organized in this fashion are available for a number of processes, the total input or outputs corresponding to any given programme of activity scales can be obtained readily by instructing a computer to operate on the above function, substituting the proper arguments.

In the principal technological tabulation found in ECLA, annex XIV, the ninety activity vectors listed in detail have been presented in the form of coefficients referring to the linear part, together with nonlinear inputs in absolute magnitudes specified for different scales. In other words, the fractional-power input function for labour and capital has not been utilized in the presentation, even though it is discussed in detail in the accompanying notes in relation to capital. In this regard, the presentation differs from the one followed in previous technological summaries, for example, in Isard and Schooler, op. cit., Isard, Schooler and Victorisz, op. cit., and in the first version of the present programming data summary. None the less, in ECLA, annex XVIII capital coefficients for selected reference scales, together with applicable exponents and the range of validity for the latter, are given for a smaller number (eighteen) of chemical processes.

The advantage of the procedure followed in the ECLA document lies in its ability to present factual information without having to make an assumption with regard to the proper correlating function for nonlinear inputs. This advantage is particularly notable at very small or very large scales, which would fall outside the proper approximating range for a constant-exponent correlating function. Other reasons advanced for avoiding the presentation of the parameters of a correlating function are the following:[35] insufficient data; lack of homogeneity in published investment information with regard to specification of the process, ancillaries, reserve capacities, provision for future expansion and safety factors in design; and lack of exact definition of the approximating interval for constant-exponent functions.

While this method of presentation will lead to a high degree of reliability in the published figures and may thus be the best way of presenting the technological information underlying a study with the objectives of the ECLA

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[34] This choice follows the one in ECLA, annex XVIII for representing economies of scale in regard to capital. This annex, however, does not give a complete generalized activity vector.

[35] *See* ECLA, annex XIV, page 248.

chemical industry study—*see* earlier discussion under "Examples and practical applications" (*c*)—presentation is probably not the best for the purposes of programming data summaries. In the practical planning application of such summaries, the exploration of variants of investment projects differing in regard to scale is often of the greatest interest, and a high degree of precision in the estimating parameters can be readily sacrificed for the sake of having simple methods at hand that will yield correct orders of magnitude. The constant-exponent correlating functions serve this end admirably, and it is of secondary importance that they are somewhat unreliable near the limits of the approximating range. It is of course essential that their application should not be pushed beyond the limit of what their accuracy will bear.

Given these considerations, it becomes a matter of opinion and even of temperament at what level of accuracy programming data are to be regarded as meriting circulation. There are those who maintain that data that are not highly reliable are certain to be misused; such persons will part with data only after much checking and then only with great trepidation. There are others who argue that too many planning decisions tend to be taken intuitively or on the basis of flimsy facts torn out of context; under such conditions, a well-established simple approach complemented with data that represent correct orders of magnitude cannot fail to do some good. The author has long argued for the latter approach and, in line with it, would like to see the revised ECLA data presented in the form of fractional-power approximating functions, accompanied if necessary by such cautionary comments as may be required in each particular case. As the data stand now, it is of course possible to fit correlating functions to them as has been done above (*see* figure VIII) and as has in fact been done for eighteen processes in ECLA, annex XVIII. It is, however, desirable to fit such functions to the full set of available points for each activity, rather than only to the selected points included in ECLA, annex XIV. In the cases where the scatter is very large or where only a single point is available for an activity,[36] any knowledge that may be derived from a comparison with other technologically similar processes must be brought to bear on the selection of representative parameters: thus, in the case of a single point, the exponents of other similar processes may be applied. (If none are available, in the last instance an exponent of 0·7 for capital and 0·2 for labour may be preferred as a stopgap measure.) It is, however, most essential that such judgements be exercised by experts, for example, a working group of engineers and economists who have conducted a study of the industry, rather than by a planner using the data summary who finds himself forced to improvise in filling gaps; and that the expert judgements concerning the numerical values of the parameters be accompanied by an appraisal of their probable degree or realiability.

On the basis of the above discussion, the vector concept can be regarded as a suitable basis for organizing the technological information in the chemical and many other chemical process type industries. In addition to the data included in generalized activity vectors, such as presented in the table (or equivalent technological descriptions), supplementary material is needed in regard to the following items:

Approximating range: lower and upper limits of validity of constant exponent

Accounting items and ancillaries

Working capital requirements

Maturation period and construction period

Information concerning restrictions with regard to additivity within families of vectors.

The problems concerning the approximating range have already been referred to above. Problems concerning the other items of supplementary information required will be taken up in subsequent sections.

(*b*) Taking the vector concept as a point of departure, *the question arises as to the proper level of detail to be represented.* A unit activity can be used, from the conceptual point of view, equally well to describe (i) an exceedingly detailed process step (for example, the oxidation step in the preparation of synthesis gas in ammonia manufacture from natural gas by the Texaco partial oxidation process); (ii) an entire transformation process employing a given technology (such as the ammonia process indicated above); (iii) an aggregate of processes (such as an entire fertilizer plant comprising ammonia production and its transformation into nitrogenous fertilizer); (iv) an entire industrial branch; (v) an entire industry or industrial sector. For the purposes of this data summary, the unit activity has generally been defined at the level of a self-contained chemical transformation process, that is, at a level above the process step, but below the typical chemical plant comprising several processes.

Alternative routes of transformation can be represented by alternative activity vectors. These alternative vectors may differ in regard to raw materials, service inputs or product assortments. When the difference between technological alternatives are slight (as for example in the case of different processes for converting a given raw material into ammonia) one or a few of the several alternatives can be taken as representative of all; or some weighted average of the alternatives may be adopted. Larger differences in raw material (for example, natural gas versus fuel oil for ammonia production) call for distinct alternative vectors.

Ammonia production points up the case of a continuously variable composition of the feed-stock inputs; between wide limits any gaseous or liquid hydrocarbon mixture can serve equally well as the starting material.[37]

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[36] In ECLA, annex XIV, Nos. 20, 26, 32, 46, 64, 77 and 90 are single-point activities.

[37] While only two ammonia production processes (based on natural gas and fuel oil) are included in ECLA, annex XIV, three ammonia processes (based on natural gas, refinery gas and coke oven gas) have been included in Vietorisz and Szabo, op. cit., 1959 and eight ammonia activities (based on hydrogen, methane, ethylene,

This case differs from the simpler situation prevailing, for example, with regard to chlorine and caustic production by electrolysis[38] where the proportions of major inputs and outputs are fixed with almost complete rigidity by the laws of chemical transformations. In addition to feedstock proportions, product assortments are often continuously variable, as in the case of the distribution of principal and by-products in response to different cracking conditions in the manufacture of ethylene and propylene from naphtha.[39] Substitution possibilities may also exist between primary factor inputs, such as labour and capital. In all of these cases, the production function can be approximated by a set of activity vectors which substitute a limited number of representative proportions for the continuous range of variation. As the number of vectors used for the approximation increases, errors due to this source tend to diminish; thus, for practical purposes, any desired degree of approximation to a continuous range of variation is feasible.

The above discussion raises a question as to the appropriate degree of detail which is to be included in a programming data summary. For any given application, the criterion is to suppress all detail which does not have a substantial effect on the solution. This, however, introduces circularity into the argument: the sensitivity of a particular solution to the degree of detail in the data ought to be known before the data can be organized; in the case of programming data summaries, moreover, the kinds of solutions which might be obtained by the use of these data ought to be anticipated.

The only possible way of dealing with the present dilemma is the use of trial and error. By such trial and error the degree of detail included in the present programming data summary has been found to be more or less suitable for the problems to which these data have been applied heretofore, including some development programming applications. In broader versions of this data summary it might be advantageous to include data representing differing degrees of detail, in order to allow the user to select the proper level of detail for his particular problem on the basis of the nature of the problem itself.[40]

In the particular case of capital-labour substitution, the existing experience indicates that this possibility is only of minor importance in the chemical processes presented. In the core of each process, that is, in the chemical transformation itself, there is often no opportunity at all for the substitution of capital by direct operating labour. There is some possibility of substituting in the ancillary processes, such as maintenance, materials handling and the like, but the significance of this is not large, since the proportion of the total wage bill in the production cost of chemicals is low even in such a high-wage country as the United States; the potential capital savings, nevertheless, merit further study.

(*c*) *Some key technological factors of decision making with regard to the programming of the development of the chemical sector remain outside the present description of technology.* For example, in the evaluation of the prospects of the ethylene complex (*see* figure V) for any given country, the availability of ethane in natural gas or refinery gases, or the availability of ethylene in refinery gases is of decisive importance. Whether ethane should be separated from natural gas or whether the operating conditions of certain refineries should be modified in order to increase their ethane or ethylene yields are decisions which affect the entire analysis of the ethylene complex, but they have not been covered here. Similar omissions concern the production costs of salt; the separation of propane, propylene, butane and butylenes from refinery gases; the costs of coal mining and limestone quarrying; the determination of the opportunity costs of fuels. All of these have been omitted, as they would carry us too far out of the field of the chemical industry proper. The omissions relating to refineries are covered by a complementary data summary;[41] taking care of the other omissions requires special cost studies in each practical application. In a broader version of the present data summary, it might be worth while to fill some of these gaps; this depends, however, on the timing and nature of the coverage of these industrial or extractive activities by data summaries of their own. If such data summaries can be expected in the near future, duplication would be undesirable; if not, however, supplying the pertinent data would perform a useful practical purpose.

(*d*) In programming applications of the data in all data summaries, the question arises as to their *macro-economic significance*. Do these data represent averages or marginal values from the point of view of the economy as a whole? Do they represent averages or best practice? Which of these alternatives should they represent? Should they perhaps be expanded to describe distinctly each alternative?

Except for capital investment, which will be discussed separately below, the average versus marginal problem does not arise unless unit activities are defined at a higher

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ethane, propylene, propane, heavy residual oil and cycle oil) have been published in Isard, Schooler and Vietorisz, op. cit., pages 44 and 45.

[38] *See* ECLA, annex XIV, activity No. 6, page 265.

[39] *Ibid.*, activity No. 21, page 269. This activity represents one typical product distribution taken from a continuous range of product outputs. The same applies to activities Nos. 19 and 20, pages 268 and 269.

[40] For example, in Isard, Schooler and Vietorisz, op. cit., pages 40 and 41, six prototype refineries are given as individual activities representing the operations of a refinery as a whole. In this study, the emphasis was on the exploration of petrochemical production possibilities, and it was not considered essential to take up in full detail the question of the best internal structure of a refinery as a component of an integrated refinery petrochemical complex. In other cases, however, the feasibility of certain petrochemical operations may hinge on the exact structure of the refinery: in such cases, it will often be indispensable to consider more detail, for example at the level of disaggregation represented by Manne, "Programming Data for the Petroleum Refining Industry" in this *Bulletin*. There is no reason why these two levels of aggregation of refineries might not be included within the same programming data summary.

[41] *See* Manne, "Programming Data for the Petroleum Refining Industry", in this *Bulletin*.

level of aggregation than the ones presented here. When activities producing a common product are aggregated, some of which use one kind of resource and some another kind, it may happen that in expanding the scale of use of the common product one resource limitation is reached earlier than another. In this case, average coefficients of resource use would differ from marginal ones. A simple illustration is the case of ethylene production. Up to the limit of availability, it is generally more economical to separate out existing ethylene that is mixed with refinery gases than to produce ethylene by cracking. If all ethylene-using and producing processes are aggregated into a single industrial branch, and total ethylene production is above the limit indicated, average production coefficients are clearly more favourable (owing to the inclusion of ethylene separation) than marginal ones. As long, however, as ethylene separation and ethylene via cracking are kept apart in the form of distinct unit activities, the average versus marginal distinction due to this source cannot arise.

The distinction between average coefficients and those representing best practice is also an important one, but the data sources so far used have not been sufficiently accurate to allow a careful distinction. Since most data have been obtained from recent sources referring to new installations in the United States and Europe,[42] they can be taken to be representative of *best* practice in these countries shortly before the time of publication, rather than of the industry average. However, since technological change in some branches of the chemical industry is exceedingly rapid, the best practice of only a few years ago might no longer be the best practice of today. While the data in ECLA, annex XIV represent a recent revision, further information would be desirable on the rate of replacement of obsolete equipment in the industrialized countries in order to make possible a judgement concerning the lag of average practice behind best current practice. One indication of the rate of obsolescence could be derived from internal (as distinguished from taxable) depreciation allowance on different classes of equipment.[43] The present data summary has not been extended to the analysis of these issues.

A different aspect of the problem of best practice versus average industry practice is connected with the efficiency of enterprises in non-industrialized countries. The data included in this summary refer to technology as it exists today in the industrialized countries. The transferability of these data to non-industrialized countries, together with the corrections for lesser efficiency which might become necessary, will be discussed under "Transferability of the data between countries".

(*e*) Technological change: any data summary is subject to obsolescence, and the task of keeping it up to date is unavoidable if it is to continue to be useful. It is submitted, however, that the task of keeping an existing data summary up to date is less onerous than the task of setting it up originally. Once an acceptable data summary is in existence, the methodology of organizing and presenting it can be taken largely as standardized, and new information can be added as it accrues.[44]

If there is a systematic way of selecting an optimum programme on the basis of the available unit activities, it is not necessary to eliminate technically obsolete activities, since they will not be included in an optimum solution if a better alternative vector exists. Nevertheless, the elimination of superseded vectors will save time and computational effort and is worth while. Care has to be exercised, however, in classifying a vector as superseded. This can be decided unequivocally only if all coefficients of the new vector are at least as favourable as those of the old one; that is, the amount of any input (or noxious waste product) is equal or lower and the amount of any output is equal or higher (with the former exception). In many cases, new vectors may not be superior to old ones in this strict sense, but may rather represent changes, such as labor savings at the expense of additional investment or savings on the input of some raw material at the expense of an increase of some other input. The new vector in these cases can be superior to the old one under certain price configurations and inferior under others. Generally, the motive for such technological "improvements" is an advantage of the new vector under the price constellation prevailing in some industrialized country; it is, however, not a foregone conclusion that the same will apply under the prices, especially the social accounting prices (as distinct from the market prices) in non-industrialized countries. Whenever there is a doubt on this score, it is best to leave the old vector in the technology matrix alongside of the new one, and to allow the process of programming itself to lead to a choice between them.

(*f*) *Problems of batch size, number of shifts and equipment flexibility*, which play a role of central importance in some industries and industrial branches, are of minor significance in relation to the processes covered in this data summary, although they might be more important in some related industrial branches not yet covered, such as dyes, pharmaceuticals and other fine organic chemicals. To begin with, almost all of the processes are either of the continuous flow type or are undertaken in batches of sufficiently long duration to imply round-the-clock operation of the process. The production of bicalcium phosphate and triple superphosphate fertilizer constitutes a possible exception, together with some of the typically smaller tonnage organic processes connected with detergent manufacture: for these, one- or two-shift operation is conceivable, but not probable and most unlikely to be economical in a non-industrialized country. It should be noted, however, that this aspect of the problem of representing technology has not received sufficient attention so far and may merit some additional exploration.

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[42] ECLA, annex XIV, page 247, foot-note *b*.

[43] J. Ryan, *Current Depreciation Allowances—An Evaluation and Criticism*, Fordham University Press, New York, 1958.

[44] In this connexion, *see* the suggestion advanced in the introductory note to this article.

Equipment flexibility is the term used to denote the utilization of the same equipment for different productive uses. This is not typical of the processes covered, as in these, each process is generally associated with highly specialized equipment which is unsuited to any other production task. Two known exceptions to this generalization comprise the production of propylene tetramer (which can be undertaken in the same equipment used for producing polymer gasoline in refineries) and the first process step in the production of phenol from benzene via cumene (which can be undertaken in the alkylation equipment used for the production of alkylate aviation gasoline, also in refineries). In these two cases, equipment flexibility allows the production of these chemicals in conjunction with aviation gasoline in batches of varying lengths superimposed on processes which are essentially of the continuous flow type. This permits full utilization of the equipment even if the chemical demand is low or fluctuating, owing to the fact that spare capacity may always be used for aviation gasoline production.

In contrast to most of the chemical processes covered here, equipment flexibility and the prevalence of the batch size or lot size problem is a characteristic of the metal-working industry, where a machine is set up for a job lot, run for a few hours, days or weeks, and then torn down to be replaced by a new setup on the same basic equipment. It is anticipated that this same kind of batch size problem will be a central feature of some chemical industrial branches not yet covered, which are characterized by a few simple classes of organic-chemical transformations undertaken in standard equipment, leading to a wide variety of closely related end-products. As mentioned before, these include dyes and pharmaceuticals, and other organic product groups such as insecticides, herbicides, fungicides, detergents, emulsifiers, surface active agents, essential oils, perfume ingredients and so on. The fact that attention has so far been focused on heavy homogeneous products has led to the neglect of this entire class of problems; however, this gap will have to be filled in the future. It is hoped that this effort will be facilitated by the experiences accumulating in the meantime in relation to the methodology applicable to metal-working processes.

(g) A final problem, connected with the vector concept, though by no means the least important one, relates to the issue of *additivity*. It is assumed that unit activity vectors, operated at any chosen scale, are additive in the sense that two such vectors taken in conjunction have a total of each commodity input or output which is the same as the algebraic sum of the inputs or outputs of the individual vectors. As a first approximation, this assumption can be accepted provisionally for almost all of the vectors included in the present data summary: yet the known importance of external economies and the economies accruing to the integrated operation of several processes at a large resulting scale of total production in the industrial development of developing countries makes it mandatory to explore this issue further.

If two unit activities are closely related, that is, if the degree of detail entering the representation of a process becomes fine enough, the general statement regarding the absence of equipment substitution can no longer be maintained. In such cases it can be assumed, on the contrary, that all or part of the equipment lends itself reasonably well to either process variant. In the case of perfect substitutability, instead of adding the investment and operation labour requirements of the two variants (each calculated on the basis of its own scale), the total investment and operating labour requirements are to be calculated on the basis of the *combined scale* of the two variants, leading to substantially lower total requirements. Among the activity vectors occurring in ECLA, annex XIV, several families exist within which such a combination of scales may be preferable to the assumption of additivity; these are acetylene, activities Nos. 17, 18 and 19; ammonia, activities Nos. 10 and 11; methanol, activities Nos. 14 and 15; ethylene, activities Nos. 21, 24, 25 and 26, and sulphuric acid, activities Nos. 1 and 2. For limited substitutability, an input that is intermediate between those corresponding to complete additivity and to perfect substitutability will be most appropriate.

In this connexion it should be noted that, while the assumption of additivity overstates the total labour and investment needs of these related processes whenever they are in fact used in an integrated fashion in a given plant, the combination of scales will lead to the opposite error because the flexibility of equipment between related yet distinct uses is not perfect. Moreover, the conversion of efficiency of inputs to products in the combined operation will also be somewhat lower: if the combination consists of successive batches of the variants processed in the same equipment, the inefficiency will be caused by start-up and shut-down needs; if feed-stocks are actually mixed, the loss of efficiency will be due to the divergence in optimum operating conditions (temperature, pressure and so on) required for each individual feed-stock. Whether the investment and labour requirement gains due to the combination of scales are offset by inefficiencies depends on the divergence of the variants.

In the case of the integrated operation of widely divergent processes, the assumption of simple additivity is better than in the case of close variants and constitutes a workable first approximation. Yet, even in such cases, there exist analogous scale-combination effects, which have so far been entirely neglected and which constitute a weak link in the methodology given in the present version of the programming data summary. Every process represented by a unit activity in this data summary is in reality an aggregate of several processes: a core process (which may consist of several steps) and ancillary processes, such as steam and power generation, materials handling, maintenance, transport within the plant, storage, employee services and the like. In the estimating methodology based on the use of the unit activities, these ancillary processes are taken into account only in an approximate fashion, without allowing for the fact that they may have independent economies of scale of their own, which can in some cases be as important as the economies of scale associated with the core processes.[45] The estimating procedure allows for the economies of scale of these ancillary processes only in so far as it includes them in fixed investment or relates them proportionally to the direct investment and operating labour needs of the core process. Thus, the independent expression of these economies of scale is suppressed, and no account can be taken of the fact that the integration of several core processes into a single plant will lead to an increase in the scale of the ancillary processes, with consequent economies of scale which can at times be as important as the economies of scale of the core processes themselves.

The problems raised by the handling of capital investment and by ancillary processes will be discussed in the following sections.

Capital investment

(*a*) It was mentioned in the previous section that one of the problems in the representation of technology for the chemical industries is the integration between core processes and ancillary processes in chemical plants. This leads to an uncertainty in published figures concerning fixed capital investment, since it is generally not specified which ancillaries are and which are not included in the global investment figure. Ideally, investment figures ought to be specified separately for the core process and for the ancillary processes, and in this case a separate programme corresponding to each possible integration between core and ancillaries could be calculated on the basis of the given coefficients. However, the data on which such a detailed breakdown might be based are hard of access. Generally, *published data are insufficiently specified* in the following respects:

Kind and scale of ancillaries included in the global investment figure

Exact specification of the technical nature of the core process

Design tolerances, safety factors and other considerations affecting practical performance versus design capacity

Capacities of individual equipment components or sections of components (these capacities may not all correspond to each other, leaving some slack in certain sections, while the over-all capacity is determined by the section with the lowest capacity)

Provision for future expansion.

At the very least, global investment figures ought to indicate whether a given datum refers to new plants at new locations, new plants at existing locations, balanced additions or unbalanced additions.

(*b*) The defects of published data make it essential to complement such information with other sources, primarily the data of engineering and construction firms that can refer to their own recent experience in providing well-specified figures. It may also be possible to obtain from such sources estimates for several plant scales or for variable feed-stock or product compositions that are homogeneous with regard to the other main determinants of investment; the labour and capital exponents in the nonlinear approximating functions derived from such homogeneous sets of data points are likely to be considerably more reliable than functions fitted to a small number of points subject to considerable scatter owing to uncontrolled variables. There has been an attempt to base the information included in ECLA, annex XIV on such sources to the extent possible.[46]

(*c*) Investment data appearing in a programming data summary ought to be adequately dated. While most data in ECLA, annex XIV are apparently of recent origin, it would be desirable in the future to refer all investment information to a standard point of time by the use of some price index, such as the Engineering News Record Construction Cost Index for the United States. This could be done for data derived from United States sources with a comparatively modest effort. The problem of comparing United States data with data derived from sources in other countries is, however, a more difficult one, which has not been tackled explicitly up to the present time. Further work in this direction is desirable, especially since the United States is a high-cost supplier of industrial equipment and many developing countries can benefit by relying on other, lower cost sources of supply.

(*d*) One of the major shortcomings of the present programming data in ECLA, annex XIV is the fact that all information relating to investment is given merely as a lump sum expressed in dollars, without a breakdown of the components of this investment in physical terms. Thus, all investment information is weighted by the implicit prices in the countries from which the data were gathered.

In using lump-sum investment data, two main problems arise. First there is a difference in construction costs between the country which supplies the data and the country where the data are to be applied. Generally, if all equipment is imported, the f.o.b. costs of this equipment will have to be raised by the amount of overseas transport costs; at the same time, erection costs may be lower in the developing countries than in the more industrialized ones. Thus, the two factors affecting the comparison of construction costs tend to offset each other. For preliminary orientation purposes, it is often appropriate to assume that the United States plant cost consists of 70 per cent materials and

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[45] Steam and power generation are among the most important ancillary processes. In the unit activities given in this paper, steam and power inputs appear explicitly, permitting the estimation of their costs either on the basis of utilities purchased from outside or as separate complementary activities. Steam and power production vectors are not given here, but cost estimation pertaining to these commodities is discussed in some detail in the following references: Isard, Schooler and Victorisz, op. cit.; ECLA, annex XV; United Nations, "Electricity in the Chemical Industry" (mimeographed document E/CN.11/1 and T/104), November 1954; and H. Arguimbau and J. P. O'Donnell, "Energy for Process Industries", *Chemical Engineering*, July 1959.

[46] ECLA, annex XIV, section 2, pages 247 and 248.

equipment cost and 30 per cent installation and erection cost. More detailed information on this point, process by process, could be assembled with a relatively modest expenditure of effort which would result in an important improvement of the data.[47]

Second, in making a chemical industry development plan for a country which already has some metal-working industries, it is desirable to separate those classes of equipment which can be domestically manufactured from those classes that cannot. A sample analysis for five processes performed on the basis of conditions pertaining in Chile has indicated that there is a wide divergence between individual chemical processes with regard to the proportion of domestically procurable capital equipment items: the variation ranged between one-third and three-fourths. Evidently, no reasonable generalization can be based on these data. It might, however, be suggested, as a compromise between supplying bare lump-sum investment figures and the very onerous task of securing complete construction and equipment breakdowns for each process, that all construction and equipment be classified into four or five principal classes according to the ease of domestic procurement in developing countries of differing degrees of development. In the first class would be the simple erection tasks and simple construction and in the fifth class the most complex and difficult manufactured equipment items. Thus, the foreign exchange outlays for alternative development programmes could be estimated in a short-cut fashion, and reliance would be placed on a qualitative appraisal of the level of development of the domestic metal working industry.

(*e*) *Design and construction lead times and the maturation period* of investment are topics in regard to which there is hardly more available than a bare beginning. A recent paper by the United Nations Centre for Industrial Development[48] presents a literature survey, suggests a definition for maturation period and tabulates some of the available data. The only reasonably firm information relative to the chemical industry that can be derived from this source is that the construction periods for this industry, together with iron and steel and coke, are relatively long. In the somewhat related industry of pulp production, a rough estimate of construction and maturation periods has been six and two years, respectively. It should be noted that the definition of a maturation period attempts to measure the number of years over which the investment in a plant is unproductive *on the average;* that is, the waiting periods of different investment components are weighted by the amount of investment involved to arrive at an average. Where an acceptable social rate of return or market rate of interest that can be used as an effective yardstick for measuring the social rate of return on investment is known, the interest charge on construction capital is an acceptable substitute for the exact knowledge of the maturation period. The investment figures reported in ECLA, annex XIV include such interest charges, together with all design, engineering, start-up and other expenditures, in other words, the fixed investment is reported on a so-called "turn-key" basis. Even so, the knowledge of the design lead times and total construction period is essential for the proper timing of other planning decisions that tie in with a given chemical project. It is desirable that the existing data be complemented in this direction.

Ancillary processes

(*a*) In the methodology given in the present programming data summary, certain accounting costs have been estimated – *see* "Description of technology" (*c*) above – on the basis of direct operating labour, supervision, and fixed investment (plant and equipment) requirements. These estimates are not wholly satisfactory; the reason for including them in the present form is the lack of sufficient study of this matter to identify a better alternative.[49] Apart from supervision, the accounting items included in the description of technology – supervision, maintenance, depreciation and general expenses – violate the general principle of separation between technological coefficients and pricing data.

The origin of these accounting item estimates is twofold. In part they represent physical inputs due to the operation of ancillary processes; and in part they have the nature of purely financial charges whose physical counterparts cannot be readily identified.

Ancillary processes as distinguished from core processes have been mentioned before. A more complete list of ancillary processes follows:

Supervision
Power and steam generation

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[47] In ECLA, annex XIV, page 247, it is indicated that the net balance may favour some of the less developed countries to the extent of 10 to 15 per cent.

[48] United Nations, "Maturation Period of Investment in Selected Industrial Projects" (mimeographed document E/C.5/42), January 1964.

[49] In Isard and Schooler, op. cit.; Victorisz, op. cit., 1965; Isard, Schooler and Victorisz, op. cit., and Victorisz and Szabo, op. cit., 1959, a slightly different version of estimation is given which, nevertheless, is based largely on the same underlying assumptions. The difference is that in the references listed a larger number of items were estimated than in the description of technology as given by ECLA, annex XIV; these estimating percentages, moreover, were not adjusted to the needs of developing countries, but were derived directly from United States usage. While the notes accompanying ECLA, annex XIV, do not state explicitly to what conditions the estimating percentages given there are taken to apply, it is apparent that they have been defined with the needs of the Latin American chemical industry in mind. A further difference lies in the handling of supervision: in ECLA, annex XIV, this item is handled as an explicit input described in physical units, not as an estimating percentage based on labour. This is clearly superior to the use of a percentage figure, however derived. Apart from supervision, the percentages given in the listed sources are reasonably consistent with the percentages given in ECLA, annex XIV. The main difference is that in the latter source, minor items have been omitted, and, on the other hand, individual estimates are presented for each process; whereas in the earlier listed sources standard percentages were applied to all processes. These percentages will be found for example in Isard, Schooler and Victorisz, op. cit, page 59

Provision of other plant services (water purification, sewage and waste disposal, compressed air, vacuum, lighting, hot water, heating)

Maintenance, repair and replacement of capital equipment: (*a*) productive equipment and buildings; (*b*) roads, yards, storage etc.

Storage and inventory maintenance

Materials handling, internal transport

External transport connexions: loading and unloading, terminals, joining arteries

Laboratory and technical inspection services

Protection: fire, police, safety services

Employee services: first aid, wash-rooms and locker rooms, cafeterias

Office services

Insurance.

In so far as the accounting cost estimates refer to concrete physical counterparts, they lump together into large value categories a wide collection of physical inputs of diverse sorts. They thus provide an estimating short cut and avoid the listing of all inputs individually and the application of a correct price to each input. They do this by applying implicit prices to the inputs; in other words, the estimating factors are derived from practical experience with certain value totals based on the market prices of the various inputs.

A list of accounting cost items of a financial nature (financial charges) which have no readily identifiable physical counterparts follows:

Payroll overhead: fringe benefits, social security, bonuses, vacations etc.

Depreciation charges (as distinct from physical capital consumption)

Taxes

Interest on invested capital, including working capital.

(*b*) These financial charges are more closely relating to pricing type information than to physical inputs. Payroll overhead based on existing practices can be determined for any country in the same fashion as its wage structure; it does not form a part of the intended coverage of the programming data summary. Taxes and interest rates are in the same category. Depreciation charges have in part the nature of pricing type information in that they are attributed as a percentage (like interest) to the fixed capital investment. This percentage charge is assigned in some uniform fashion year after year and bears no strict relation to the actual consumption of the physical stock of capital goods in the productive process. In part, nevertheless, there is a physical basis for depreciation charges, since more durable types of capital stock, such as buildings and earthworks, are assigned lower depreciation charges than less durable ones, such as machines. In the evaluation of processes from the point of view of private profitability, a depreciation rate based on the reasonably expected lifetime of capital goods is appropriate; however, in describing the process from the point of view of planning, it would be essential to be able to define a capital consumption profile over the life of a plan, including the specification of expected maintenance inputs over the years and a probable terminal replacement date.

(*c*) In regard to the accounting cost items which do have physical counterparts in the various ancillary processes, it appears appropriate to suggest that these processes be studied as individual unit activities and that their input requirements be specified as closely as possible in function of scale. Unfortunately, this appears to raise some major problems: (i) The requirements of ancillary processes per unit of core process are often hard to specify; in fact, to do so would probably require a revision of all individual unit activities from this point of view. It cannot yet be accurately foreseen to what extent such a revision will be justified by an increase in the accuracy of description. Possibly, only a few major ancillary-process categories might be covered in detail, and some aggregative approach might be used for the rest. (ii) While some ancillary processes can be handled by the methodology appropriate for chemical process type industries (steam and power generation, water purification, other plant services), others clearly cannot. Maintenance and repair are predominantly metal-working activities and have to be handled by the methodology appropriate to that industrial sector. Still other ancillaries have characteristics of their own, such as storage and inventory maintenance, internal transport and materials handling, protection services, office services and insurance. Inventory and insurance services, for example, must be attacked from a statistical point of view quite distinct from the methodology of the usual process descriptions.

These problems appear important and difficult, but they are surely not insuperable. It is emphasized, however, that this problem area needs thorough and extensive future research if the present shortcomings of the data summary are to be significantly improved upon. It should be borne in mind especially that, according to many indications, developing countries often suffer from inefficiencies in the area of ancillary processes as great as or greater than in the area of the core processes themselves.

(*d*) One final note should be added regarding capital-labour substitution. Preliminary considerations indicate that the range of possibilities in this regard is greater in the ancillary processes than in the chemical core processes themselves, making a study of this problem of special interest to developing countries which are on the point of industrialization.

Transferability of the data between countries

Before discussing the problems in this area, it is worth stating that the data incorporated in the present summary have already been transferred from country to country several times. Originally developed for a study of petrochemical location problems in the United States, the technological coefficients, after suitable complementation, have been used for analysing the possibilities of establishing a chemical industry in Puerto Rico. Thereafter, again through reliance on some complementation and a modest amount of revision, the same coefficients embodied in unit activity vectors have been used for analysing the locational structure of the chemical industry in the Latin American regional market. Finally, essentially the same technological data have formed the basis, in the hands of technical specialists in co-operation with industrial economists, for the formulation of a concrete chemical industry development plan in Chile, and have played a significant role in similar studies in at least two other countries (*see* "Examples and practical applications" above).

Some of the problems of transferring the data have been discussed in previous sections. Under "Capital investment" construction cost comparisons and domestic versus imported equipment needs have been discussed; in the preceding section, the problem raised by accounting costs and the adjustment of their estimating percentages to local conditions has been mentioned. No definitive solutions could be suggested at this stage, except for the indication of possible lines of attack of these problems for future revisions of the data summary.

Two additional considerations will be mentioned here; the issue of commodity proportions (including factor proportions) and the issue of production efficiency:

(*a*) With regard to commodity proportions, including factor substitution possibilities, differences in raw material availabilities and differences in product assortments, it is sufficient to mention briefly the well-known fact that no adequate amount of attention has ever been given to the design of technological processes for the specific price constellations prevailing in many non-industrialized countries; thus, it is not surprising that the existing technological alternatives often do not appear advantageous under the conditions prevailing in these countries. This fact does not indicate an inherent lack of transferability in the technological information from industrialized to developing countries, only an insufficiently broad exploration of the technological choices open to any country.

(*b*) In developing countries, it is often encountered that the entire production possibility function is shifted in the direction of less efficiency; in other words, less product is obtained with an identical input of production factors, or larger amounts of the inputs of all factors are required to produce a given quantity of product. This shift is often expressed by saying that the individual productive factors, especially labour, have a lower productivity in developing countries than in industrialized ones.

Care has to be exercised in keeping apart several influences each of which tends to lower productive efficiency. Labour productivity might indeed be inherently lower; however, low-grade management will also reveal itself in low measured labour productivity, regardless of the inherent efficiency of labour. The same result may also be due to poor supervision at the foreman level. While all of the foregoing influences originate within the firm, low productive efficiency might also be caused by outside factors over which the firm itself has no control, such as erratic fluctuations in demand due to haphazard regulatory activities, unreliable raw material deliveries, delay in receiving replacement parts for equipment and many similar factors. A better understanding of these factors appears essential for improving the prediction of comparative productivities of technological processes transferred from industrialized to less developed countries by the use of correction factors or other means of adjustment.

Summary: practical application

(a) *The major sources of error* connected with the use of programming data summary for the chemical industry, in its present form, can be summarized as follows:

(i) Deficient estimation of accounting items
(ii) Additivity assumption for unrelated vectors: neglect of economies of scale of ancillary processes
(iii) Lack of allowance for physical capital consumption profiles over time
(iv) Insufficiently specified investment figures
(v) Lack of criteria for comparative productivity corrections

In addition to the sources of error specified above, the gradual obsolescence of the technological information will introduce ever-increasing sources of error unless the data summary is kept up to date.

(b) *The major omissions* which restrict the use of the data summary and should be remedied are the following:

(i) Capital investment: more breakdown needed, at least in relation to construction costs and imported versus domestically produceable items; data on construction and maturation periods needed
(ii) Ancillary processes: detail required at least on main sources of economies of scale
(iii) Unless covered by separate profiles, estimating methods for steam, power, hydrocarbon separation, coal mining, salt production, limestone quarrying etc. have to be added

(*c*) In addition to the above errors and omissions, the programming procedure may be subject to *errors committed outside the range of the programming data summary.* The principal sources of error in this area are:

(i) Market projections
(ii) Price estimation, especially social accounting prices
(iii) Neglect of important non-quantifiable factors

(*d*) *In sum, do the above sources of errors and omissions preclude the use of the programming data summary for planning applications?*

It is submitted that planning is an art, not a science. By the very nature of industrial development planning, decisions cannot be avoided: not making a decision is also a decision. In so far as decisions must inescapably be made, they should be based on the widest information available. When well-explored theoretical methods are available to aid in the decision-making process, they should by all means be relied upon. Where no such methods exist, reliance must be placed on rules of thumb. Where no rules of thumb exist either, a decision must still be taken, so any bit of information that may be brought to bear on the problem is sure to be of help.

Given these premises, a wide and comparatively well-organized body of information such as is discussed in this data summary cannot fail to be useful regardless of its shortcomings, provided that its limitations are carefully borne in mind.

Accordingly, the following suggestions are made:

(i) In using the programming data summary for planning applications in its present form, the many possibilities of error suggest that heavy complementary reliance be placed on advice and revision by technical experts in industrial chemistry and chemical engineering.

(ii) In using this programming data summary as a prototype for other data summaries describing other industries or industrial branches, the problem areas specified in the second half of this paper, under "Critique" should be given special attention.

(iii) The major sources of errors and omissions should be corrected and the corrections incorporated into a more definitive future version of this data summary.

ANNEX

NUMERICAL INFORMATION[a]

ACTIVITY TABLES

[a] The numerical information supplied in the first version of this data summary (United Nations, "Pre-investment Data Summary for the Chemical Industry", mimeographed document IDP EWG.5, 12 May 1961, tables 1 to 3) has been replaced by the following material in United Nations, op. cit., 1964: annex XIV ("Technology", pages 264 to 286, comprising ninety activity tables); and annex XVIII ("Economics of Scale in the Chemical Industry", section 2, "Economics of capital", paragraphs 5 to 13, including table A, and the tabulation in paragraph 12, pages 294 to 295).

Note: Reference to "tons" indicates metric tons, and to "dollars" United States dollars, unless otherwise stated.

A-1. SULPHURIC ACID

Process: Contact from Sulphur

Output:		
Sulphuric acid	Tons	1
Steam	Tons	1·2
Input:		
Sulphur	Tons	0·345
Electric power	kWh	35[a]
Water	m³	22
Labour:		
Capacity (thousands of tons/year)		18 to 300
Workers/shift		1 to 3
Supervisory staff/shift		1 to 2

Maintenance: 2·5 per cent
Depreciation: 6 per cent
Overhead: 140 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
18	350
36	600
54	800
100	1,350
160	2,000
300	3,400

[a] Varies according to the scale of production.

A-2. SULPHURIC ACID

Process: Contact from sulphurous gases

Output:		
Sulphuric acid	Tons	1
Steam[a]		
Input:		
Sulphurous gases[b]		
Electric power	kWh	45
Water	m³	40

Labour			
Capacity (thousands of tons/year)	36	100	300
Workers/shift	2	4	6
Supervisory staff/shift	1	2	3

Maintenance: 3 per cent
Depreciation: 6 per cent
Overhead: 120 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
36	900
54	1,200
100	1,800
300	4,800

[a] The recovery of steam, which varies according to the temperature and continuity of the gases, occurs at a minimum concentration (6 per cent SO_2) of sulphurous gas.

[b] Minimum SO_2 content: 4 per cent (240 m³ of pure SO_2 gas per ton of acid).

A-3. NITRIC ACID

Output:		
Nitric acid (100 per cent)	Tons	1[a]
Steam	Tons	0·75
Input:		
Ammonia	Tons	0·29
Miscellaneous[b] and royalties	Dollars/ton	6
Electric power	kWh	190
Water	m³	90
Labour:		
Capacity (thousands of tons/year)		5 to 46
Workers/shift		2
Supervisory staff/shift		1 to 2

Maintenance: 3 per cent
Depreciation: 6 per cent
Overhead: 100 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
10	650
20	970
46	1,700

[a] In the form of 56 to 58 per cent acid.

[b] Includes losses of catalyst: approximately 0·8 grams of platinum.

A-4. SODIUM CARBONATE

Output:		
Sodium carbonate	Tons	1
Surplus power	kWh	300
Input:		
Salt	Tons	1·65
Limestone	Tons	1·3
Coke[a]	Tons	0·09
Ammonia	Tons	0·002
Fuel	1,000 kcal	3,800
Electric power[b]	kWh	
Water for cooling	m³	70
Pure water	m³	15

Labour:					
Capacity (tons/day)	100	150	300	600	1,000
Man-hours/ton	6	5·5	5	4·5	4
Supervisory staff/shift	2	3	4	5	6

Maintenance: 2 per cent

Depreciation: 5·5 per cent

Overhead: 40 per cent (30 per cent from 300 tons/day)

INVESTMENT[c]

Capacity in thousands of tons/year	*Thousands of dollars*
36	7,000
54	8,600
108	12,200
216	18,600
360	26,000

[a] Replaceable by 900,000 kcal (fuel, gas)

[b] Own production included.

[c] Does not include installations for the production of raw materials.

A-5. SODIUM BICARBONATE

Process: Solvay[a] *(carbonation of soda)*

Output:		
Sodium bicarbonate	Tons	1
Input:		
Sodium carbonate	Tons	0·63
Carbon dioxide (CO_2)	Tons	0·27
Fuel	1,000 kcal	500
Electric power	kWh	60
Labour:		
Workers/shift	3 for 50 tons/day; 5 for 100 tons/day	
Supervisory staff/shift	½ to 1	

Maintenance: 3 per cent

Depreciation 7 per cent

Overhead: 50 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
2	160
16	550
30	800

[a] Usually in a unit attached to a sodium carbonate plant; the figures show the additional investment required.

A-6. CHLORINE AND SODIUM HYDROXIDE

Process: Mercury cathode

Output:		
Chlorine (99 to 99·5 per cent)	Tons	1
Sodium hydroxide (98 per cent)	Tons	1·14
Hydrogen	m³	306
Input:		
Salt	Tons	1·55
Mercury	kg	0·2
Graphite	kg	2·5
Other chemicals	Dollars/ton	2·5
Fuel	1,000 kcal	2,000
Electric power	kWh	3,900
Water	m³	20

Labour:			
Capacity (thousands of tons/year)	Up to 50	65 to 80	100
Workers/shift	20	40	50
Supervisory staff/shift	2	2	2

Maintenance: 4 per cent

Depreciation: 9 per cent

Overhead: 40 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
16·5	8,200
33	9,000
50	12,800
100	20,700

A-7. HYDROCHLORIC ACID

Output:		
Hydrochloric acid (32 per cent)[a]	Tons	1
Input:		
Electric power	kWh	2
Water	m³	4
Chlorine	Tons	0·31
Hydrogen	Tons	0·009[b]
Labour:		
Capacity (thousands of tons/year)		10 to 26
Workers/shift		2
Supervisory staff/shift		½ to 1[c]

Maintenance: 4 per cent

Depreciation: 8 per cent

Overhead: 80 per cent

INVESTMENT

Capacity in thousands of tons/year expressed in terms of 100 per cent acid	*Thousands of dollars*
10	380
26	650

[a] Normal concentration.

[b] Obtained as a by-product of chlorine production.

[c] Usually forms part of another plant (chlorine-soda).

A-8. CALCIUM CARBIDE

Output:			
Calcium carbide	Tons	1	1
Inputs:			
Limestone	Tons	1·80	1·6
Furnace coke	Tons	0·65	0·60
Coke for lime	Tons	0·15	0·13
Electrode paste	Tons	0·032	0·018
Electric power	kWh	4,100 to 4,300	3,900
Water	m³	140	100
Labour:			
Capacity (thousands of tons/year)	15	30	100
Workers/shift	25	30	40
Supervisory staff/shift	2	2	2

INVESTMENT[b]

Capacity in thousands of tons/year	Thousands of dollars
10	2,300
20	3,500
50	6,600
100	10,800
200	18,000

[a] In plants with a capacity below 50,000 tons per year.

[b] Includes plant for lime production.

A-9. CALCIUM OXIDE (quicklime)

Output:		
1 ton CaO	Tons	1
Carbon dioxide (CO_2)	Tons	1·2
Input:		
Limestone	Tons	1·95 to 2·2
Coke[a]	Tons	0·17
Miscellaneous	Dollars/ton	0·20
Electric power	kWh	2
Labour:		
Workers/shift	2 up to 180 tons/day 6 up to 600 tons/day	
Supervisory staff[b]	½ to 1, up to 600 tons/day	

Maintenance: 2 per cent
Depreciation: 6 per cent
Overhead: 80 per cent

INVESTMENT

Capacity in thousands of tons/year	Thousands of dollars
6	360
10	480
60	1,440
200	3,000

[a] For use in classical vertical kiln.

[b] Usually integrated with other products.

A-10. AMMONIA

Process: Natural gas

Output:		
Ammonia	Tons	1
Input:		
Natural gas[a]	m^3	1,500
Caustic soda	Tons	0·004
Catalysts, chemicals[b] and royalties	Dollars/ton	2·0
Electric power[a]	kWh	120
Water	m^3	25

	tons/day	workers/shift
Labour:		
Workers/shift	100	7
	200	10
	300	12
	500	15
		men/shift
Supervisory staff/shift	50 to 200	2
	More than 200	4

Maintenance: 3·0 per cent
Depreciation: 8·0 per cent
Overhead: 100 per cent for 50 to 250 tons/day
80 per cent for more thean 250 tons/day

INVESTMENT

Capacity in thousands of tons/year	Thousands of dollars
36	5,000
108	11,000
180	16,000

[a] 800 m^3 of gas and 1,200 kWh were considered as an alternative (see fuel oil process, table A-11).

[b] Monoethanolamine, lubricating oils, etc.

A-11. AMMONIA

Process: From fuel oil[a]

Output:		
Ammonia	Tons	1
Steam	Tons	0·8
Input:		
Fuel oil	Tons	0·8
Caustic soda	Tons	0·004
Catalysts, chemicals and royalties	Dollars/ton	2·0
Electric power	kWh	1,100
Water	m^3	26

	tons/day	workers/shift
Labour:		
Workers/shift	100	7
	300	12
	More than 500	15
		men/shift
Supervisory staff/shift	50 to 200	2
	More than 300	4

Maintenance: 3·0 per cent
Depreciation: 8·0 per cent
Overhead: 100 per cent up to 250 tons/day
80 per cent up to 500 tons/day

INVESTMENT

Capacity in thousands of tons/year	Thousands of dollars
36	5,500
108	12,000
180	17,000

[a] The use of less electric power (compression turbines instead of electric motors) was examined as an alternative. In that case the fuel oil input rose to 1·25 tons, the electric power input fell to 130 kWh and investment rose by 6 per cent.

A-12. SYNTHETIC GAS FROM FUEL OIL

Process: Partial oxidation with oxygen

Output:				
Gas[a] at 350 pounds	m^3		1,000	
Steam at 400 pounds	Tons		0·70	
Inputs:				
Oxygen (95 per cent)	Tons		0·38	
Other minor ingredients	Dollars/ton		1·30	
Fuel oil	Tons		0·36	
Electric power	kWh		20	
Water	m^3		50	
Labour:				
Capacity (thousands of m^3/day)	100	140	170	
Workers/shift	2	2	2	
Supervision	1	1	1	

Maintenance: 3 per cent
Depreciation: 7 per cent
Overhead: 60 per cent

INVESTMENT

Capacity in thousands of m³/day	Thousands of dollars
120	1,560
150	1,750
300	2,500

[a] Composition variable, about 40 to 48 per cent CO and 45 to 60 per cent H_2.

A-13 OXYGEN

Output:		
Oxygen (99·5 per cent at 450 pounds)	Tons	1
Nitrogen, minimum	Tons	1·60 (about 1,440 m³)
Input:		
Air	m³	3,850
Lubricants, miscellaneous, etc.	Dollars/ton	0·[illegible]
Electric power	kWh	500
Water for cooling	m³	40

Labour:

Workers/shift . . . 1 up to 50,000 tons; 2 workers/shift up to 200,000 tons/year; 4 above 200,000 tons

Supervisory staff/shift . . . . . ½ to 1 (from 500 to 200,000 tons)

Maintenance: 2·5 per cent

Depreciation: 6·5 per cent

Overhead: 70 per cent

INVESTMENT

Capacity in thousands of tons/year	Thousands of dollars
10	800
20	1,200
50	2,000
100	3,200
150	4,450
300	7,600

A-14. METHANOL

Process: From synthetic gas

Output:					
Methanol	Tons		1		
Input:					
Synthetic gas[a]	m³		2,600		
Fuel	1,000 kcal		800		
Steam	Tons		2		
Electric power	kWh		1,100		
Water for cooling	m³		350		
Labour:					
Capacity (thousands of tons/year)	6	10	15	30	
Workers/shift	6	8	12	12	
Supervisory staff	1	1	2	2	

Maintenance: 4 per cent

Depreciation: 8 per cent

Overhead: 60 per cent

INVESTMENT

Capacity in thousands of tons/year	Thousands of dollars
6	800
10	1,100
15[b]	1,500
30	2,800
33	3,050

[a] Unrefined: ($CO + H_2$), 90 to 95 per cent.

[b] Requires about 120,000 m³ of synthetic gas/day.

A-15. METHANOL

Process: From natural gas

Output:			
Methanol	Tons		1
Input:			
Natural gas	m³		1,400
Catalysts and chemicals	Dollars/ton		0·50
Miscellaneous materials and royalties	Dollars/ton		1·10
Fuel	1,000 kcal		6,050
Steam	Tons		1
Electric power	kWh		815
Cooling water	m³		350
Labour:			
Capacity (thousands of ton/year)		33	55
Workers/shift		7	10
Supervisory staff		1	1

Maintenance: 2·5 per cent

Depreciation: 7 per cent

Overhead: 40 per cent

INVESTMENT

Capacity in thousands of tons/year	Thousands of dollars
33	6,400
55	9,720

A-16. ACETYLENE

Process: From calcium carbide

Output:		
Acetylene	Tons	1
Input:		
Carbide	Tons	3·2
Miscellaneous products	Dollars/ton	5·00
Electric power	kWh	100
Water	m³	4

Labour:

Workers/shift . . . . 2 up to 3,000 tons; 3 up to 20,000 tons; 4 for more than 20,000 tons/year

Supervisory staff . . . . ½ up to 10,000 tons; 1 up to 30,000 tons

Maintenance: 2·5 per cent

Depreciation: 6 per cent

Overhead: 60 per cent

INVESTMENT

Capacity in thousands of tons/year	Thousands of dollars
1·73	190
4·88	320
19·2	710
28·8	910

A-17. ACETYLENE

Process: From natural gas, partial oxidation with oxygen

Output:		
Acetylene	Tons	1
Recovered gases	1,000 kcal	17,000
Input:		
Natural gas (5,960 m³)	1,000 kcal	52,500
Ammonia[a]	Tons	0·035
Kerosene, losses[a]	Tons	0·140
Caustic soda[a]	Tons	0·035
Miscellaneous and royalties	Dollars	22
Electric power	kWh	3,800
Treated water	m³	10
Untreated water, for refilling	m³	45

Labour			
Capacity (thousands of tons year)	13·6	27·3	45
Workers shift	7	8	11
Supervisory staff shift	2	2	3

Maintenance: 3·5 per cent
Depreciation: 10 per cent
Overhead: 80 per cent

INVESTMENT

Capacity in thousands of tons year	*Thousands of dollars*
13·6	5,850
27·3	9,400
45·0	13,300

[a] Included in "Miscellaneous".

A-18. ACETYLENE

Process: From naphtha, partial oxidation with oxygen

Output:		
Acetylene (99·88 per cent.)	Tons	1
Crude aromatics	Tons	0·16
Input:		
Naphtha (light)	Tons	3·08
Oxygen: 4·6 tons[c]		
Methanol	Tons	0·020[b]
Kerosene	Tons	0·090[b]
Scrubber oil	Tons	0·100[b]
Ammonia	Tons	0·035[b]
Caustic soda	Tons	0·020[b]
Miscellaneous, royalties, etc.	Dollars ton	18·00
Fuel	1,000 kcal	12,500
Electric power	kWh	3,660
Treated water	m³	14
Untreated water for refilling	m³	55

Labour:			
Capacity (thousands of tons year)	13	27·3	45
Workers shift	7	8	11
Supervisory staff shift	2	2	3

Maintenance: 3 per cent
Depreciation: 10 per cent
Overhead: 80 per cent

INVESTMENT[a]

Capacity in thousands of tons year	*Thousands of dollars*
13	6,200
27·3	10,000
45	14,200

[a] Production included.
[b] Included in "Miscelleneous, royalties, etc."
[c] Includes oxygen unit.

A-19. ETHYLENE AND ACETYLENE

Process: From naphtha, oxidation with oxygen

Output:		
Ethylene, 99 per cent	Tons	1
Acetylene, 99·0 per cent	Tons	0·8
By-products[a]	Tons	0·3
Input:		
Light naphtha	Tons	3·08
Miscellaneous,[b] royalties, etc.	Dollars ton	20
Fuel	1,000 kcal	9,300
Electric power	kWh	3,000
Pure water	m³	10
Water for cooling	m³	1,200

Labour:			
Capacity (thousands of tons year)	27	54	90
Workers shift	8	12	14
Supervisory staff shift	2	3	3

Maintenance: 3 per cent
Depreciation: 10 per cent
Overhead: 100 to 80 per cent

INVESTMENT

Capacity in thousands of tons year	*Thousands of dollars*
27·3	10,200
54·6	16,000
90	24,500

[a] Residual aromatic oils.
[b] Includes *inter alia* kerosene and flushing oils (100 and 120 kg respectively), methanol (20 kg), caustic soda (12 kg) and ammonia (17 kg).

A-20. ACETYLENE : ETHYLENE (30:70) *Process: HTP (Hoechst process)*

Output:		
Ethylene	Tons	1
Acetylene	Tons	0·43
Residual gas	1,000 kcal	9,800
Residual oil	Tons	0·33
Input:		
Naphtha[a]	Tons	2·68
Oxygen[b]	m³	(1,740)
Chemicals, solvents and licences	Dollars ton	15·00
Fuel	1,000 kcal	18,800
Steam	Tons	2
Electric power	kWh	770
Treated water	m³	12
Water for cooling	m³	1,200

Labour:	
Capacity (thousands of tons year)	63
Workers shift	14
Supervisory staff shift	3

Maintenance: 3 per cent
Depreciation: 10 per cent
Overhead: 100 per cent

INVESTMENT[c]

Capacity in thousands of tons year	*Thousands of dollars*
63·8	20,000

[a] Light virgin naphtha.
[b] Production included.
[c] Includes oxygen unit.

A-21. ETHYLENE-PROPYLENE

Process: Naphtha cracking

Output:		
Ethylene	Tons	1
Propylene	Tons	0·606
H_2 gas[a] and methane[b]	Tons	0·60
LPG	Tons	0·125
[illegible] fraction	Tons	0·420
Gasoline	Tons	1·34
Fuel oil	Tons	0·45
Steam	Tons	1·09
Input:		
Naphtha	Tons	4·5[illegible]
Chemicals, catalysts and royalties	Dollars ton	6·00
Fuel	1,000 kcal	7,350
Electric power	kWh	1,300
Untreated water	m³	200

Labour:

Capacity (thousands of tons/year)	30 to 80
Workers/shift	6
Supervisory staff/shift	2

Maintenance: 3·5 per cent
Depreciation: 9 per cent
Overhead: 80 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
31·8	6,600
77·3	11,000
122·7	15,000

[a] Gas, 70 per cent H_2: 185 kg.
[b] Gas, 95 per cent CH_4: 417 kg.
[c] Low gravity.

A-22. ETHANE

Process: Separation of natural gas[a]

Output:			
Ethane	Tons		1
Higher fractions (C_3-C_5)	(according to composition of gas)		...
Input:			
Chemical (glycols, oils, etc.)	Dollars/ton		1·20
Volume of the ethane extracted from natural gas	m³		800
Fuel	1,000 kcal		3,000
Electric power	kWh		25
Untreated water	m³		1
Labour:			
Capacity (thousands of tons/year)		50 to 60	61 to 180
Workers/shift		4	6
Supervisory staff/shift		2	2

Maintenance: 2·5 per cent
Depreciation: 7 per cent
Overhead: 60 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*[b]
5	600
10	900
25	1,630
60	2,850
150	5,000

[a] Conditions: Natural gas with 6 to 14 per cent ethane. Recovery: 10 to 20 per cent. Maximum investment: Corresponds to plant installed for ethane separation. The separation of C_3-C_4 and gasoline does not require additional investment. The input corresponds to the minimum attributable to ethane.

[b] Varies according to the original concentration of ethane.

A-23. ETHANE

Process: Separation of natural gas[a]

Output:			
Ethane	Tons		1
Input:			
Minor chemicals	Dollars/ton		1·20
Gas "shrinkage"[b]	m³	1,500	
Fuel	1,000 kcal	5,000	
Electric power	kWh	50	
Water	m³	4	
Labour:			
Capacity (thousands of tons/year)		5 to 60	60 to 70
Workers/shift		4	6
Supervisory staff/shift		2	2

Maintenance: 3 per cent
Depreciations: 10 per cent
Overhead: 100 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
5	200
10	225
25	300
60	500
150	900

[a] Conditions: Gas containing 10 to 20 per cent ethane. Recovery: 15 to 20 per cent. Minimum investment, equivalent to proportion attributable to ethane. Remainder for separation of C_3, C_4 and gasoline, in case of gas plant already in existence and additions for ethane recovery.

[b] Reduction in volume of treated gas through extraction of ethane and other minor constituents.

A-24. ETHYLENE

Process: Ethane cracking

Output:						
Ethylene[a]	Tons		1			
Input:						
Ethane	Tons		1·40			
Various chemicals and other	Dollars/ton		4·00			
Fuel, net	1,000 kcal		1,000[b]			
Steam	Tons		5			
Electric power	kWh		90			
Water	m³		20			
Labour:						
Capacity (thousands of tons/year)	5	10	20	60	100	
Workers/shift	4	5	5	7	8	
Supervision	1	1	1	2	3	

Maintenance: 3 per cent
Depreciation: 9 per cent
Overhead: 100 per cent up to 20,000 tons/year
80 per cent up to 100,000 tons/year
60 per cent over 100,000 tons/year

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
5	1,800
10	2,700
20	4,000
60	7,700
100	10,500

[a] The gas recovery compensates for the fuel consumption.
[b] Figure varies.

A-25. ETHYLENE

Process: Separation and cracking of ethane in refinery gas

Output:		
Ethylene (99·9 per cent)	Tons	1
Propylene-propane	Tons	0·45[a]
Butanes and higher fractions	Tons	0·22[a]
Natural gas, $C_1 + C_2$ hydrocarbons	m³	2,900[b]
Input:		
Refinery gas	m³	3,500[c]
Fuel gas	1,000 kcal	3,400
Minor chemicals and other	Dollars/ton	5·00
Steam	Ton	9·2
Electric power	kWh	200
Water for cooling	m³	16

Labour:

Capacity (thousands of tons)	5	10	20	60	100
Workers/shift	4	5	5	7	8
Supervisory staff/shift	1	1	1	2	3

Maintenance: 3 per cent
Depreciation: 9 per cent
Overhead: 100 per cent up to 20,000 tons
80 per cent up to 100,000 tons
60 per cent over 100,000 tons

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
5	1,680
10	2,500
35	5,100
60	7,000
100	9,500

[a] The recovery of propane-propylene, which is present in the initial gases, depends on the type of gas; *see* note [c] of this table for butanes.

[b] The residual gas (tail gas) contains inert gases (N, CO), hydrogen, methane, ethane. Its calorific value can be estimated at a maximum of 6,000 cal/m³.

[c] The treated gas is assumed to have a composition considered representative in refineries as follows:

	per cent		*per cent*
Methane	25	Propylene	6
Hydrogen	19	Nitrogen	16
Ethane	15	CO, CO_2	
Ethylene	–	Hydrocarbons	
Propane	12	C_4	

A-26. ETHYLENE

Process: In refinery[a]

Output:		
Ethylene	Tons	1
Fuel oil, distillation	Barrels	1·47
n-Butane	Barrels	2·03
TEL, liquid	Litres	6·20
Input:		
Chemicals and catalysts	Dollars/ton	0·80
Licences and other	Dollars/ton	3
Gasoline	Barrels	8·76
LPG	Barrels	5·58
Residual fuel oil	Barrels	4·70
Electric power	kWh	240
Water for cooling	m³	600

Labour:

Capacity (thousands of tons/year)	60
Workers/shift	[illegible]
Supervision	1

Maintenance: 4 per cent
Depreciation: 10 per cent
Overhead: 80 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
60	8,000

[a] Example worked out on the basis of 60,000 tons per year in a 50,000 BSD refinery (*Oil and Gas Journal*, 24 July 1961).

A-27. PROPYLENE

Process: Separation by distillation

Output:		
Propylene 99 per cent	Tons	1
Propane (LPG)	Tons	1·2
Input:		
"Propane-propylene" 50 per cent	Tons	2·2
Auxiliary products	Dollars/ton	2
Steam	Tons	2·1
Electric power	kWh	12

Labour:

Capacity (thousands of tons/year)	10	30
Workers/shift	2	4
Supervisory staff/shift	1	2

Maintenance: 3 per cent
Depreciation: 7 per cent
Overhead: 60 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
10	360
22·5	610
40	900

A-28. PETROCHEMICAL BENZENE

Processes: Udex and hydroalkylation

Output:		
Benzene (99 per cent)	Tons	1
Paraffin spirit[a]	Barrels	21·3
Residual fuel oil	Barrels	4·0
Fuel gas	1,000 kcal	1,500[b]
Input:		
Charge	Barrels	32·8[c]
Gas with hydrogen	Tons	0·040[d]
Catalysing chemicals and royalties	Dollars/ton	7·50
Fuel	1,000 kcal	9,300
Steam	Tons	3·2
Electric power	kWh	240
Water for cooling	m³	100

Labour:

Capacity (thousands of tons/year)	20 to 100
Workers/shift	4
Supervisory staff/shift	2

Maintenance: 4 per cent
Depreciation: 8 per cent
Overhead: 100 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
43	3,500

[a] Typical characteristics of "refined spirit": density, 110 kg/barrel; octane rating with cm³ TEL: 85.

[b] Residual gas: 220 m³ at 6,800 kcal/m³; 83 per cent methane: 0·546 kg/m³.

[c] Typical composition of charge: benzene 17.3 per cent of liquid volume and toluene 9·4 per cent of liquid volume. Hydrocarbon for heating 64·6 per cent (C_6-C_7) of liquid (Depentamized reformate, platformer).

[d] Gas with hydrogen: hydrogen 54 per cent by weight; C_1-C_2 28 per cent by weight; 0·040 tons equals approximately 270 m³ and 820,000 kcal (d = 0·15 kg/m³).

A-29. CYCLOHEXANE

Process: From benzene

Output:		
Cyclohexane (98/99 per cent)	Tons	1
Steam	Tons	0·5

Input:

Benzene	Tons	0·97
Hydrogen or hydrogen-rich gas		0·075
Catalysts and royalties	Dollars/ton	10
Electric power	kWh	35
Water	m³	25

Labour:

Capacity (thousands of tons/year)	10	50	Over 50
Workers/shift	1	2	3
Supervisory staff/shift	1	1	2

Maintenance: 3 per cent
Depreciation: 8 per cent
Overhead: 60 to 140 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
4·5	250
10	360
18	480
70	1,000

A-30. PARAXYLENE

Process: Separation by crystallization[a]

Output:

Paraxylene (98 per cent)	Tons	1
Mixed paraxylene[b]	Tons	0·5

Input:

Udex extract equivalent to 1·5 tons for mixed xylenes		
Inert gas and other minor constituents[c]	Dollars/ton	0·50
Steam	Tons	0·8
Electric power	kWh	700
Water for cooling	m³	90

Labour:

Capacity (thousands of tons)	4·5	22·7
Workers/shift	1	2
Supervisory staff/shift	1	1

Maintenance: 3 per cent
Depreciation: 8 per cent
Overhead: 100 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
4·5	900
10	1,600
23	3,000

[a] Example used as basis: 7·7 tons of xylene mixture. Recovery is 60 to 70 per cent of the paraxylene contained in the extract (C_8).

[b] Unseparated paraxylene present in the mixed xylenes.

[c] Includes losses of refrigerants and 2·5 kg of nitrogen.

A-31. ORTHOXYLENE

Process: Separation by distillation

Output:

Orthoxylene (95 per cent)	Tons	1
Recovered in mixtures (mixed xylenes)	Tons	0·3

Input:

Orthoxylene in xylene mixture[a]	Tons	1·3
Fuel	1,000 kcal	5,000
Electric power	kWh	110
Water for cooling	m³	20

Labour:

Capacity (thousands of tons/year)	From 5 to 30
Workers/shift	1
Supervisory staff/shift	1

Maintenance: 2·5 per cent
Depreciation: 8 per cent
Overhead: 100 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
4·5	450
10	680
27	1,100

[a] 5·3 tons of xylenes and ethylbenzene derived from a separation (Udex) with approximately 20 to 25 per cent orthoxylene content.

A-32. PETROLEUM NAPHTHALENE

Process: Hydroalkylation

Output:

Naphthalene	Tons	1
Aromatic naphtha	Tons	0·17[a]
Heavy residue	Tons	0·47

Input:

Heavy reformate[b]	Tons	1·96
Hydrogen	(Recovered)	
Fuel	1,000 kcal	2,700
Steam	Tons	0·06
Electric power	kWh	300
Water for cooling	m³	200
Chemicals catalysts and royalties	Dollars/ton	0·60

Labour:

Workers/shift	3
Supervisory staff/shift	1

Maintenance: 4 per cent
Depreciation: 6 per cent
Overhead: 100 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
22·5	2,000

[a] 60 per cent benzene, 9 per cent toluene, 27 per cent xylenes and higher fractions.

[b] Higher aromatics, mono- and dimethylnaphthalenes.

A-33. DICHLORETHANE

Output:

Dichlorethane	Tons	1

Input:

Ethylene	Tons	0·315
Chlorine	Tons	0·80
Steam	Tons	1
Electric power	kWh	5
Water	m³	40

Labour:

Workers/shift	5 up to 18,000 tons; 7 up to 72,000 tons; 9 up to 108,000 tons
Supervisory staff/shift	1 up to 36,000; 2 up to 108,000

Maintenance: 4 per cent
Depreciation: 8 per cent
Overhead: 88 per cent

INVESTMENT

Capacity in thousands of tons/year	Thousands of dollars
4·5	700
18	1,800
72	5,200

A-34 ETHYLENE GLYCOL

Output		
Ethylene glycol	Tons	1
Input:		
Ethylene	Tons	0·80
Chlorine	Tons	1·50
Lime (calcium oxide)	Tons	1·40
Caustic soda	Tons	0·02
Steam	Tons	12·00
Electric power	kWh	220
Water	m³	340
Miscellaneous chemicals, catalysts and royalties	Dollars/ton	6·00
Labour:		

Capacity (thousands of tons/year)	2	5	20
Workers/shift	5	6	10
Supervisory staff/shift	1	1	2

Maintenance: 3 per cent
Depreciation: 8 per cent
Overhead: 60 per cent

INVESTMENT

Capacity in thousands of tons/year	Thousands of dollars
2	827·5
5	1,440
20	2,900

A-35. PHENOL

Process: Isopropylbenzene

Output:		
Phenol	Tons	1
Acetone	Tons	0·6
Gasoline (premium)	Gallons	25
Input:		
Benzene	Tons	1·09
Propylene	Tons	0·52
Auxiliary products and royalties	Dollars/tons	15·0
Steam	Tons	3
Electric power	kWh	80
Water	m³	100
Labour::		

Capacity (thousands of tons/year)	5	10	15
Workers/shift	8	13	15
Supervisory staff/shift	1	2	2

Maintenance: 3 per cent
Depreciation: 7 per cent
Overhead: 40 to 60 per cent

INVESTMENT

Capacity in thousands of tons/year	Thousands of dollars
5	3,500
10	5,700
15	7,600

A-36. PHENOL

Process: Chlorination

Output:		
Phenol	Tons	1
Various by-products[a]	Tons	0·15
Sodium chloride	Tons	1·4
Input:		
Benzene	Tons	1·01
Caustic soda	Tons	1·10
Chlorine	Tons	1·01
Other chemicals and royalties	Dollars/ton	12·00
Fuel	1,000 kcal	7,500
Electric power	kWh	500
Untreated water	m³	220
Labour:		

Capacity (thousands of tons/year)	2	5	10 to 15
Workers/shift	6	7	10
Supervisory staff/shift	1	1	2

Maintenance: 3 per cent
Depreciation: 7 per cent
Overhead: 40 to 50 per cent

INVESTMENT

Capacity in thousands of tons/year	Thousands of dollars
5	3,600
10	6,000
15	8,000

[a] Dichlorobenzene 60 kg, oxydiphenyl 60 kg and diphenyl ether 30 kg.

A-37. PHENOL

Process: Sulphonation of benzene[a]

Output:		
Phenol	Tons	1
Sodium sulphite	Tons	1·2
calcium sulphate	Tons	1·6
Input:		
Benzene	Tons	0·92
Sulphuric acid	Tons	2·20
Caustic soda	Tons	1·10
Calcium carbonate	Tons	1·60
Fuel petroleum	Tons	0·400
Steam	Tons	12
Electric power	kWh	500
Untreated water	m³	600
Miscellaneous chemicals	Dollars/ton	3·00
Labour:		

Capacity (thousands of tons/year)	3 to 5	5 to 15	20 or more
Workers/shift	4	14	18
Supervisory staff/shift	1	1	1

Maintenance: 4 per cent
Depreciation: 8 per cent
Overhead: 50 to 80 per cent

INVESTMENT

Capacity in thousands of tons/year	Thousands of dollars
3·6	2,100
5	2,400
10	3,100
15	3,800

[a] Minimum capacity 3,600 tons per year.

A-38. FORMALDEHYDE 37 per cent

Process: Oxidation of methanol

Output:		
Formol (37 per cent)	Tons	1
Steam	Tons	0·32
Input:		
Methanol	Tons	0·435
Catalyst, miscellaneous and licences	Dollars/ton	5·00
Electric power	kWh	77
Untreated water	m^3	24
Pure water	m^3	1
Labour:		
Workers/shift	3 (1,000 to 20,000 tons/year)	
Supervisory staff/shift	1	

Maintenance: 5 per cent
Depreciation: 6 per cent
Overhead: 80 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
3·6	150
5	180
10	300
20	400

A-39. ACETALDEHYDE

Process: From ethylene, oxidation by air

Output:		
Acetaldehyde	Tons	1
Input:		
Ethylene (99·7 per cent)	Tons	0·67
Minor chemicals, catalysts, and licences	Dollars/ton	6
Steam	Tons	1·3
Electric power	kWh	375
Cold water	m^3	15
Water for cooling	m^3	20

Labour:

Capacity (thousands of tons/year)	Up to 15	15 to 60	60 and over
Workers/shift	3	4	5 to 8
Supervisory staff/shift	1	1 to 2	2

Maintenance: 6 per cent
Depreciation: 8 per cent
Overhead: 80 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
15	1,675
30	2,400
60	3,700

A-40. ACETALDEHYDE

Process: From acetylene

Output:		
Acetaldehyde	Tons	1
Input:		
Acetylene	Tons	0·620
Caustic soda	Tons	0·005
Nitric acid (50 per cent)	Tons	0·007
Sulphuric acid	Tons	0·001
Other chemicals and licences	Dollars/ton	1·00
Steam	Tons	2
Electric power	kWh	115
Water	m^3	130

Labour:

Capacity (thousands of tons/year)	Up to 10	Up to 50
Workers/shift	4	6
Supervisory staff/shift	1	2

Maintenance: 4 per cent
Depreciation: 8 per cent
Overhead: 60 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
10	1,120
20	1,600

A-41. ACETIC ACID

Process: from acetaldehyde

Output:		
Acetic acid 99 per cent	Tons	1
Input:		
Acetaldehyde	Tons	0·9
Catalysts and minor chemicals	Dollars/ton	20
Steam	Tons	3
Electric power	kWh	140
Water for cooling	m^3	130

Labour:

Capacity (thousands of tons/year)	Up to 10	Up to 50
Workers/shift	3	4
Supervisory staff/shift	1	2

Maintenance: 4 per cent
Depreciation: 10 per cent
Overhead: 100 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
4·5	380
9	600
18	1,000
68	2,500

A-42. ACETIC ANHYDRIDE

Process: From acetaldehyde

Output:		
Acetic anhydride	Tons	1
Input:		
Acetaldehyde	Tons	1·2
Catalysts[a] and chemicals	Dollars/ton	5·0
Fuel	1,000 kcal	1,200
Steam	Tons	6
Electric power	kWh	280
Water for cooling	m^3	700

Labour:

Capacity (thousands of tons/year)	Up to 7	Up to 15	Over 15
Workers/shift	4	6	8
Supervisory staff/shift	1	1	2

Maintenance: 4 per cent
Depreciation: 10 per cent
Overhead: 80 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
4·5	800
9	1,300
18	2,100

[a] Manganese or cobalt and copper acetates.

A-43. PHTHALIC ANHYDRIDE

Process: From naphthalene[a]

Output:		
Phthalic anhydride	Tons	1
Steam	Tons	1
Input:		
Naphthalene	Tons	1·14
Other, royalties and catalysts	Dollars/ton	15
Fuel	1,000 kcal	800
Electric power	kWh	800
Water for cooling	m³	3
Treated water	m³	1

Labour:			
Capacity (thousands of tons/year)	1·5 to 3	3 to 10	More than 10
Workers/shift	5	7	10
Supervisory staff/shift	1	2	2

Maintenance: 3 per cent
Depreciation: 9 per cent
Overhead: 100 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
0·6	270
1·5	425
5	1,000
7	1,300

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[a] Scale suitable from 1,500 tons per year upwards.

A-44. PHTHALIC ANHYDRIDE

Process: From orthoxylene

Output:		
Phthalic anhydride	Tons	1
Steam	Tons	4·00
Input:		
Orthoxylene	Tons	1·25
Catalyst	Dollars/ton	2·50
Chemicals and royalties	Dollars/ton	8·00
Fuel	1,000 kcal	3,200
Electric power	kWh	1,370
Treated water	m³	10
Water for cooling	m³	14

Labour:			
Capacity (thousands of tons/year)	5	10	30
Workers/shift	3	4	5
Supervisory staff/shift	1	1	2

Maintenance: 3·5 per cent
Depreciation: 8 per cent
Overhead: 100 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
5	2,100
10	3,200
20	4,800
30	6,000

A-45. MALEIC ANHYDRIDE

Process: Catalytic oxidation of benzene

Output:		
Maleic anhydride	Tons	1
Input:		
Benzene	Tons	1·28
Various chemicals and catalysts	Dollars/ton	12
Steam	Tons	1
Electric power	kWh	2,400
Water for cooling	m³	100

Labour:			
Capacity (thousands of tons/year)	1·5	4	5·5
Workers/shift	5	8	8
Supervisory staff/shift	1	2	2

Maintenance: 4 per cent
Depreciation: 8 per cent
Overhead: 100 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
1·5	960
4	2,100
5·5	2,700

A-46. BISPHENOL

Output:		
Bisphenol	Tons	1
Input:		
Phenol	Tons	0·93
Acetone	Tons	0·33
Sulphuric acid	Tons	0·004
Toluene	Tons	0·038
Electric power	kWh	100
Water	m³	10

Labour:	
Capacity (tons/year)	3,000
Workers/shift	2
Staff/shift	1

Maintenance: 3 per cent
Depreciation: 8 per cent
Overhead: 150 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
3	1,100

A-47. AMMONIUM NITRATE

Output:		
Ammonium nitrate	Tons	1
Input:		
Ammonia	Tons	0·215
100 per cent nitric acid	Tons	0·80
Fuel	1,000 kcal	100
Electric power	kWh	30
Water	m³	8

Labour:		
Capacity (thousands of tons/year)	Up to 36	36 to 160
Workers/shift	2	4
Supervisory staff/shift	1	2

Maintenance: 3·5 per cent
Depreciation: 8 per cent
Overhead: 50 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
36	850
50	1,000
120	1,550
160	2,000

A-48. AMMONIUM SULPHATE

Output:		
Ammonium sulphate	Tons	1
Input:		
Ammonia	Tons	0·260
Sulphuric acid	Tons	0·760
Steam	Tons	0·2
Electric power	kWh	25
Treated water	m³	20

Labour:			
Capacity (thousands of tons/year)	30	30 to 100	Over 100
Workers/shift	2	3	4
Supervisory staff/shift	1/2	1	1

Maintenance: 3 per cent
Depreciation: 8 per cent
Overhead: 50 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
24	230
50	360
100	550
180	800

A-49. UREA

Process: Without 6:1 recycle

Output:		
Urea	Tons	1
Input:		
Ammonia	Ton	0·58
Carbon dioxide	Tons	1 (maximum)
Fuel	1,000 kcal	1,260
Electric power	kWh	185
Water	m³	85

Labour:		
Capacity (thousands of tons/year)	Up to 36	Up to 130
Workers/shift	8	12
Supervisory staff/shift	2	3

Maintenance: 3 per cent
Depreciation: 8 per cent
Overhead: 50 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
27	2,200
35	2,700
85	4,800
170	7,700
330	13,500

A-50. PHOSPHORIC ACID

Process: Via sulphuric acid

Output:		
100 per cent phosphoric acid	Tons	1[a]
Residual calcium sulphate		
Input:		
Phosphorite (31·5 per cent)	Tons	2·46
Sulphuric acid	Tons	1·90
Auxiliary chemicals and miscellaneous	Dollars/ton	3·00
Fuel	1,000 kcal	1,300
Steam	Tons	0·1
Electric power	kWh	65
Untreated water	m³	15

Labour:			
Capacity (thousands of tons/year)	10 to 30	30 to 60	60 to 90
Workers/shift	4	5	6
Supervisory staff/shift	1	1·5	2

Maintenance: 4 per cent
Depreciation: 8 per cent
Overhead: 60 to 100 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
15	600
28	950
46	1,450
90	2,500
150	4,000

[a] Contains 100 per cent H_3PO_4 or 72·4 per cent P_2O_5. The true concentration as obtained in the process is only 70 per cent H_3PO_4 (approximately 50 per cent P_2O_5).

A-51. TRIPLE SUPERPHOSPHATE

Output:		
Triple superphosphate[a]	Tons	1
Input:		
Phosphorite (31/32 per cent)	Tons	0·42
Phosphoric acid (100 per cent)[b]	Tons	0·47
Minor chemicals	Dollars/ton	1
Electric power	kWh	9

Labour:			
Capacity (thousands of tons/year)	10 to 70	80 to 200	Up to 400
Workers/shift	3	5	6
Supervisory staff/shift	1	2	2

Maintenance: 3 per cent
Depreciation: 6 per cent
Overhead: 100 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
60	550
120	800
200	1,100

[a] With a P_2O_5 content varying between 46 and 48 per cent.
[b] Generally used in the form of 70 to 75 per cent acid (0·6 to 0·65 tons).

A-52. SIMPLE SUPERPHOSPHATE (18 to 20 per cent P_2O_5)

Ouput:		
Simple superphosphate	Tons	1

Input:				
Phosphorite (31/32 per cent)	Tons		0·62	
Sulphuric acid	Tons		0·38	
Electric power	kWh		18	
Labour:				
Capacity (thousands of tons/year)		72 to 108	150 to 250	Up to 360
Workers/shift		5	7	8
Supervisory staff/shift		1	1	2

Maintenance: 4 per cent
Depreciation: 6 per cent
Overhead: 80 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
72	360
108	480
150	580
250	950
360	1,260

A-53. DICALCIUM PHOSPHATE

Output:		
Dicalcium phosphate (39/40 per cent)	Tons	1
Input:		
Phosphate rock (32/33 per cent)	Tons	1·30
Hydrochloric acid 100 per cent	Tons	0·65[a]
Calcium oxide	Tons	0·26
Fuel	1,000 kcal	680
Electric power	kWh	120
Water	m^3	35
Auxiliary chemicals and licences	Dollars/ton	2·50
Labour:		
Workers/shift	6 up to 70 tons/day; 8 up to 150 tons; 12 to 230 tons/day	
Supervisory staff/shift	2 up to 70 tons/day; 3 up to 150; 4 up to 230 tons/day	

Maintenance: 3·5 per cent
Depreciation: 7 per cent
Overhead: 60 per cent

INVESTMENT

Capacity in thousands of tons/day	*Thousands of dollars*
13	700
23	1,000
50	1,700
75	2,400

[a] Varies from 0·6 to 0·9 tons according to the type of phosphate rock and the efficiency of the extracting process.

A-54. POTASSIUM SULPHATE

Output:			
Potassium sulphate	Tons	1	
Hydrochloric acid, 100 per cent	Tons	0·41	
Input:			
Sulphuric acid, 100 per cent	Tons	0·62	
Potassium chloride (60 per cent)	Tons	0·85[a]	
Fuel	1,000 kcal	1,000	
Electric power	kWh	100	
Labour:			
Capacity (thousands of tons/year)		20	80
Workers/shift		9	30
Supervisory staff/shift		1	2

Maintenance: 4 per cent
Depreciation: 7 per cent
Overhead: 80 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
20	2,500
80	5,800

[a] Type with 60 to 62 per cent K_2O.

A-55. PVC, POLYMER

Process: Polymerization

Output:		
Polyvinyl chloride (PVC)	Tons	1
Input:		
Vinyl chloride, monomer	Tons	1·06
Other products and reagents	Dollars/ton	22
Fuel petroleum	Tons	0·4
Steam	Tons	0·6
Electric power	kWh	550
Water	m^3	75
Labour:		
Workers/shift	5 up to 3,600 tons; 8 up to 20,000 tons; 10 up to 60,000 tons	
Supervisory staff/shift	1 up to 3,600 tons; 2 up to 20,000 tons; 3 over 20,000 tons	

Maintenance: 4 per cent
Depreciation: 7·5 per cent
Overhead: 100 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
1·2	550
2·5	800
10	1,400
40	3,200
60	4,500

A-56. POLYVYNIL CHLORIDE

Process: From calcium carbide

Output:		
PVC (polymer)	Tons	1
Input:		
Calcium carbide	Tons	1·50
Chlorine	Tons	0·72
Hydrogen	Tons	0·02
Auxiliary products	Dollars/ton	26
Fuel petroleum	Tons	0·4
Steam	Tons	1·5
Electric power	kWh	1,040
Water	m^3	120
Labour:		
Workers/shift	12 up to 3,600 tons; 18 up to 20,000 tons; 22 up to 60,000 tons	
Supervisory staff/shift	4 up to 20,000 tons; 6 up to 40,000 tons; 7 up to 60,000 tons	

Maintenance: 4 per cent
Depreciation: 8 per cent
Overhead: 80 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
2·5	1,330
6	1,870
10	2,500
40	5,900
60	8,000

A-57. POLYVINYL CHLORIDE *Process: From acetylene*

Output:		
PVC	Tons	1
Input:		
Acetylene	Tons	0·48
Chlorine	Tons	0·72
Hydrogen	Tons	0·02
Miscellaneous and chemicals	Dollars/ton	26
Fuel petroleum	Tons	0·4
Electric power	kWh	1,000
Water	m³	120

Labour:

Workers/shift .... 9 up to 3,600 tons/year; 13 up to 20,000 tons; 15 up to 60,000 tons

Supervisory staff/shift ..... 4 up to 20,000 tons/year; 6 up to 60,000 tons

Maintenance: 4 per cent
Depreciation: 8 per cent
Overhead: 80 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
2·5	1,200
6	1,650
10	2,200
40	5,150
60	7,100

A-58. POLYVINYL CHLORIDE *Process: From dichloroethane*

Output:		
Polyvinyl chloride (PVC)	Tons	1
Hydrochloric acid (100 per cent)	Tons	0·67
Input:		
Dichloroethane	Tons	1·80
Fuel petroleum	Tons	0·2
Steam	Tons	7
Electric power	kWh	1,000
Water	m³	360

Labour:

Workers/shift .... 15 up to 10,000 tons; 20 up to 60,000 tons

Supervisory staff/shift .... 4 up to 20,000 tons; 6 up to 60,000 tons

Maintenance: 4 per cent
Depreciation: 8 per cent
Overhead: 80 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
2·5	950
10	1,600
40	3,500
60	4,900

A-59. VINYL CHLORIDE, MONOMER *Process: From calcium carbide*

Output:		
Vinyl chloride	Tons	1
Input:		
Calcium carbide	Tons	1·42
Chlorine	Tons	0·68
Other chemicals	Dollars/ton	8
Steam	Tons	0·7
Electric power	kWh	450
Water	m³	45

Labour:

Workers/shift .... 7 up to 3,800 tons, 10 up to 21,200 tons; 12 up to 63,600 tons

Supervisory staff/shift .. 2 up to 21,000 tons; 4 up to 42,400 tons, 5 up to 63,600 tons

Maintenance: 4 per cent
Depreciation: 8 per cent
Overhead: 75 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
2·65	530
6·36	770
10·6	1,100
42·4	2,700
63·6	3,500

A-60. VINYL CHLORIDE, MONOMER *Process: From acetylene*

Output:		
Vinyl chloride	Tons	1
Input:		
Acetylene	Tons	0·46
Chlorine	Tons	0·68
Other chemicals and reagents	Dollars/ton	8·00
Steam	Tons	0·7
Electric power	kWh	400
Water	m³	45

Labour:

Workers/shift .... 5 up to 3,800 tons; 7 up to 21,200 tons; 10 up to 63,600 tons

Supervisory staff/shift .. 2 up to 21,200 tons; 3 up to 42,400 tons; 4 up to 60,000 tons

Maintenance: 4 per cent
Depreciation: 8 per cent
Overhead: 70 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
2·65	400
6·36	550
10·6	800
42·4	2,000
63·6	2,600

A-61. POLYVINYL ACETATE

Process: Polymerization

Output:		
Polyvinyl acetate	Tons	1
Input:		
Monomer, vinyl acetate	Tons	1·02
Steam	Tons	0·7
Electric power	kWh	66
Water	m^3	17

Labour:			
Capacity (thousands of tons year)	2 to 5	5 to 10	Over 10
Workers shift	4	5	7
Supervisory staff shift	1	1	2

Maintenance: 3 per cent
Depreciation: 8 pet cent
Overhead: 80 per cent

INVESTMENT

Capacity in thousands of tons year	*Thousands of dollars*
3	800
5	1,100
10	1,700
15	2,200

A-62. VINYL ACETATE (MONOMER)

Output:		
Vinyl acetate	Tons	1
Input:		
Acetylene	Tons	0·335
Acetic acid[a]	Tons	0·775
Chemicals and catalysts	Dollars ton	5·00
Steam	Tons	3
Electric power	kWh	500
Water	m^3	600

Labour:			
Capacity (thousands of tons year)	2 to 5	5 to 15	Over 15
Workers shift	3	5	8
Supervisory staff/shift	2	2	3

Maintenance: 3 per cent
Depreciation: 8 per cent
Overhead: 80 per cent up to 10,000 tons
60 per cent above 10,000 tons

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
3	1,400
10	2,700
20	4,500

[a] Pure or "glacial".

A-63. STYRENE

Process: From benzene and ethylene

Output:		
Styrene	Tons	1
Input:		
Benzene	Tons	0·92
Ethylene[a]	Tons	0·34
Minor chemicals, catalysts and royalties	Dollars ton	28·00
Fuel	1,000 kcal	6,200
Steam	Tons	20
Electric power	kWh	305
Water	m^3	400

Labour:				
Capacity (thousands of tons year)	10	20	40	60
Workers shift	6	11	15	20
Supervisory staff shift	1	1	2	2

Maintenance: 3 per cent
Depreciation: 8 per cent
Overhead: 40, 60 per cent

INVESTMENT

Capacity in thousands of tons year	*Thousands of dollars*
5	2,500
10	3,600
20	5,200
40	7,500
60	8,800

[a] Gases with 40 to 60 per cent ethylene can be used.

A-64. POLYSTYRENE

Process: From styrene

Output:		
Polystyrene	Tons	1
Input:		
Styrene	Tons	1·1
Miscellaneous chemicals[a] and royalties	Dollars ton	20
Steam	Tons	1
Electric power	kWh	450
Water	m^3	20

Labour:		
Capacity (thousands of tons year)	3 to 10	10 to 20
Workers shift	20	40
Supervisory staff shift	4	5

Maintenance: 3 per cent
Depreciation: 7 per cent
Overhead: 40 per cent

INVESTMENT

Capacity in thousands of tons year	*Thousands of dollars*
10	3,000

[a] These include acetic acid, benzoyl peroxide, nitrogen gas and others.

A-65. POLYETHYLENE

Process: High pressure (low density)

Output:		
Polyethylene	Tons	1
Input:		
Ethylene (minimum 99·7 per cent)	Tons	1·1
Minor chemicals[a] and royalties	Dollars ton	38·00
Steam	Tons	1·5
Electric power	kWh	200
Water	m^3	135

Labour:

Capacity (thousands of tons/year)	3 to 8	10 to 30	35 to 75
Workers/shift	10	16	20
Supervisory staff/shift	1	2	2

Maintenance: 3·5 per cent
Depreciation: 10 per cent
Overhead: 80 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
3	4,500
8	7,300
18	11,000
30	15,000
50	19,000
75	24,000

[a] These include methanol, NaOH (20 to 50 kg), benzoyl peroxide (20 kg), etc.

A-66. POLYETHYLENE

Process: Low pressure (Ziegler)

Output:			
Polyethylene	Tons	1	
Input:			
Ethylene (more than 99 per cent)	Tons	1·12	
Minor chemicals and royalties	Dollars/ton	34·00	
Steam, high pressure	Tons	11·7	
Electric power	kWh	1,350	
Water for cooling	m³	900	
Pure water	m³	20	
Labour:			
Capacity (thousands of tons/year)		10	30
Workers/shift		20	26
Supervisory staff/shift		3	3

Maintenance: 3·5 per cent
Depreciation: 10 per cent
Overhead: 80 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
5	5,300
8	7,600
10	9,000
15	11,700

A-67. POLYESTER RESINS (typical formulation)[a]

Output:			
Polyester resin	Tons	1	
Input:			
Phthalic anhydride	Tons	0·175	
Maleic anhydride	Tons	0·354	
Ethylene glycol	Tons	0·308	
Styrene	Tons	0·300	
Minor chemicals and royalties	Dollars/ton	35	
Fuel petroleum	Tons	0·1	
Electric power	kWh	400	
Water for cooling	m³	110	
Labour:			
Capacity (thousands of tons/year)		4	10
Workers/shift		4	7
Supervisory staff/shift		1	1

Maintenance: 4 per cent
Depreciation: 10 per cent
Overhead: 120 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
4	500
10	1,100

[a] There are many variations according to the use to which the resin is put.

A-68. CELLULOSE ACETATE (flake)

Output:				
Cellulose acetate	Tons			1·0
Recovered acetic acid	Tons			1·75
Input:				
Cellulose	Tons			0·7
Acetic anhydride	Tons			2·0
Sulphuric acid	Tons			0·1
Miscellaneous chemicals, losses, etc.	Dollars/ton			40
Labour:				
Capacity (thousands of tons/year)		2 to 5	6 to 20	Over 20
Workers/shift		10	15	25
Supervisory staff/shift		2	2	3

Maintenance: 3 per cent
Depreciation: 8 per cent
Overhead: 80 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
3·6	2,800
10	5,000
20	7,700

A-69. ADIPIC ACID

Process: From cyclohexane

Output:				
Adipic acid	Tons	1		
Input:				
Cyclohexane[a]	Tons	0·85		
100 per cent nitric acid	Tons	1·20		
Chemicals, catalysts and licences	Dollars/ton	42		
Fuel	1,000 kcal	1,100		
Steam	Tons	10		
Electric power	kWh	600		
Water	m³			
Labour:				
Capacity (thousands of tons/year)	1	5	10	
Workers/shift	8	10	12	
Supervisory staff/shift	1	2	2	

Maintenance: 4 per cent
Depreciation: 8 per cent
Overhead: 60 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
1	2,500
5	4,300
10	5,500

[a] 96 to 98 per cent. Two-step oxidation process with mean total yield of 70 per cent.

A-70 ADIPONITRYL

Process: From adipic acid

Output:		
Adiponitryl	Tons	1
Input:		
Adipic acid	Tons	1·82
Ammonia	Tons	0·34
Auxiliary products and licences	Dollars/ton	30
Fuel	1,000 kcal	1,200
Steam	Tons	2·5
Electric power	kWh	330
Water	m³	...

Labour:		
Capacity (thousands of tons/year)	1	5
Workers/shift	8	10
Supervisory staff/shift	1	1

Maintenance: 4 per cent
Depreciation: 9 per cent
Overhead: 80 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
1	2,120
1·6	2,550
5	4,320

A-71. HEXAMETHYLENEDIAMINE

Process: From adiponitryl

Output:		
Hexamethylenediamine	Tons	1
Input:		
Adiponitryl	Tons	1·03
Hydrogen	Tons	0·073
Catalysts, royalties, etc.	Dollars/ton	30
Steam	Tons	10
Electric power	kWh	250

Labour:		
Capacity (thousands of tons/year)	1	5
Workers/shift	6	8
Supervisory staff/shift	1	1

Maintenance: 3·5 per cent
Depreciation: 8 per cent
Overhead: 50 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
1	2,640
1·6	3,150
5	4,750

A-72. NYLON SALT (6–6)[a]

Output:		
Nylon salt	Tons	1
Input:		
Adipic acid	Tons	0·645
Hexamethylenediamine	Tons	0·520
Auxiliary products and royalties	Dollars/ton	25
Steam	Tons	9
Electric power	kWh	240
Water	m³	...

Labour:			
Capacity (thousands of tons/year)	1	4·5	10
Workers/shift	2	3	5
Supervisory staff/shift	1	1	2

Maintenance: 3 per cent
Depreciation: 8 per cent
Overhead: 40 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
1	915
1·6	1,050
3	1,300
10	1,852

[a] Or hexamethylenediamine adipate.

A-73. NYLON 6–6

Process: Polymerization and spinning

Output:		
Nylon 6–6	Tons	1
Input:		
Nylon salt	Tons	1·02
Miscellaneous and royalties	Dollars/ton	30
Steam	Tons	52
Electric power	kWh	3,200
Water	m³	1,030

Labour:			
Capacity (thousands of tons/year)	0·7	3	4·5
Workers/shift	8	16	20
Supervisory staff/shift	2	2	2

Maintenance: 4 per cent
Depreciation: 8 per cent
Overhead: 60 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
0·7	510
3	1,000
4·8	1,300

A-74. CAPROLACTAM

Process: From cyclohexane

Output:		
Caprolactam	Tons	1
Ammonium sulphate	Tons	4·3
Input:		
Cyclohexane	Tons	1·2
Sulphur	Tons	0·90
Ammonia	Tons	1·70
Sulphuric acid	Tons	1·30
Fuel petroleum	Tons	0·04
Steam	Tons	25
Electric power	kWh	2,400
Pure water	m³	40
Water for cooling	m³	1,200
Miscellaneous and royalties[a]	Dollars/ton	80

Labour:					
Capacity (thousands of tons/year)	2·5	3·6	6	10	12·25
Workers/shift	24	28	36	46	50
Supervisory staff/shift	2	2	3	3	3

Maintenance: 3 per cent
Depreciation: 9 per cent
Overhead: 60 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
2·5	4,000
3·6	5,000
6	7,000
10	9,650
12·25	11,200

[a] Including *inter alia* 0·7 tons of carbon dioxide, 20 to 50 kg of benzene solvent) and other minor ingredients.

A-75. "NYLON 6" OR POLYCAPROLACTAM

Process: Polymerization and spinning

Output:		
Nylon 6 (spun)	Tons	1
Input:		
Caprolactan	Tons	1·08
Catalysts and royalties	Dollars/ton	40
Titanium oxide	Kilogrammes	10
Steam	Tons	...
Electric power	kWh	400
Pure water	m³	20

Labour:			
Capacity (thousands of tons/year)	3	7	10
Workers/shift	5	6	9
Supervisory staff/shift	2	2	2

Maintenance: 3 per cent
Depreciation: 9 per cent
Overhead: 80 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
3	2,400
7·2	3,300
10	3,800

A-76. DIMETHYL TEREPHTHALATE

Process: From xylene

Output:		
Dimethyl terephthalate	Tons	1
Steam	Tons	3
Input:		
Paraxylene	Tons	0·68
Methanol[a]	Tons	0·07
Miscellaneous and royalties	Dollars/ton	40
Fuel	1,000 kcal	1,560
Electric power	kWh	1,150
Water	m³	215

Labour:		
Capacity (thousands of tons/year)	5	27
Workers/shift	4	7
Supervisory staff/shift	2	2

Maintenance: 3 per cent
Depreciation: 8 per cent
Overhead: 60 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
5·4	4,000
27	10,500

[a] Net consumption after subtracting the recovery during polyester production.

A-77. POLYESTER FIBRE[a]

Output:		
Polyester fibre	Tons	1
Input:		
Dimethyl terephthalate	Tons	0·86
Glycol ethylene	Tons	0·31
Miscellaneous, royalties, etc.	Dollars/ton	50·00
Fuel	1,000 kcal	560
Steam	Tons	6
Electric power	kWh	550
Water	m³	
Labour:		
Workers/shift		20
Supervisory staff/shift		2

Maintenance: 4 per cent
Depreciation: 8 per cent
Overhead: 40 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
4	1,300

[a] Estimated partly on the basis of Nylon 6-6 (table A-73).

A-78. BUTADIENE

Process: From normal butane

Output:		
Butadiene	Tons	1
Combustible gas	1,000 kcal	6,800
C_5 and higher hydrocarbons (to gasoline)	Tons	0·048
Input:		
Butane[a]	Tons	1·64
Catalysts and minor chemicals	Dollars/ton	30
Fuel	1,000 kcal	8,500
Steam	Tons	11
Electric power	kWh	2,300
Untreated water	m³	200
Treated water	m³	8

Labour:		
Capacity (thousands of tons/year)	20 to 30	40
Workers/shift	12	15
Supervisory staff/shift	2	2

Maintenance: 4 per cent
Depreciation: 8 per cent
Overhead: 60 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
20	6,000
30	8,000
40	9,400

[a] 97 to 98 per cent n-butane and 2 per cent isobutane.

A-79. SBR RUBBER

Process: Copolymerization

Output:		
Styrene-butadiene rubber	Tons	1
Input:		
Butadiene	Tons	0·75
Styrene	Tons	0·25
Various reagents[a]	Dollars/ton	62·00
Fuel	1,000 kcal	4,000
Steam	Tons	20
Electric power	kWh	400
Treated water	m³	2
Untreated water	m³	400

Labour:

Capacity (thousands of tons/year)	20	40	70
Workers/shift	18	26	32
Supervisory staff/shift	2	4	6

Maintenance: 3 per cent
Depreciation: 8 per cent
Overhead: 120 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
20	8,000
40	13,000
70	20,000

[a] Including 43 kg soap, 200 kg salt, 5 kg mercaptan and 2 kg persulphate.

A-80. CIS-POLYBUTADIENE

Output:		
Cis-polybutadiene rubber	Tons	1
Input:		
Butadiene (98·5 per cent)	Tons	1·09
Chemicals, catalysts and royalties	Dollars/ton	95
Fuel[a]	1,000 kcal	15,000
Electric power[a]	kWh	2,000
Water[a]	m^3	500

Labour:

Capacity (thousands of tons/year)	13	27
Workers/shift	15	24
Supervisory staff/shift	2	3

Maintenance: 3 per cent
Depreciation: 8 per cent
Overhead: 100 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
13	8,300
27	14,000

Note: Generally in 20,000 to 45,000-ton plants which can alternatively produce other similar polymers.

[a] Figures are estimates and similar to those for butyl rubber.

A-81. BUTYL RUBBER (OR GR-I)

Process: Copolymerization of isobutylene and isoprene

Output:		
Butyl rubber	Tons	1
Input:		
Isobutylene (in C_4)	Tons	1·1[a]
Isoprene	Tons	0·03[b]
Miscellaneous and royalties	Dollars/ton	50
Fuel	1,000 kcal	20,000
Electric power	kWh	900
Water for cooling	m^3	800
Treated water	m^3	120

Labour:

Workers/shift	8
Supervisory staff/shift	3

Maintenance: 3 per cent
Depreciation: 8 per cent
Overhead: 100 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
15	9,800
20	12,000

[a] The separation, which is carried out in the plant, is in practice quantitative.

[b] Varies between 2 and 3 per cent according to the type manufactured.

A-82. CARBON BLACK (oil furnace)

Process: Furnace

Output:		
Carbon black[a]	Tons	1
Input:		
Residual oils[b]	Tons	2
Fuel, gas	1,000 kcal	4,000
Electric power	kWh	1,200
Water for cooling	m^3	60

Labour:

Capacity (thousands of tons/year)	4 to 8	10	40
Workers/shift	12	20	30
Supervisory staff/shift	2	2	3

Maintenance: 3 per cent
Depreciation: 8 per cent
Overhead: 60 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
4	1,900
6	2,300
10	3,000
20	4,500
40	6,800
80	11,000

[a] Represents the usual types (HAF, ISAF, SAF) used as rubber stiffeners in tyre covers.

[b] With high aromatic hydrocarbon content.

A-83. CARBON BLACK (gas furnace)

Process: Furnace

Output:		
Carbon black[a]	Tons	1
Input:		
Natural gas	m^3	6,000
Electric power	kWh	1,100
Water	m^3	60

Labour:

Capacity (thousands of tons/year)	4 to 8	10 to 40
Workers/shift	12	20
Supervisory staff/shift	2	2

Maintenance: 3 per cent
Depreciation: 8 per cent
Overhead: 60 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
4	1,400
10	2,000
20	3,200

[a] Types: FF (fire furnace), SRF (semi-reinforcing), HMF (high modular). Applicable to thermal types (pigments) with variations in yield.

A-84. TRISODIUM PHOSPHATE (anhydrous)

Output:		
Trisodium phosphate	Tons	1
Input:		
Phosphoric acid, 100 per cent	Tons	0·68[a]
Sodium carbonate	Tons	0·78
Caustic soda	Tons	0·28
Fuel	1,000 kcal	3,000
Steam	Tons	2
Electric power	kWh	80
Untreated water	m³	400

Labour:		
Capacity (thousands of tons/year)	Below 10	Over 10
Workers/shift	6	10
Supervisory staff/shift	1	2

Maintenance: 3 per cent
Depreciation: 8 per cent
Overhead: 70 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
6	400
18	780

Note: Another commercial form: hydrate (12 molecules of water), 2·4 tons being the equivalent of 1 ton of "anhydrous".

[a] Wet process acid; less than 0·61 tons with dry process acid

A-85. SODIUM TRIPOLYPHOSPHATE

Output:		
Sodium tripolyphosphates	Tons	1
Input:		
100 per cent phosphoric acid[a]	Tons	0·90
Sodium carbonate	Tons	0·78
Minor chemicals and other[b]	Dollars/ton	15·00
Fuel	1,000 kcal	1,200
Steam	Tons	3
Electric power	kWh	50
Water	m³	800

Labour:			
Capacity (thousands of tons/year)	Below 10	10 to 30	Over 30
Workers/shift	8	10	15
Supervisory staff/shift	1	2	2

Maintenance: 3 per cent
Depreciation: 8 per cent
Overhead: 60 to 80 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
6	500
18	960
50	2,100

[a] Wet process type.

[b] Including small quantities of barium carbonate, active carbon, oxidizing agents, etc.

A-86. TITANIUM DIOXIDE

Output:		
Titanium dioxide	Tons	1
Input:[a]		
Sulphuric acid	Tons	4·0
Ilmenite	Tons	3·2
Minor chemicals and miscellaneous	Dollars/ton	15·00
Fuel	1,000 kcal	7,000
Electric power	kWh	400
Water	m³	50

Labour:			
Capacity (thousands of tons/year)	10	20	40
Workers/shift	20	24	30
Supervisory staff/shift	2	2	3

Maintenance: 4 per cent
Depreciation: 8 per cent
Overhead: 60 per cent

INVESTMENT[b]

Capacity in thousands of tons/year	*Thousands of dollars*
10	8,500
20	14,000
25	16,200
40	22,500

[a] Figures for services estimated from cost data.

[b] According to published figures covering nine plants.

A-87. PROPYLENE TETRAMER

Output:		
Propylene tetramer	Tons	1
Propane gas (LPG)	Tons	5·5
Heavy polymers, to gasoline	Tons	0·2
Input:		
Propane-propylene[a]	Tons	6·85
Catalysts, minor chemicals, etc.	Dollars/ton	6·00
Fuels, gas	1,000 kcal	11,300
Electric power	kWh	215
Water for cooling	m³	70

Labour:			
Capacity (thousands of tons/year)	Up to 10	12 to 18	25
Workers/shift	2	3	5
Supervisory staff/shift	1	2	2

Maintenance: 3 per cent
Depreciation: 8 per cent
Overhead: 80 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
2·5	500
3·6	600
5·5	750
9·2	980
14·0	1,200

[a] 25 per cent propylene by volume.

A-88. DODECYLBENZENE

Output:		
Dodecylbenzene	Tons	1
Residual alkylates	Tons	0·38
Input:		
Propylene tetramer	Tons	0·92
Benzene	Tons	0·50
Catalysts, chemicals and royalties	Dollars/ton	10
Fuel	1,000 kcal	1,500
Steam	Tons	2
Electric power	kWh	120
Untreated and cooling water	m³	20

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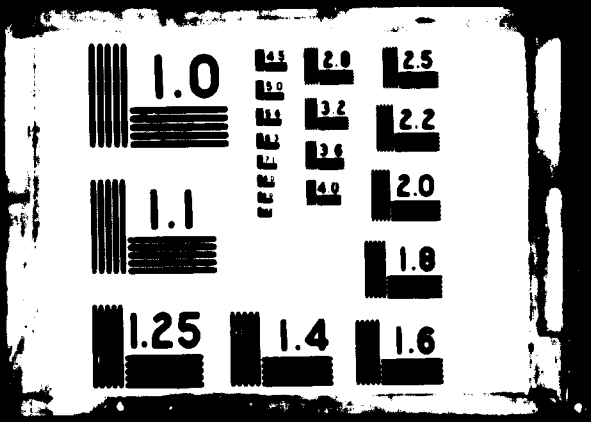

Labour:

Capacity (thousands of tons/year)	1 to 5	5·5 to 16	20 to 30
Workers/shift	2	3	5
Supervisory staff/shift	1	1	2

Maintenance: 3 per cent
Depreciation: 8 per cent
Overhead: 150 per cent (below 5,000 tons)
100 per cent (over 5,000 tons)

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
2·5	630
4	780
10	1,250
30	2,500

A-89. ISOPROPYL ALCOHOL

Output:		
Isopropyl alcohol	Tons	1
Input:		
100 per cent propylene[a]	Tons	0·74
Sulphuric acid	Tons	0·1
Other chemicals	Dollars/ton	1·00
Steam	Tons	6
Electric power	kWh	53
Water for cooling	m^3	200
Labour:		
Capacity (thousands of tons/year)	1·5 to 50	
Workers/shift	4	
Supervisory staff/shift	1	

Maintenance: 4 per cent
Depreciation: 6·7 per cent
Overhead: 60 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
1·5	634
4	1,143
10	1,967
25	3,440
50	5,225

[a] Propane-propylene with 60 per cent propylene is used; the propane is recovered.

A-90. ACETONE

Process: From isopropanol (IFP)

Output:		
Acetone	Tons	1
Combustible gas[a]	1,000 kcal	900
Input:		
Isopropanol	Tons	1·20
Catalysts, miscellaneous and royalties	Dollars/ton	15·00
Steam	Tons	3·3
Electric power	kWh	20
Water for cooling	m^3	100
Labour:		
Capacity (thousands of tons/year)	10	
Workers/shift	2	
Supervisory staff/shift	1	

Maintenance: 3 per cent
Depreciation: 10 per cent
Overhead: 120 per cent

INVESTMENT

Capacity in thousands of tons/year	*Thousands of dollars*
10	330

Remarks: Minimum scale: 1,000 tons per year.
[a] Virtually hydrogen.

ECONOMIES OF CAPITAL[b]

A characteristic common to both the chemical and the processing industries is that the unit investment (investment per ton of annual capacity) decreases as the size of plant and facilities increases. The relationship between the cost of two plants of different size is not directly proportional to their respective productive capacities. Although it varies for different processes, it generally obeys an exponential function of the type:

$$\frac{I_1}{I_0} = \left(\frac{C_1}{C_0}\right)^{\alpha}$$

in which C_0 and C_1 represent different productive capacities and I_0 and I_1 are the total investment necessary in the two cases.[c] The exponent alpha, which is usually called the capital factor, presents a number of variations as between different processes and varies in the case of a single product according to the range of capacities that is being considered. It is debatable whether a chemical process can be characterized on the basis of a constant value of alpha applicable to any size of plant; experience has shown that alpha has different values in the lower range of the known capacities.

This fact indicates that the economies of scale are high in the case of the low productive capacities, the reason being that it is impossible to reduce the size of some elements of the processing equipment (heat exchangers, pumps, agitators, filters, distillation columns) below certain technically feasible limits. The result is that certain equipment components unavoidably have a relatively excessive capacity. For higher productive capacities, the exponent alpha tends to become stabilized and to assume a value which is characteristic for the process. This continues until a new level of capacities is reached at which some elements of the equipment must be duplicated because they have reached the maximum feasible size for single units. At that level the capital factor increases in value and tends to unity.

The capital factors derived from an analysis of the investment needed for eighteen chemical processes at different levels of capacity range from 0·5 to 0·8 and the characteristic economies from 22 to 40 per cent in the transition from a nominal production scale C_0[d] to a triple scale C_3. The investments considered relate to fully equipped plants and include their physical components (installed processing equipment, buildings, auxiliary facilities and the like); design, engineering and erection costs, and in general the usual overheads. They are therefore equivalent to the concept of turn-key cost for complete plants not integrated into industrial

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[b] See foot-note a.

[c] Among the first works published on the capital factor in various chemical industries are those by R. Williams, Jr., "Six-tenths Factor Aids in Approximating Costs", *Chemical Engineering*, December 1948; and H. Chilton, op. cit.

[d] The scale of production used as the central term of comparison C_0 is referred to below as the scale of reference or base scale and corresponds roughly to the criterion of "economic size" for each case studied.

UNIT INVESTMENT, ECONOMIES OF SCALE AND CAPITAL FACTOR

Product	*Percentage of economies obtainable from investment*[a]	I_0 *Unit investment of reference (dollars/ton)*	C_0 *Scale of reference (tons)*	*Exponent* x[b]
Isopropanol	43	242	6,000	0·5
Calcium carbide	41	167	15,000	0·5 to 0·6
Polyvynil chloride	38	285	6,000	0·55
Calcium oxide	38	34	15,000	0·58
Butadiene	38	600	10,000	0·59
Acetylene carbide	37	71	4,880	0·60
Acetaldehyde	37	100	20,000	0·60
Carbon black	37	300	10,000	0·58 to 0·60
Ethylene	35	570	10,000	0·54
Titanium dioxide	34	1,200	5,000	0·61
Urea	31	85	33,000	0·67
Acetylene (from natural gas)	30	465	13,600	0·67
Styrene	23	280	10,000	0·76
Polyethylene (high pressure)	22	492	8,130	0·87
Methanol	22	444	10,000	0·78
Chlorine-soda	22	340	16,500	0·76 to 0·80
Ammonia	22	139	36,000	0·73
Sulphuric acid	17	18	36,000	0·80

[a] Equal to $\frac{I_0 - I_3}{I_0} \cdot 100$

where: I_0 investment per ton per year at the scale C_0.
I_3 investment per ton per year at the scale C_3.

[b] Valid for the range C_0 to C_3.

complexes which might provide an additional economy, particularly in the form of jointly used general facilities. These investments accordingly represent nothing more than an over-all figure subject to appreciable variations as the result of local conditions such as wages, labour productivity, topography and the availability of supplies. Such local conditions are of course responsible for the considerable variations from country to country between plants with similar production capacity. The degree of care and expense devoted to matters of relatively secondary importance, such as the type of construction used for laboratories, offices and so on or the facilities provided for the staff, also makes it difficult to compare the corresponding investments in two or more plants of equal capacity.

The most probable values of investments at the different capacities were expressed in terms of unit investment, that is, the capital cost per ton of annual capacity. A capacity or scale of reference C_0 with its corresponding unit investment, was established for each product. The unit investments at other capacities were compared with this, the differences being expressed as a percentage of the unit investment I_0 of reference. The products analysed were arranged in a descending order of the percentage of the economies obtainable from investments that would triple the capacity C_0. It was found that the resulting economies would range between 22 and 40 per cent of I_0. The "Unit Investment, Economics of Scale and Capital Factor" table shows the values of the economies of scale for this capacity relationship (from C_0 to C_3), together with the value of the investment of reference I_0, the productive capacity at the scale of reference C_0 and the resultant capital exponent in the range C_0 to C_3.

It must be admitted that these values of the economies obtainable from investments that would triple the capacity of reference are to some extent a reflection of the criterion on which the selection of the capacity of reference was based. For example in the extreme cases relatively high scales of reference (for sulphuric acid, 100 tons a day) or relatively low ones (for isopropanol, a product of the petrochemical type, 6,000 tons per year) were chosen. In other words, if a plant of the type usually found in Latin America (30 to 50 tons a day) had been adopted as the scale of reference for sulphuric acid, the economies of investment resulting from an increase in capacity to between 90 and 150 tons a day would be more than the 17 per cent calculated and, instead, would amount to more than 20 per cent.

In the cases examined, it is possible, starting from a given minimum level, to determine the range of capacities in which economies of scale are significant. These ranges are as follows:

	Tons/year
Isopropanol	2,000 to 30,000
Calcium carbide	5,000 to 60,000
Polyvinyl chloride	2,500 to 40,000
Calcium oxide	5,000 to 100,000
Butadiene	5,000 to 60,000
Acetylene carbide	2,000 to 20,000
Acetaldehyde	10,000 to 60,000
Carbon black	4,000 to 30,000
Ethylene	10,000 to 60,000
Titanium dioxide	4,000 to 30,000
Urea	16,000 to 165,000
Acetylene (from natural gas)	10,000 to 45,000
Styrene	5,000 to 50,000
Polyethylene (high pressure)	6,000 to 12,000
Methanol	5,000 to 60,000
Chlorine-soda	6,000 to 35,000
Ammonia	18,000 to 180,000
Sulphuric acid	10,000 to 100,000

The first figure approximates to what, with due allowance for local conditions, is considered to be the minimum capacity.

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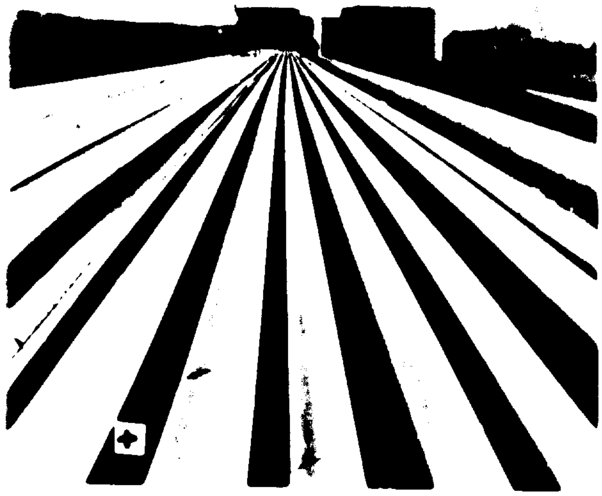
Programming Data for the Petroleum Refining Industry



By ALAN S. MANNE

SCOPE AND PURPOSE

THE SET OF tables and the figures which follow are for world-wide use in planning petroleum refining investments. They are set up in such a way as to allow for a wide variety of the process alternatives and product-mix options confronting the refiner. These programming data are intended both for the purpose of preliminary project evaluation and for inter-industry economic analyses. However, they should always be supplemented with whatever specific information is available on local conditions. It should be a comparatively easy matter, for example, to adjust the crude oil compositions shown in table 2 and bring them into line with the properties of the crudes that are locally available.

In assembling these data, an attempt was made to strike some sort of reasonable compromise between simplicity and flexibility in use. For example, in the interest of simplicity, no distinction was drawn between the octane numbers of various straight-run gasolines. In the interest of flexibility, however, there is no typical octane number shown for finished motor gasoline. Instead, there is included a tetraethyl lead blending chart so that the user can insert whatever octane number specification seems most appropriate for his own purposes.

These charts and tables are predicated upon the use of typical raw materials and typical operating conditions for the various refinery processes. It is altogether likely, however, that there will be individual cases where the yields of major products differ by as much as ± 10 per cent from those indicated here. The initial investment costs are probably accurate to within ± 25 per cent. The yields of minor products such as coke and refinery gases are even more variable, and may be in error by as much as ± 50 per cent. Also subject to errors of similar magnitude are the inputs of refinery fuel, sulphuric acid, caustic soda, electricity and manpower. (These latter coefficients were estimated through United States Census data on total inputs per barrel of crude charged to refineries in 1954.[1])

ARRANGEMENTS OF CHARTS AND TABLES

Investment costs for individual process units are subject to considerable economies of scale—typically in the form of a "six-tenths exponent" relationship. In order to reflect these economies of scale, investment costs are shown as a function of plant capacity in figure II. All investment costs are stated in terms of 1960 dollars and refer to plants operating round the clock 365 days a year except for normal maintenance downtime.

All current inputs and outputs are measured in terms of physical units: barrels, pounds, kilowatt-hours, etc. These

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[1] The United States Census data provide no support for the hypothesis that there are economies of scale in terms of the *total* number of refinery employees. It is generally believed, however, that there are such economies in terms of direct operating labour.

View of an oil refinery in Argentina

Petroleum blending area of a refinery in Pakistan

current inputs and outputs are not subject to significant economies of scale, and are assembled here in the form of an activity analysis array—alternative "processes" for producing the various "items". Altogether, the tables include sixty-nine rows for the various items: equipment capacity, raw materials, intermediate streams, and end products. There are seventy-four columns, one for each of the alternative processes: primary fractionation, visbreaking, catalytic cracking, motor gasoline blending, and the like.

The various input and output flow coefficients are listed in tables 2 through 10 and in figure III. Two keys to this material are provided: table 1 and figure I. Table 1 contains a complete list of the sixty-nine items, their units of measurement, and a set of volume-weight conversion factors for the liquid materials. Figure I provides an over-all view of the processing relationship and of the connexions between the various activity analysis tables.

In order to illustrate the use of this material, table 11 contains a complete refinery balance for a case involving primary fractionation, catalytic cracking and product blending. The gasoline blend employed in this example also serves to illustrate the use of figure III, the ethyl lead blending chart.

PETROCHEMICALS MANUFACTURING

These tables have been constructed so as to provide considerable detail on the potentialities for petrochemicals production. It is because of this attempt at detail—as well as because of the fact that refinery gases altogether represent such a small fraction of the total output of the various cracking and reforming processes—that the yields of individual gas streams (e.g., item 47, butylenes) are subject to potential errors of as much as ± 50 per cent. This means that a prediction of the total yield of, say, butanes and butylenes is likely to be considerably more accurate than that for butylenes alone.

In addition to refinery gases, there is one other major raw material supplied by petroleum refineries to the chemicals industry—aromatic chemicals. These aromatics appear here under a catch-all heading—benzene, tuolene and xylenes, item 37. In the immediate future, it is safe to suppose that the petroleum refiner can trade off these individual chemicals against one another on a barrel-for-barrel basis. In the long run, however, this barrel-for-barrel trade-off possibility may disappear, and refiners may be faced with shortages of naphthenic materials in the charge stocks utilized for catalytic reforming.

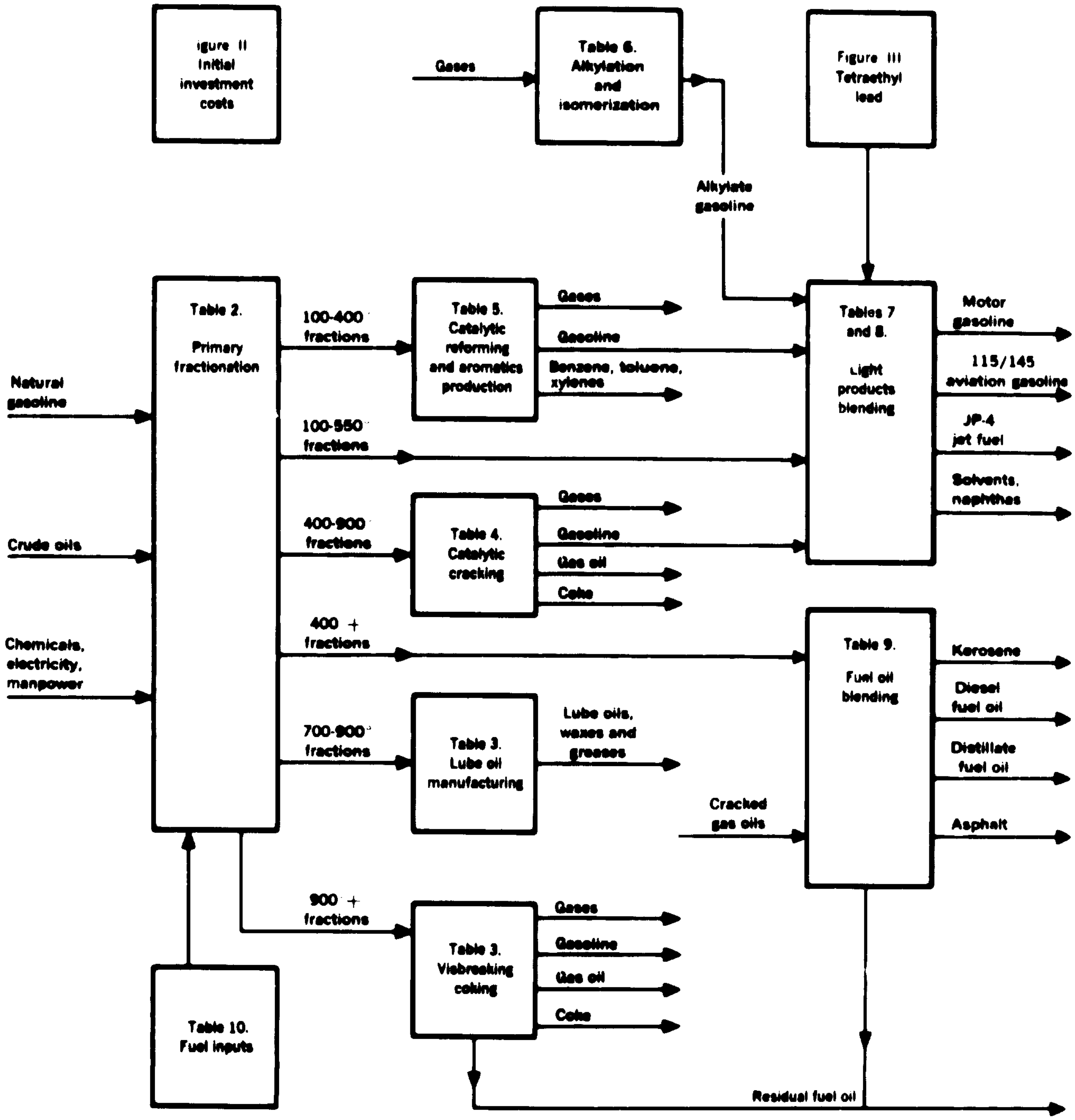
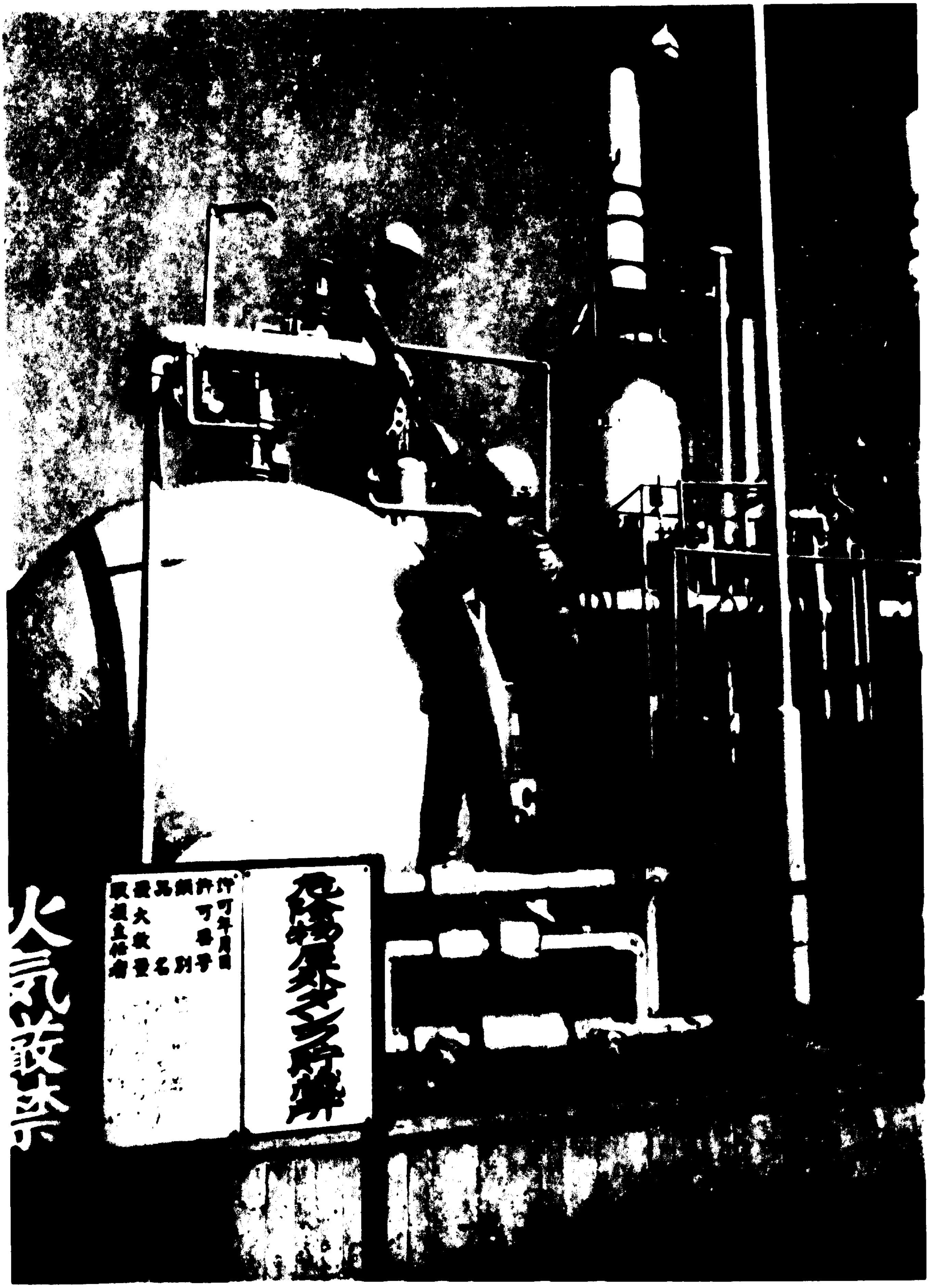


Figure I

SCHEMATIC DIAGRAM OF TABLES AND FIGURES



Mechanics at work in an oil refinery in Japan

Laying a pipeline near the Ras Tanura refinery at Al Hasa, Saudi Arabia

The reader who is particularly interested in the programming of petrochemical investments should consult the informative case study on Puerto Rican possibilities by Isard, Schooler and Vietorisz (1959).

OMISSIONS

Two of the usual motor gasoline specifications—the 50 per cent point and the F-2 Motor method octane rating—have been eliminated from these tables on the grounds that they were likely to be redundant. In any detailed application, it would be essential to check further upon the gasoline blend, and to verify that these restrictions are, in fact, satisfied.

Certain obsolescent refinery processes have been omitted from consideration here: thermal cracking, thermal reforming, and gasoline polymerization. Each of these processes has the advantage of low capital investment costs and of low royalties. However, the octane number of the gasoline product is so poor that new installations of these types would be quite unusual.

Many units of auxiliary refinery equipment do not show up here in explicit form. Their installation cost is already included in the auxiliary equipment for primary fractionation, for catalytic cracking or for one of the other plant units. Among the omissions of this type are: gas fractionation, vacuum distillation, chemical treatment, crude and products storage, and plant utilities. It is largely because of the omission of all this auxiliary equipment that line 1A (topping and atmospheric distillation) appears so much lower on figure II than does line 1 (primary fractionation and auxiliary equipment for complete refinery).

One major type of processing equipment—hydrogen processing and sulphur recovery equipment—has taken on increasing importance, but has nevertheless been omitted here. The sulphur content varies so widely among straight run fractions—anywhere from 0·2 to 5 per cent by

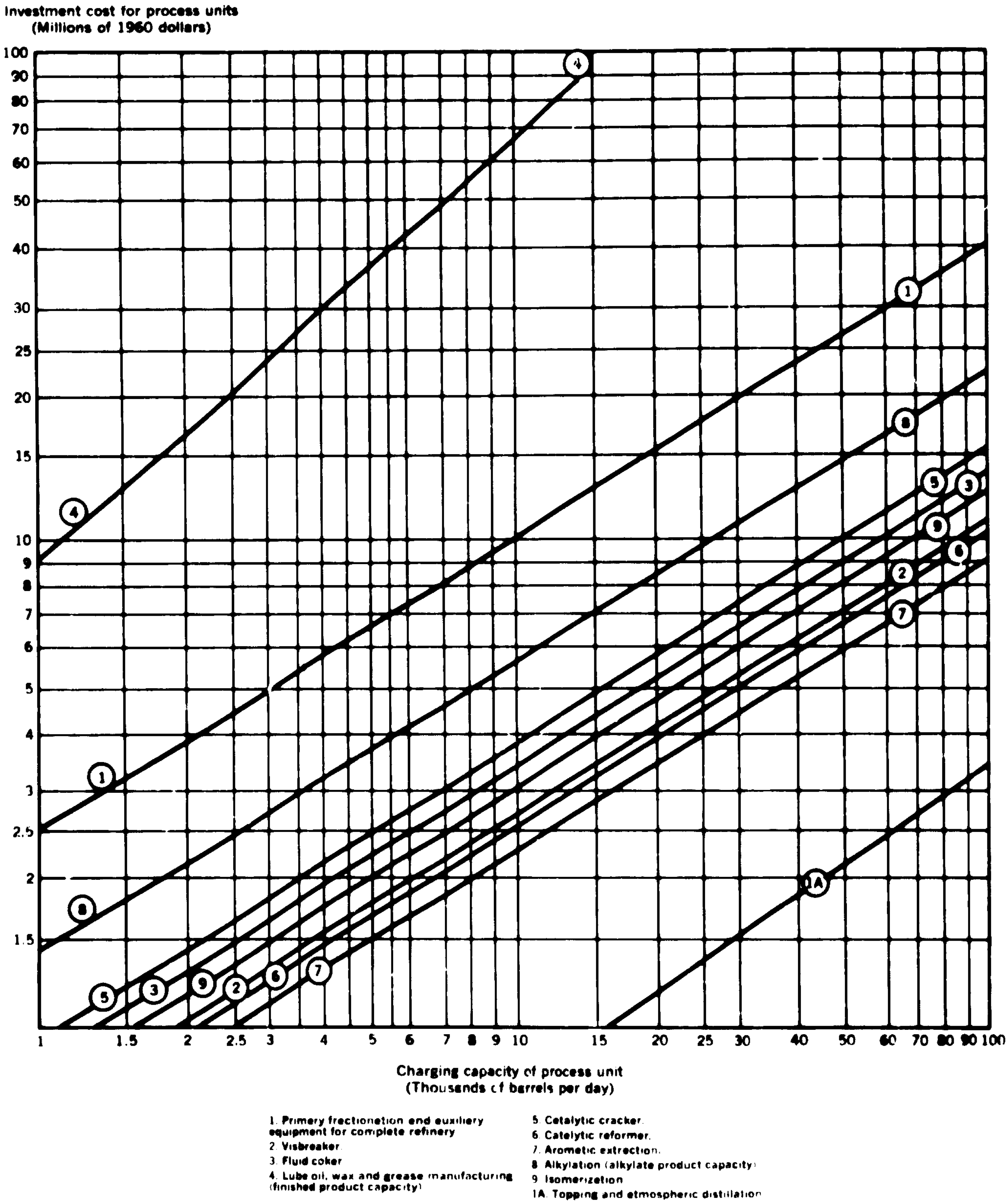


Figure II

INITIAL INVESTMENT COSTS

weight—that it would be extremely misleading to set down a single number that is intended to be representative of world-wide conditions. If sulphur removal appears worth investigating, this is best done on the basis of the particular crude oils that are locally available. Tables 4 and 5 contain one strategic piece of information in planning for this type of processing—the hydrogen yields from cracking and reforming. According to Slyngstad and Lempert (1960), it takes approximately 0·25 pounds of hydrogen in order to remove one pound of sulphur.

SOURCES OF DATA

All sources are listed in the references below. Major reliance was placed upon Nelson (1958), a work that should be consulted by anyone with a serious interest in petroleum refining. The starting point of this entire analysis—the primary fractionation yields appearing in table 2 below—was taken directly from Nelson, figure 4-3, page 90. Among the other key estimates taken directly from Nelson are those on investment costs for the following equipment categories: (2) visbreaker; (3) fluid coker; (4) lube oil manufacturing; and (14) topping and atmospheric distillation.

Operating a molecular still in a research laboratory in New Jersey, United States. The still is used for distilling and purifying materials used in the production of petroleum additives and lubricants

Partial view of the petroleum exporting port in Kuwait

Each of the major construction and engineering companies provides useful reprints upon request. Among these reprints are the papers by Curry and Haag (1956) and Curry and Schnabel (1960) drawing upon the experience of the Universal Oil Products Company. All investment costs not derived from Nelson were adapted from these two papers. These investment costs checked fairly closely with reports on complete plants constructed by the M. W. Kellogg Company.

The catalytic cracking and reforming yields were based on two articles in the *Oil and Gas Journal* (1955) dealing, respectively, with Houdriflow catalytic cracking and with Houdriforming. These data agreed fairly closely with those of Nelson and also of Read and Weinert (1956). The detailed composition of refinery gases produced by cracking and reforming processes came from two sources: Nelson page 417, and Sutherland and Belden (1958).

ILLUSTRATIVE EXAMPLE

The illustrative example in table 11 is based on a plant refining 50,000 barrels per day of 30° API crude oil. Two types of process equipment are employed: primary fractionation and catalytic cracking. In addition, there are facilities for blending a variety of end products: motor

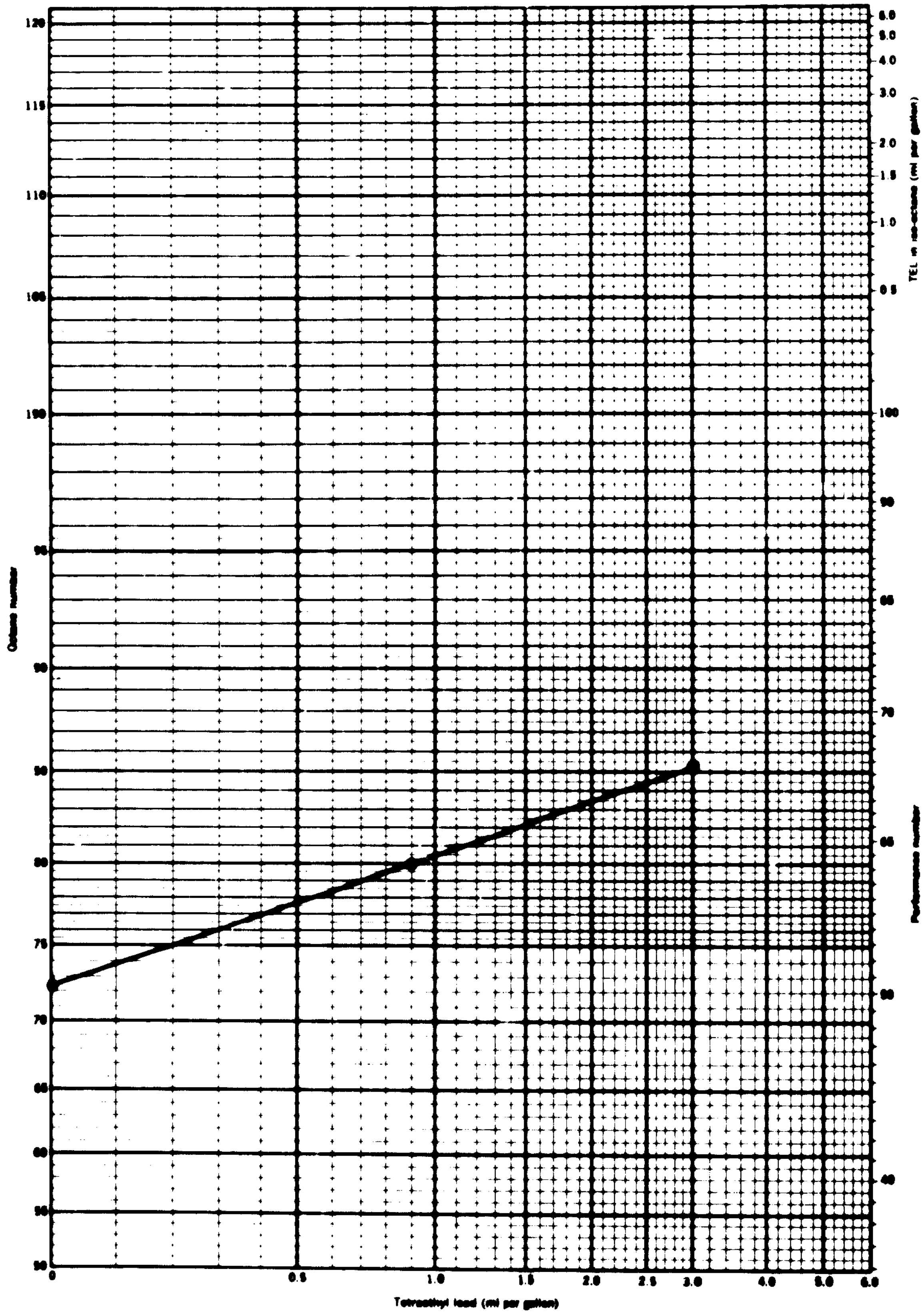


Figure III

TETRAETHYL LEAD SUSCEPTIBILITY CHART

(*Reprinted by permission of the Ethyl Corporation*)

Example: Blend has an F-1, clear, octane rating of 72·6 and an F-1, 3 ml TEL, of 85·3. In order to meet an 80 octane number specification, it will be necessary to add 0·9 ml TEL to each gallon of the blend.

N.B. It is customary to limit the lead concentration to a maximum of 3·0 ml per gallon.

gasoline, JP-4 jet fuel, diesel fuel, and so forth. The motor gasoline is to meet an 80 octane number specification. All cracked refinery gases are to be reserved for petrochemical manufacturing, except those butanes required for meeting the Reid vapour pressure specification of the gasoline blend.

Each column appearing in table 11 is derived by simple multiplication from the corresponding column listed previously in tables 2 through 10. Columns 2-6, for example, specifies that for each barrel of charge of 30° crude oil, there are the following inputs: 1·0 unit of primary fractionation capacity, and 1·0 unit of refinery fuel, among others. Among the outputs per barrel of crude charge are the following: 0·10 units of straight-run material in the 100–250° fraction and 0·14 units in the 250–400° fraction. Accordingly, 50,000 barrels of daily charge will require an input of 50,000 units of primary fractionation capacity, 50,000 units of refinery fuel, etc., and will produce outputs of 5,000 units of straight-run material in the 100–250° fraction, 7,000 units in the 250–400° fraction, etc.

Totals for each of the rows in table 11 appear in the right-hand column. This column indicates that on balance the refinery requires the following inputs among others: 50,000 barrels of daily fractionation capacity, and 22,500 barrels of daily catalytic cracker capacity. The plant is self-sufficient with respect to refinery fuel. The daily output of hydrogen gas is 9,000 pounds, of methane gas, 84,000 pounds. The figure for the daily motor gasoline output of 20,000 barrels does not appear explicitly in this right hand balancing column, but instead shows up in column 7-12, row 50.

In order to complete this example, use must be made of the charts for investment costs and for ethyl blending. According to figure II, the investment costs here are reckoned as follows:

	Equipment capacity (barrels per day)	*Initial investment (millions of dollars)*
1. Primary fractionation	50,000	26·0
5. Catalytic cracker	22,500	6·2
TOTAL INITIAL INVESTMENT		32·2

Figure III enables us to calculate the inputs of tetraethyl lead required to meet the 80 octane number specification for motor gasoline. From table 11, columns 7-1, 7-2, 7-4, 7-7 and 7-8, we already know the following about the motor gasoline blend:

50. Motor gasoline product	20,000 barrels per day
52. F-1, clear, motor gasoline	1,451,300 octane-barrels per day
53. F-1, 3 ml TEL, motor gasoline	1,705,500 octane-barrels per day

Dividing the number of octane-barrels per day in the blend by the 20,000 barrels per day of motor gasoline product, we note that the octane number ratings are, respectively, 72·6 F-1, clear, and 85·3 F-1, 3 ml TEL. According to figure III, these two points indicate that in order to reach the 80 octane number specification for the motor gasoline blend, it will be necessary to add approximately 0·9 ml of ethyl fluid to each gallon.

The total ethyl fluid input for motor gasoline blending, therefore, is shown in row 54 as 756 litres per day: 756 litres = (0·9 ml per gallon) (42 gallons per barrel) 20,000 barrels per day ÷ (1,000 ml per litre).

The reader who is interested in seeing just how this type of ethyl fluid blending relationship may be fitted into the activity analysis format should consult Kawaratani, Ullman and Dantzig (1960). For more general references on linear programming applications to petroleum refining, see Symonds (1955) and Manne (1958).

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Table 1

LIST OF ITEMS AND OF VOLUME-WEIGHT CONVERSION FACTORS

Item number	*Item*	*Unit of measurement*[a]	*API of typical liquid*	*Barrels*[a] *per metric ton*
1.	Primary fractionation capacity	Barrels of daily charge	—	—
2.	Visbreaker capacity	Barrels of daily charge	—	—
3.	Fluid coker capacity	Barrels of daily charge	—	—
4.	Lube oil, wax and grease capacity	Barrels of daily product	—	—
5.	Catalytic cracker capacity	Barrels of daily charge	—	—
6.	Catalytic reformer capacity	Barrels of daily charge	—	—
7.	Aromatics extraction capacity	Barrels of daily charge	—	—
8.	Alkylation capacity	Barrels of daily alkylate product	—	—
9.	Isomerization capacity	Barrels of daily charge	—	—
10.	Refinery fuel	700,000 BTU per day	—	—
11.	Crude oil, 10 API	Barrels per day	10	6·3
12.	Crude oil, 12 API	Barrels per day	12	6·4
13.	Crude oil, 15° API	Barrels per day	15	6·5
14.	Crude oil, 20° API	Barrels per day	20	6·7
15.	Crude oil, 25° API	Barrels per day	25	7·0
16.	Crude oil, 30° API	Barrels per day	30	7·2
17.	Crude oil, 35 API	Barrels per day	35	7·4
18.	Crude oil, 40° API	Barrels per day	40	7·6
19.	Crude oil, 45 API	Barrels per day	45	7·9
20.	Crude oil, 50° API	Barrels per day	50	8·1
21.	Straight-run fraction, 100–250 F	Barrels per day	70	9·0
22.	Straight-run fraction, 250–400° F	Barrels per day	50	8·1
23.	Straight-run fraction, 400–550° F	Barrels per day	40	7·6
24.	Straight-run fraction, 550–700° F	Barrels per day	30	7·2
25.	Straight-run fraction, 700–900° F	Barrels per day	20	6·7
26.	Straight-run fraction, 900° F	Barrels per day	10	6·3
27.	Visbreaker/coker gasoline	Barrels per day	60	8·5
28.	Visbreaker/coker gas oil	Barrels per day	30	7·2
29.	Petroleum coke	Pounds per day	—	—
30.	Lube, oils, waxes and grease products	Barrels per day	20	6·7
31.	Catalytic cracking charge stock	Barrels per day	30	7·2
32.	Catalytic cracked gasoline	Barrels per day	60	8·5
33.	Catalytic cracked gas oil	Barrels per day	30	7·2
34.	Catalytic coke	Pounds per day	—	—
35.	Debutanized reformate, 80 F-1, clear	Barrels per day	60	8·5
36.	Debutanized reformate, 92 F-1, clear	Barrels per day	60	8·5
37.	Benzene, toluene, xylenes	Barrels per day	30	7·2
38.	Natural gasoline	Barrels per day	90	9·9
39.	Hydrogen	Pounds per day	—	—
40.	Methane	Pounds per day	—	—
41.	Ethane	Pounds per day	—	—
42.	Ethylene	Pounds per day	—	—
43.	Propane	Barrels per day	146	12·4
44.	Propylene	Barrels per day	136	12·0
45.	Isobutane	Barrels per day	119	11·2
46.	Normal butane	Barrels per day	111	10·8
47.	Butylenes	Barrels per day	104	10·5
48.	Isopentane	Barrels per day	95	10·1
49.	Alkylate	Barrels per day	60	8·5
50.	Motor gasoline product	Barrels per day	60	8·5
51.	Reid vapour pressure of motor gasoline	RVP-barrels per day	—	—

[a] Barrel referred to is the U.S. barrel of 42 gallons.

Table 1 continued

Item number	*Item*	*Unit of measurement*[a]	*API of typical liquid*	*Barrels*[a] *per metric ton*
52.	F-1, clear, motor gasoline	Octane-barrels per day		
53.	F-1, 3 ml TEL, motor gasoline	Octane-barrels per day		
54.	Tetraethyl lead (TEL)	Litres per day		
55.	115/145 aviation gasoline	Barrels per day	60	8·5
56.	JP-4 jet fuel	Barrels per day	50	8·1
57.	Solvents and naphthas	Barrels per day	50	8·1
58.	Kerosene	Barrels per day	40	7·6
59.	Diesel fuel oil	Barrels per day	30	7·2
60.	Distillate fuel oil	Barrels per day	30	7·2
61.	Asphalt	Barrels per day	10	6·3
62.	Residual fuel oil	Barrels per day	10	6·3
63.	Coal	Pounds per day		
64.	Natural gas	Thousands of cubic feet per day		
65.	Sulphuric acid (100 per cent H_2SO_4)	Pounds per day		
66.	Caustic soda (100 per cent NaOH)	Pounds per day		
67.	Electrical energy	Kilowatt-hours per day		
68.	Peak electric power	Kilowatts		
69.	Manpower	Employees		

Table 2

PRIMARY FRACTIONATION

Item number	*Item*	*Crude oil fractionation*										*Natural gasoline fractionation*
		10 oil (2·1)	*12 oil* (2·2)	*15 oil* (2·3)	*20 oil* (2·4)	*25 oil* (2·5)	*30 oil* (2·6)	*35 oil* (2·7)	*40 oil* (2·8)	*45 oil* (2·9)	*50 oil* (2·10)	(2·11)
1.	Primary fractionation capacity	1·0	1·0	1·0	1·0	1·0	1·0	1·0	1·0	1·0	1·0	
10.	Refinery fuel	1·0	1·0	1·0	1·0	1·0	1·0	1·0	1·0	1·0	1·0	
11.	Crude oil, 10 API	1·0										
12.	Crude oil, 12 API		1·0									
13.	Crude oil, 15 API			1·0								
14.	Crude oil, 20 API				1·0							
15.	Crude oil, 25 API					1·0						
16.	Crude oil, 30 API						1·0					
17.	Crude oil, 35 API							1·0				
18.	Crude oil, 40 API								1·0			
19.	Crude oil, 45 API									1·0		
20.	Crude oil, 50 API										1·0	
21.	Straight-run fraction, 100–250° F	0	0·02	0·03	0·05	0·07	0·10	0·14	0·18	0·27	0·43	0·49
22.	Straight-run fraction, 250–400 F	0·03	0·03	0·05	0·08	0·11	0·14	0·16	0·19	0·20	0·20	
23.	Straight-run fraction, 400–550 F	0·07	0·09	0·10	0·13	0·16	0·16	0·17	0·18	0·16	0·15	
24.	Straight-run fraction, 550–700 F	0·10	0·13	0·16	0·16	0·16	0·16	0·16	0·15	0·14	0·12	
25.	Straight-run fraction, 700–900 F	0·14	0·16	0·19	0·19	0·19	0·19	0·17	0·17	0·15	0·07	
26.	Straight-run fraction, 900° F +	0·66	0·57	0·47	0·39	0·31	0·25	0·20	0·13	0·08	0·03	
38.	Natural gasoline	—	—	—	—	—	—	—	—			1·0
45.	Isobutane	—	—	—	—	—	—	—	—			0·08
46.	Normal butane	—	—	—	—	—	—	—	—			0·24
48.	Isopentane	—	—	—	—	—	—	—	—			0·19
65.	Sulphuric acid	1·15	-1·15	1·15	1·15	1·15	1·15	1·15	1·15	1·15	1·15	
66.	Caustic soda	0·21	0·21	0·21	0·21	0·21	0·21	0·21	0·21	0·21	0·21	
67.	Electrical energy[b]	3·7	3·7	3·7	3·7	3·7	3·7	3·7	3·7	3·7	3·7	
68.	Peak electric power	-0·16	0·16	0·16	0·16	0·16	0·16	0·16	0·16	0·16	0·16	
69.	Manpower	-0·02	-0·02	0·02	0·02	0·02	0·02	0·02	0·02	0·02	0·02	

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[a] In this table and the following tables a minus sign (–) indicates net inputs.

[b] 3·7 kilowatt-hours per barrel of crude = (24 hours per day) (0·95 onstream factor) (peak 0·16 killowatts per barrel of crude).

Table 3

VISBREAKING, COKING AND LUBE OIL MANUFACTURING

Item number	Item	*Visbreaking*		*Coking*		
		50 per cent gas oil yield (3-1)	*70 per cent gas oil yield* (3-2)	*50 per cent gas oil yield* (3-3)	*80 per cent gas oil yield* (3-4)	*Lube oil manufacturing* (3-5)
2.	Visbreaker capacity	1·0	1·0	—	—	—
3.	Fluid coker capacity	—	—	−1·0	−1·0	—
4.	Lube oil, wax and grease capacity		—	—	—	1·0
25.	Straight-run fraction, 700–900 F	—	—	—	—	−1·0
26.	Straight-run fraction, 900 F +	1·0	1·0	1·0	1·0	—
27.	Visbreaker/coker gasoline	0·15	0·05	0·22	0·03	—
28.	Visbreaker/coker gas oil	0·50	0·70	0·50	0·80	—
29.	Petroleum coke	—		80·0	50·0	—
30.	Lube oils, waxes and grease products			—		1·0
40.	Methane	2·4	1·4	6·4	4·0	—
41.	Ethane	2·9	1·7	7·6	4·7	—
42.	Ethylene	0·7	0·4	2·0	1·2	—
43.	Propane	0·020	0·012	0·053	0·033	—
44.	Propylene	0·012	0·007	0·033	0·020	—
45.	Isobutane	0·002	0·001	0·004	0·003	—
46.	Normal butane	0·006	0·003	0·015	0·009	—
47.	Butylenes	0·008	0·005	0·022	0·013	—
62.	Residual fuel oil	0·35	0·26	—	—	—

Table 4

CATALYTIC CRACKING

Item number	Item	*Alternate charge stocks*				*Alternate recycle ratios*		
		Straight-run, 400–550 F (4-1)	*Straight-run, 550–700 F* (4-2)	*Straight-run, 700–900 F* (4-3)	*Visbreaker, coker, gas oil* (4-4)	*Cycle, fresh = 0·25* (4-5)	*Cycle, fresh = 0·50* (4-6)	*Cycle fresh 1·2–* (4-7)
5.	Catalytic cracker capacity	—	—	—	—	−1·25	−1·50	2·20
23.	Straight-run fraction, 400–550 F	−1·0	—	—	—	—	—	—
24.	Straight-run fraction, 550–700 F	—	1·0	—	—	—	—	—
25.	Straight-run fraction, 700–900 F	—	—	−1·0	—	—	—	—
28.	Visbreaker/coker gas oil	—	—	—	−1·0	—	—	—
31.	Catalytic cracking charge stock	1·0	1·0	1·0	1·0	−1·0	−1·0	−1·0
32.	Catalytic cracked gasoline	—	—	—	—	0·41	0·54	0·65
33.	Catalytic cracked gas oil	—	—	—	—	0·50	0·31	0·12
34.	Catalytic coke	—	—	—	—	15·0	17·0	27·0
39.	Hydrogen	—	—	—	—	0·4	0·6	0·9
40.	Methane	—	—	—	—	3·9	5·6	7·7
41.	Ethane	—	—	—	—	3·1	4·5	6·2
42.	Ethylene	—	—	—	—	3·6	5·3	7·3
43.	Propane	—	—	—	—	0·016	0·019	0·025
44.	Propylene	—	—	—	—	0·038	0·046	0·060
45.	Isobutane	—	—	—	—	0·056	0·066	0·087
46.	Normal butane	—	—	—	—	0·008	0·010	0·013
47.	Butylenes	—	—	—	—	0·042	0·049	0·065

Table 5

CATALYTIC REFORMING AND AROMATICS PRODUCTION

Item number	*Item*	*Mild reforming*		*Severe reforming*		
		Straight-run, 100–250 F (5–1)	*Straight-run, 250–400 F (5–2)*	*Straight-run, 100–250 F (5–3)*	*Straight-run, 250–400 F (5–4)*	*Aromatics production (5–5)*
6.	Catalytic reformer capacity	1·0	1·0	1·0	1·0	
7.	Aromatics extraction capacity			—		1·0
21.	Straight-run fraction, 100–250 F . . .	1·0		1·0		0·6
22.	Straight-run fraction, 250–400 F . . .	—	1·0		1·0	
35.	Debutanized reformate, 80 F-1, clear	0·91	0·91			
36.	Debutanized reformate, 92 F-1, clear			0·83	0·83	1·0
37.	Benzene, toluene, xylenes	—	—			0·4
39.	Hydrogen	4·2	4·2	3·4	3·4	
40.	Methane	1·3	1·3	2·6	2·6	
41.	Ethane	2·1	2·1	6·4	6·4	
43.	Propane	0·018	0·018	0·056	0·056	
45.	Isobutane	0·011	0·011	0·025	0·025	
46.	Normal butane	0·016	0·016	0·037	0·037	

Table 6

ALKYLATION AND ISOMERIZATION

Item number	*Item*	*Alkylation*		
		Propylene feed (6–1)	*Butylene feed (6–2)*	*Butane isomerization (6–3)*
8.	**Alkylation capacity**	1·0	1·0	
9.	**Isomerization capacity**	—		1·0
44.	**Propylene**	0·56	—	
45.	**Isobutane**	0·72	0·64	1·0
46.	**Normal butane**	—	—	−1·0
47.	**Butylenes**		0·58	
49.	**Alkylate**	1·0	1·0	—

Table 7

MOTOR GASOLINE BLENDING

Item number	Item	*Motor gasoline components:* Straight-run, 100–250 F (7–1)	Straight-run, 250–400 F (7–2)	Visbreaker coker gasoline (7–3)	Catalytic cracked gasoline (7–4)	Reformate, 80 F-1 (7–5)	Reformate, 92 F-1 (7–6)	Iso-butane (7–7)	Normal butane (7–8)	Butylenes (7–9)	Iso-pentane (7–10)	Alkylate (7–11)	Motor gasoline product (7–12)
21.	Straight-run fraction, 100–250 F	1·0	—	—	—	—	—	—	—	—	—	—	—
22.	Straight-run fraction, 250–400 F	—	1·0	—	—	—	—	—	—	—	—	—	—
27.	Visbreaker coker gasoline	—	—	1·0	—	—	—	—	—	—	—	—	—
32.	Catalytic cracked gasoline	—	—	—	1·0	—	—	—	—	—	—	—	—
35.	Debutanized reformate, 80 F-1, clear	—	—	—	—	1·0	—	—	—	—	—	—	—
36.	Debutanized reformate, 92 F-1, clear	—	—	—	—	—	1·0	—	—	—	—	—	—
45.	Isobutane	—	—	—	—	—	—	1·0	—	—	—	—	—
46.	Normal butane	—	—	—	—	—	—	—	1·0	—	—	—	—
47.	Butylenes	—	—	—	—	—	—	—	—	1·0	—	—	—
48.	Isopentane	—	—	—	—	—	—	—	—	—	1·0	—	—
49.	Alkylate	—	—	—	—	—	—	—	—	—	—	1·0	—
50.	Motor gasoline product	1·0	1·0	1·0	1·0	1·0	1·0	1·0	1·0	1·0	1·0	1·0	1·0
51.	Reid vapour pressure of motor gasoline	10·0	2.0	10·0	10·0	3·0	3·0	65·0	65·0	65·0	22·0	5·0	10·0
52.	F-1, clear, motor gasoline	57·0	57·0	77·0	91·0	80·0	92·0	97·0	97·0	97·0	95·0	93·0	See figure 3
53.	F-1, 3 ml TEL, motor gasoline	75·0	75·0	87·0	97·0	93·0	100·0	105·0[a]	105·0[a]	105·0[a]	103·0[a]	107·0[a]	
54.	Tetraethyl lead (TEL)	—	—	—	—	—	—	—	—	—	—	—	

[a] F-1 numbers above 100 are based on the Wiese scale: $100 + \frac{\text{Performance number} - 100}{3}$

Table 8

AVIATION GASOLINE, JET FUEL, SOLVENTS AND NAPHTHAS

Item number	Item	*115/145 aviation gasoline:* Blend 1 (8–1)	Blend 2 (8–2)	Blend 3 (8–3)	*JP-4 jet fuel[a]:* Blend 1 (8–4)	Blend 2 (8–5)	Solvents and naphthas (8–6)
22.	Straight-run fraction, 250–400 F	—	—	—	−1·0	−0·50	−1·0
23.	Straight-run fraction, 400–550 F	—	—	—	—	−0·50	—
32.	Catalytic cracked gasoline	—	0·14	—	—	—	—
37.	Benzene, toluene, xylenes	—	—	0·88	—	—	—
48.	Isopentane	−0·12	−0·12	−0·12	—	—	—
49.	Alkylate	0·88	0·74	—	—	—	—
54.	Tetraethyl lead (TEL)	0·185	−0·193	0·193	—	—	—
55.	115/145 aviation gasoline	1·0	1·0	1·0	—	—	—
56.	JP-4 jet fuel	—	—	—	1·0	1·0	—
57.	Solvents and naphthas	—	—	—	—	—	1·0

[a] Additional quantities of JP-4 jet fuel could be obtained by using cracked materials in the 250–550 F boiling range. Use of these materials would depend upon either lowering jet fuel specification limits or installing hydrogen treating facilities.

Table 9

FUEL OILS

Item number	*Item*	*Kerosene (9–1)*	*Diesel fuel oil (9–2)*	*Distillate fuel oil* *Blend 1 (9–3)*	*Blend 2 (9–4)*	*Blend 3 (9–5)*	*Blend 4 (9–6)*	*Asphalt (9–7)*	*Residual fuel oil* *Blend 1 (9–8)*	*Blend 2 (9–9)*	*Blend 3 (9–10)*	*Blend 4 (9–11)*
23.	Straight-run fraction, 400–550°F	1·0	—	-1·0	—	—	—	—	—	—	—	—
24.	Straight-run fraction, 550–700°F	—	1·0	—	-1·0	—	—		—	—	—	—
25.	Straight-run fraction, 700–900°F	—	—	—	—	—	—	—	-1·0	—		0·50
26.	Straight-run fraction, 900°F+	—	—	—	—	—	—	1·0	—	—	0·60	0·50
28.	Visbreaker/coker gas oil	—	—	—	—	1·0	—	—	—	—	—	—
33.	Catalytic cracked gas oil	—	—	—	—	—	1·0	—	—	—	—	—
58.	Kerosene	1·0	—	—	—	—	—	—	—	—	—	—
59.	Diesel fuel oil	—	1·0	—	—	—	—	—	—	—	—	—
60.	Distillate fuel oil	—	—	1·0	1·0	1·0	1·0	—	—	1·0	0·40	—
61.	Asphalt	—	—	—	—	—	—	1·0	—	—	—	—
62.	Residual fuel oil	—	—	—	—	—	—	—	1·0	1·0	1·0	1·0

Table 10

Fuel inputs

Item number	*Item*	*Alternate fuel sources* *Petroleum coke (10–1)*	*Catalytic coke (10–2)*	*Hydrogen (10–3)*	*Methane (10–4)*	*Ethane (10–5)*	*Ethylene (10–6)*	*Propane (10–7)*	*Propylene (10–8)*	*Isobutane (10–9)*	*Normal butane (10–10)*	*Butylenes (10–11)*	*Residual fuel oil (10–12)*	*Coal (10–13)*	*Natural gas (10–14)*
10.	Refinery fuel	1·0	1·0	1·0	1·0	1·0	1·0	1·0	1·0	1·0	1·0	1·0	1·0	1·0	1·0
29.	Petroleum coke	−50·0													
34.	Catalytic coke		50·0		—										
39.	Hydrogen	—		11·0	—										
40.	Methane				29·0										
41.	Ethane					−31·0									
42.	Ethylene						−32·0								
43.	Propane							0·18							
44.	Propylene								-0·18						
45.	Isobutane								—	0·16					
46.	Normal butane										-0·16				
47.	Butylene											0·16			
62.	Residual fuel oil												-0·11		
63.	Coal													50·0	
64.	Natural gas														0·64

Tab

ILLUSTRATIV

(Crude charge=50,00

Item number	Item	Crude oil fractionation (2-6)	Catalytic cracking: Straight-run, 550-700 F (4-2)	Catalytic cracking: Straight-run, 700-900 F (4-3)	Catalytic cracking: Cycle fresh 0:50 (4-6)	Motor gasoline blending: Straight-run, 100-250 F (7-1)	Motor gasoline blending: Straight-run, 250-400 F (7-2)	Motor gasoline blending: Catalytic cracked gasoline (7-4)	Motor gasoline blending: Isobutane (7-7)	Motor gasoline blending: Normal butane (7-8)	Motor gasoline blending: Motor gasoline product (7-12)
1.	Primary fractionation capacity	50,000				—		—		—	—
5.	Catalytic cracker capacity		—		22,500	—				—	—
10.	Refinery fuel	50,000				—				—	—
16.	Crude oil, 30 API	50,000				—	—		—	—	—
21.	Straight-run fraction, 100-250 F	5,000				5,000	—	—	—	—	—
22.	Straight-run fraction, 250-400 F	7,000				—	6,000			—	—
23.	Straight-run fraction, 400-550 F	8,000				—	—		—	—	—
24.	Straight-run fraction, 550-700 F	8,000	5,500			—	—	—	—	—	—
25.	Straight-run fraction, 700-900 F	9,500		9,500	—	—	—	—	—	—	—
26.	Straight-run fraction, 900 F	12,500		—	—	—		—		—	—
[illegible]	Catalytic cracking charge stock		5,500	9,500	15,000	—		—		—	—
32.	Catalytic cracked gasoline				8,100	—		—	—	—	—
33.	Catalyac cracked gas oil			—	4,650	—	—	8,100	—	—	—
34.	Catalytic coke				255,000	—	—	—	—	—	—
39.	Hydrogen				9,000	—			—	—	
40.	Methane				84,000			—	—	—	—
41.	Ethane				67,500	—			—	—	—
42.	Ethylene				79,500	—		—	—	—	—
43.	Propane				285		—	—	—	—	—
44.	Propylene				690	—	—	—		—	—
45.	Isobutane				990	—			750	—	—
46.	Normal butane				150	—	—	—	—	150	—
47.	Butylenes				735	—	—	—	—	—	—
50.	Motor gasoline product					5,000	6,000	8,100	750	150	20,000
51.	Reid vapour pressure of motor gasoline				—	50,000	12,000	81,000	48,750	9,750	200,000
52.	F-1, clear, motor gasoline					285,000	342,000	737,000	72,750	14,550	1,451,300
53.	F-1, 3 ml TEL, motor gasoline					375,000	450,000	786,000	78,750	15,750	1,705,500
54.	Tetraethyl lead (TEL)					—	—	—	—	—	756
56.	JP-4 jet fuel						—	—	—	—	—
59.	Diesel fuel oil						—	—	—	—	—
60.	Distillate fuel oil						—	—	—	—	—
62.	Residual fuel oil					—	—	—	—	—	—
65.	Sulphuric acid (100 per cent H_2SO_4)	57,500				—	—	—	—	—	—
66.	Caustic soda (100 per cent NaOH)	10,500		—		—	—	—	—	—	—
67.	Electrical energy	185,000			—	—	—	—	—	—	—
68.	Peak electric power	8,000		—	—	—	—	—	—	—	—
69.	Manpower	1,000	—	—	—	—	—	—	—	—	—

AMPLE

arrels per day 30° API)

JP-4 Jet fuel: blend 2 (8–5)	Diesel fuel oil (9–2)	*Distillate fuel oil* Blend 1 (9–3)	Blend 4 (9–6)	Residual fuel oil blend 3 (9–10)	*Fuel sources* Catalytic coke (10–2)	Residual fuel oil (10–12)	Net inputs (−) or outputs	Item	Item number
—	—	—	—	—	—	—	−50,000 barrels of daily charge	Primary fractionation capacity	1
—	—		—	—	—	—	−22,500 barrels of daily charge	Catalytic cracker capacity	5
—	—		—	—	5,100	44,900	0 700,000 BTU per day	Refinery fuel	10
—	—	—	—	—	—	—	−50,000 barrels per day	Crude oil, 30° API	16
—	—	—	—	—	—	—	— 0 barrels per day	Straight-run fraction, 100–250° F	21
1,000	—	—	—	—	—	—	0 barrels per day	Straight-run fraction, 250–400° F	22
1,000	—	−7,000	—	—	—	—	0 barrels per day	Straight-run fraction, 400–550° F	23
—	−2,500	—	—		—	—	0 barrels per day	Straight-run fraction, 550–700° F	24
—	—	—	—	—	—	—	0 barrels per day	Straight-run fraction, 700–900° F	25
	—	—	—	12,500	—	—	0 barrels per day	Straight-run fraction, 900° F +	26
	—	—	—	—	—	—	0 barrels per day	Catalytic cracking charge stock	31
	—	—	—		—	—	0 barrels per day	Catalytic cracked gasoline	32
	—	—	4,650	—	—	—	0 barrels per day	Catalytic cracked gas oil	33
	—	—	—	—	225,000	—	0 pounds per day	Catalytic coke	34
	—	—	—		—	—	9,000 pounds per day	Hydrogen	39
	—	—	—		—	—	84,000 pounds per day	Methane	40
	—	—	—	—	—	—	67,500 pounds per day	Ethane	41
	—	—	—	—	—	—	79,500 pounds per day	Ethylene	42
	—	—	—	—	—	—	285 barrels per day	Propane	43
	—	—	—	—	—	—	690 barrels per day	Propylene	44
—	—	—	—	—	—	—	240 barrels per day	Isobutane	45
—	—	—	—	—	—	—	0 barrels per day	Normal butane	46
	—	—	—	—	—	—	735 barrels per day	Butylenes	47
	—	—	—	—	—	—	0 barrels per day	Motor gasoline product	50
	—	—	—		—	—	0 RVP-barrels per day	Reid vapour pressure of motor gasoline	51
	—	—	—	—	—	—	0 octane-barrels per day	F-1, clear, motor gasoline	52
	—	—			—	—	0 octane-barrels per day	F-1, 3 ml TEL, motor gasoline	53
—	—	—	—	—	—	—	−756 litres per day	Tetraethyl lead (TEL)	54
2,000	—	—	—	—	—	—	2,000 barrels per day	JP-4 jet fuel	56
—	2,500	—	—	—	—	—	2,500 barrels per day	Diesel fuel oil	59
	—	7,000	4,650	8,300	—	—	3,350 barrels per day	Distillate fuel oil	60
—	—	—	—	20,800	—	4,950	15,850 barrels per day	Residual fuel oil	62
—	—	—	—	—	—		−57,500 pounds per day	Sulphuric acid (100 per cent H_2SO_4)	65
—	—	—	—	—	—	—	−10,500 pounds per day	Caustic soda (100 per cent NaOH)	66
—	—	—	—	—	—	—	−185,000 kilowatt-hours per day	Electric energy	67
—	—	—	—	—	—	—	− 8,000 kilowatts	Peak electric power	68
	—	—	—	—	—	—	−1,000 employees	Manpower	69

05112

Repair and Maintenance of Machine Tools in the Developing Countries

By ALEKSANDR S. PRONIKOV

REGARDLESS OF THEIR *stage of development and the course of development they have chosen, and whether or not they possess particular branches of industry, developing countries setting out on the path of independent industrial development suffer an acute shortage of industrial equipment and machinery of various kinds. Many developing countries are already being obliged – and still more will be so in the future – to import various kinds of equipment, machine tools and other machinery while at the same time establishing their own industries to produce these goods. The existing stock of machinery and industrial equipment in the developing countries will thus considerably increase. As a result, the developing countries are being confronted with problems of repairing and maintaining all this stock of machinery, machine tools and industrial equipment. Proper scientific organization of the repair and maintenance of a country's machinery and industrial equipment can considerably extend the latter's useful life and thus meet part of the constantly growing demand for new machine tools and equipment.*

Metal-working machine tools occupy a central place in the entire complex of industrial equipment and machinery. Without a stock of efficient machine tools industrial development is inconceivable in any country. The experience of the developed countries shows that the useful life of machine tools can be quite long. There are machine tools now in use in developed countries that were built over twenty years ago, and in some cases even earlier. According to the American Machinist Metalworking Manufacturing *of 13 May 1963, the number of machine tools over ten years old in the United States in 1963 amounted to 64 per cent of the country's entire stock, and the corresponding figure for the United Kingdom was 59 per cent, for France 58 per cent, for the Federal Republic of Germany 55 per cent and for the Union of Soviet Socialist Republics 50 per cent. Nearly one out of every five machine tools in these countries is over twenty years old.*

A well-organized repair and maintenance system is an essential need of every stage of industrial development.

INTRODUCTION

MACHINE TOOLS, TOGETHER with welding equipment, occupy a special position in relation to other machinery, such as that used in the textile industry, transport, light industry, printing and so on. Machine tools are used to produce parts of other machines, that is, to manufacture new machines and instruments and repair existing ones.

A country's stock of machine tools—its technical level, structure and condition—to a considerable extent determines the national productive capacity and ability to solve technical and economic problems independently.

The structure and growth of the machine tool stock are closely connected with a country's level of industrialization. As the country develops, it continues to use general-purpose machine tools of normal accuracy, but it makes increasingly extensive use also of precision tools, automatic tools and lines, specialized tools for specific branches of mechanical engineering, and heavy tools for parts of large machines.

Thus, the figures in table 1 show the number of types of machine tools put into production in the Soviet Union since the establishment of a domestic machine tool industry, and indicate how the Soviet Union's need for machine tools has grown as its industry has developed.

PROFESSOR PRONIKOV, *Doctor of Sciences in Machine Tool Design, Professor of Mechanical Engineering and Rector at the Moscow Institute of Aircraft Technology, was engaged as a consultant to the Centre for Industrial Development to prepare this study for submission to the Committee for Industrial Development at its fifth session. He is known for his work on the reliability of machine tools and their maintenance, and for his theoretical research on the wear of machine parts and on optimum parameters for a planned preventive maintenance system.*

Table 1

Category of machine tools produced	*Number of types in serial production in the USSR*							
	1932	*1937*	*1940*	*1945*	*1950*	*1955*	*1958*	*1965 (planned)*
Precision		4	7	9	41	100	115	180
Automatic and semi-automatic	7	42	87	40	115	250	295	650
Specialized	6	39	54	47	141	346	370	620
Heavy	3	5	29	12	90	247	180	420
TOTAL, ALL TYPES	47	190	320	130	384	788	900	1,500

Given a stock of machine tools, the problem arises of how to use them most efficiently and extend their useful lifetime as long as possible. This can be achieved only through the organization of a special repair and maintenance system. This is a very serious problem, for modern machine tools are highly complicated machines which include precision devices, hydraulic and electrical systems, high-speed and power transmission systems, and automatic and control devices.

The functioning of a machine tool's units and mechanisms depends to a considerable extent on the methods used of operating, maintaining and servicing it. If insufficient thought is given to these methods, great waste of resources and, most important, of foreign exchange can result. Such waste is due to two factors which arise when individual units and mechanisms are taken out of service prematurely.

First, there is an increase in the amount and, accordingly, the cost of repair work. Often the repairs may entail importing spare parts. When the failure occurs in a complicated precision part, such as a precision lead screw, the bushings of a jig borer, a reading mechanism or the like, it is not always possible to repair and recondition it locally. This may be avoided by adequate methods of operation and servicing.

Secondly, wear and breakdowns increase idle time in repair and reduce the tool's use coefficient. Consequently, extra machine tools have to be acquired to do the same

Technician adjusting a horizontal turret lathe in a United States automobile factory

amount of work, and shop space has to be increased correspondingly.

Furthermore, improperly repaired and maintained machine tools may fail to meet their technical specifications, particularly as regards accuracy.

Thus, it is important not merely to acquire a stock of machine tools but also to maintain it in efficient condition, which can be done by applying a repair and maintenance system and developing methods of increasing the reliability and durability of equipment.

It is important to train national personnel armed with modern technical ideas in this field.

THE ECONOMIC ASPECT OF THE MAINTENANCE AND REPAIR OF MACHINE TOOLS

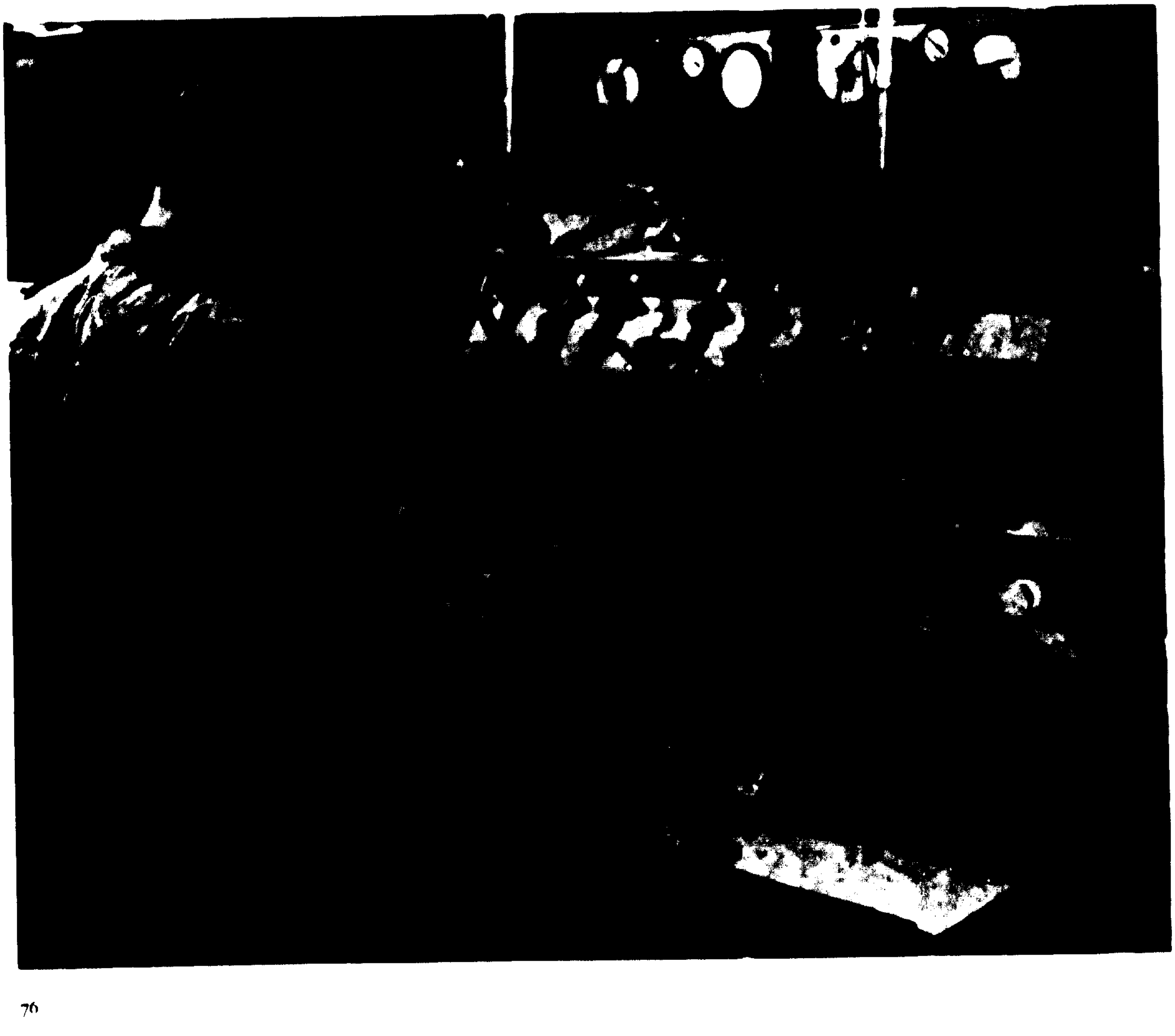
Expenditure on the repair and maintenance of equipment accounts for a considerable proportion of production costs. Research has shown that every year approximately 10 per cent of the stock of technical equipment undergoes major overhaul, 20 to 25 per cent intermediate overhaul and 90 to 100 per cent minor overhaul.

The loss of time and resources in keeping the stock of machine tools in good order is substantial, depending to a great extent on methods of operating and servicing the machines and the technology and organization of maintenance. For example, in an average-sized or small enterprise the cost of major overhaul alone is normally up to 60 per cent of the cost of a new machine in the case of medium-sized turning lathes, up to 40 per cent in the case of universal milling machines and up to 75 per cent in the case of capstan lathes. It must also be remembered that before the major overhaul a machine tool undergoes two intermediate overhauls, each of which takes about half as much labour as a major overhaul, and six minor overhauls, each of which takes about a quarter as much labour as a major overhaul.

In addition, machine tools are periodically checked for accuracy, lubricated and given preventive treatment.

Thus, the cost of maintaining and servicing a machine tool during one maintenance cycle (that is, up to and including the major overhaul) is greater than the cost of a new machine, and if maintenance and repair is badly organized can be several times greater.

Operator at work on a grinding machine in a United States factory



Operating a small milling machine in a workshop in Bombay, India

A factor of no less importance in evaluating the economics of maintenance is the idle time lost by equipment during the various kinds of overhaul.

As an example, let us consider the periods of enforced idleness for maintenance work on screw-cutting lathes and cylinder-and-core grinding machines of average size and complexity of design. These data are taken from the standards for machine tool maintenance applied in the Soviet Union (1)[1] under which maintenance of all equipment is carried out in accordance with a special system known as the "planned preventive maintenance system".

The figures given in table 2 are for maintenance teams working a single shift, and indicate how many days a machine tool must remain idle for the given type of maintenance.

As was stated above, under the present maintenance system a machine tool undergoes two intermediate and six minor overhauls before its major overhaul. Accordingly, the number of days which a screw-cutting lathe, for example, will lose for maintenance from the time it is put into operation until its major overhaul is completed (i.e., over into the period of the maintenance cycle) will be:

$$11+6{\cdot}5\times2+2{\cdot}75\times6=40 \text{ days.}$$

Table 2

Type of maintenance	*Lathe*	*Cylinder-Grinding machine*
Major overhaul	11	18
Intermediate overhaul	6·5	11
Minor overhaul	2·75	4·5
Accuracy checks	1	1·5

A machine's operating life before major overhaul, and similarly between intermediate overhauls, depends to a large extent on the methods of operation. For example, a screw-cutting lathe working single shifts at a series production factory and turning out steel parts to a normal degree of accuracy will have a working life before major overhaul of four to nine years.

If the machine tool runs for eight years before major overhaul, it follows that the time lost for maintenance will amount to an average of five days a year. If the shop has sixty machines with the same average maintenance complexity as a screw-cutting lathe, the total idle time will be 300 days, that is, the maintenance crew will have to work steadily all year round on maintaining the machines (not allowing for lubrication and preventive and other measures).

If, because of insufficient attention to operating methods, the maintenance cycle is four years the relative volume of maintenance work will be twice as great.

These figures show that great attention must be given to methods of maintaining and operating equipment. We have to know the reasons why a machine tool loses its efficiency, and the methods by which its reliability and durability can be increased; and in maintaining equipment up-to-date technological processes and methods must be applied. In addition, the equipment maintenance system must be so organized as to act in advance to reduce the progressive wear of equipment, bring maintenance costs to a minimum and ensure the proper preparation and planning of maintenance work and the efficient use of equipment.

CAUSES OF LOSS OF EFFICIENCY IN MACHINE TOOLS

In approaching machines and mechanical systems, the classical sciences such as mechanics attempted to idealize the conditions in which they functioned. The errors and inaccuracies caused in the actual performance of a machine by component wear, temperature deformation, defective materials, technological factors, etc. were viewed as aberrations from the performance of the perfect machine and as undesirable and fortuitous phenomena.

Modern science, particularly cybernetics, takes a different view of the errors in a given system. Errors and inaccuracies in a machine's execution of an assigned programme (a technological process, for example) are regarded as a natural feature of any real system. The need thus arises to investigate the sources and causes of adverse influences acting on machines and to study the machines' reactions to them.

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[1] Figures in parentheses relate to the entries in the bibliography at the end of this article.

A machine cannot be completely isolated from the effects of its environment, nor can it be isolated from the influence of the processes going on within itself as it functions.

The units and working parts of a machine tool in an industrial shop are subject to the influence of energy in all its forms, which affect its technical performance.

Mechanical energy is not only transmitted through the various working parts of the machine as it performs the given technological process but also acts on the machine as a whole in the form of vibrations transmitted by other equipment running in the shop, vibrations generated as the machine is fed material, and so on.

The forces at work in the machine are the product both of the technological process and of such forces as those arising from friction in kinematic couples or inertia in moving parts. These forces cannot be strictly defined since the very nature of their occurrence is bound up with complex physical phenomena.

It is, indeed, this degree of indefiniteness of the influences at work that gives rise to the errors and inaccuracies in the operation of mechanical systems.

Furthermore, even a constant force produces wear, deformation and fatigue, that is, causes a component's parameters to change with time.

Thermal energy affects machine parts as a result of fluctuations in shop temperature, the operation of driving gear or electrical equipment, or heat generated during the cutting process.

These phenomena, too, affect the operation of both individual working units and the entire machine. Studies have shown, for instance, that as little as two hours' exposure to the sun (at mean latitudes) of the face of a cylinder-and-core grinding machine produces a shift in the table guides, causing the table to deviate 45 microns from true linear displacement. Performance can be affected even more by the heat generated in electric motors, bearings, gear-boxes, hydraulic systems and the like. Thus, oil heating in the hydraulic systems of power heads in standard-unit machine tools can increase oil losses and decrease feed. As a result, the duration of the working cycle in the machine or automatic machine line spontaneously increases and productivity falls. It is practically impossible to make accurate allowance for thermal effects.

Chemical energy also has an effect on machine performance. Air containing moisture and aggresive elements can cause corrosion in various machine parts. Emulsion used to cool a tool may drip on to essential machine parts, especially the electrical system, causing premature failures.

Operating a numerically controlled vertical milling machine in a United States plant

Electromagnetic energy in the form of radio waves (electromagnetic oscillations) permeates the space around a machine, and may affect the performance of the electronic apparatus which is being increasingly employed in modern machine tools.

Thus, all forms of energy attack the machine and its working parts, initiating a great many undesirable processes and creating conditions making for technically inferior performance.

Before dealing with the methods by which these harmful influences may be combated, let us briefly examine the processes that cause a machine to lose its working efficiency.

Some processes occurring in a machine and affecting its performance are *reversible*, since they alter the parameters of parts, units and the entire system within given limits without tending to cause progressive deterioration.

The most typical example of a reversible process is the *deformation* of machine parts and units which occurs under the influence of external or internal forces. The sources of deformation in machine tools include not only deformation of the parts themselves but also deformation at surface junctions, such as slideways, bearings and other linkages. Deformation of parts and junctions alters the relative positions of machine units, including the position of the tool and the workpiece. The result is a loss of precision, the machine's most important technical feature. When the forces change, so does the deformation, and when the stress is removed elastic recovery takes place and the machine parts return to their original positions. It is for this reason that the deformation process is regarded as reversible.

If circumstances arise in which the forces change periodically and very frequently, vibration of the machine units occurs, that is, rapid deformation changes of minor magnitude. Vibration also seriously affects the quality of work. It usually results in inferior surface finish.

Another example of a reversible process is the *temperature deformation* of machine parts and units.

Heat production in the cutting zone or in friction couplings and ambient temperature variations lead to temperature deformations which alter the original positions of machine units and consequently reduce precision. Thus, observation of the position of a lathe spindle has shown that after some hours of operation (three to seven hours) the spindle is gradually displaced owing to the heating up of the headstock face. The displacement reaches 20 to 120 microns and then stops, a certain degree of heat exchange being established. After the machine has been switched off the spindle gradually returns to its former position.

Machine tools can sometimes be adjusted to reduce inaccuracies due to temperature deformation, but this makes their operation more difficult.

Accuracy of work is particularly affected by temperature deformation in precision units and framework members.

Whereas reversible processes occurring in a machine tool lower its efficiency as compared with its potential performance in the absence of deformation, temperature effects and the like, *irreversible processes* result in the progressive deterioration of the machine's performance with time.

The most typical irreversible processes in machines are wear, corrosion, the gradual redistribution of internal stresses, and creep (the slow building up of deformations).

The most important cause of loss of efficiency in machine tools is wear of machine parts. Wear is the result of a process of gradual change in the dimensions of machine part surfaces under the influence of friction. The process of wear arises out of numerous complex physical phenomena occurring on the friction surfaces of machine parts. As the surfaces interact they deteriorate and give off minute particles. At various points of contact the temperature rises, changes occur in the structure of the surface layers and there develop chemical processes and processes connected with the molecular attraction of the contiguous materials.

The most common types of wear met with in machine tools are the following.

Abrasive wear, in which abrasive particles found on friction surfaces attack the surfaces by cutting or scratching and produce tiny chips. The particles usually enter the lubricating fluid from the outside and travel with it to the friction surface, but they can also be produced by wear in the couple itself, or they may be hard structural components at one of the abutting parts. In many cases, therefore abrasive particles cannot be completely eliminated from the friction surfaces of machine parts. Even with efficient oil filtration and the isolation of friction surfaces, conditions for abrasive wear continue to be present. (2)

Fatigue in surface layers manifests itself in the scaling of minute particles of metal from the contact surfaces of machine parts. The appearance of fatigue in the surface layers does not mean the complete breakdown of the part, but there is usually a speeding up of the destructive process (gradual chipping).

Plastic deformation (warping) of surface layers is usually manifested in a displacement of the metal beyond the contact surface. It occurs as a friction, accompanying the process of wear, and in the absence of relative sliding motion. This type of failure is typical of materials having plastic properties.

In practice, the various kinds of surface deterioration develop concurrently, rarely occurring in pure form. To each type of friction surface there corresponds a basic form of deterioration, determined by the mechanical properties of the material, the lubricant, the magnitude of the stresses applied, the operating speed and other factors.

All processes occurring in a machine, whether reversible or irreversible, affect its performance, causing errors, reducing the quality of the technological process and necessitating periodic overhaul.

PRINCIPAL METHODS OF INCREASING THE DURABILITY AND RELIABILITY OF MACHINE TOOLS

A machine tool's reliability and durability are the indicators of its performance as a function of time: that is to say, they define the magnitude and nature of the changes in its main characteristics which take place in the course of its operation.

A machine tool must have high initial qualitative and quantitative indicators; but that alone is not enough to make it an efficient machine. Those indicators must be maintained in the course of its operation.

The *durability of a machine tool* is its ability to carry out its operational functions with minimum expenditure for the replacement of worn parts, readjustment, repairs and servicing. The smaller the total money and time spent on maintaining the efficiency of the machine tool throughout its period of use, the greater its durability.(3)

As the indicator of a machine tool's durability, we may use the coefficient of durability η_{D}, which equals the ratio of the operating time to the sum of the operating time and the time the machine is out of action for repair:

$$\frac{T_0}{T_0+T_2} = \frac{1}{1+\sum_{i=1}^{n}\frac{\tau_i}{T_i}}, \qquad (1)$$

where T_0 is the operating time of the machine tool;

T_2 is the time the machine tool is out of action for repair;

T_i is the service life of the n^{th} part or unit of the machine tool;

τ_i is the time (amount of work) required to repair the n^{th} part or unit, including dismantling, reassembly and adjustment;

n is the number of repairable parts of the machine tool.

The coefficient of durability may vary from 0 to 1. The higher its value, the more durable the machine tool.

The time the machine tool is out of action depends on the service life of its component parts and units and the amount of work required to repair them.

Stoppages of the machine tool which lower its coefficient of durability may have the following causes: breakdown of individual parts; loss of efficiency of drives and mechanisms; changes in the initial service characteristics of the machine tool (precision, freedom from vibration), and so forth.

The coefficient of durability should be calculated on the basis of the machine's entire period of operation, or, at least, of a period equivalent to the length of its maintenance cycle (the length of time before a major overhaul becomes necessary).

The *reliability of a machine tool* is the indicator of its ability to carry out its functions continuously for a given period of time.

Uninterrupted operation is an important requirement for present-day industrial equipment. Flowline methods of production, where the work is transferred from machine to machine, and automatic production lines make it essential for every unit to operate without interruption.

The reliability of a machine tool is determined on the basis of indices of probability. It may be defined as the probability (p) that the machine will operate without breakdown for a given length of time under normal operating conditions. If the probability that a machine tool will operate for one year without breakdown is $p=0{\cdot}95$, for example, this means that out of a large number of machine tools of the model in question an average of 5 per cent will lose their efficiency in less than one year of operation.

What does "loss of efficiency" or, as it is called in reliability theory, "failure" mean in relation to machine tools? Does a "failure" occur, for example, when it becomes necessary to change a drive belt or adjust a clutch?

The meaning of "failure" must be defined in the light of analysis of the operating and servicing methods used for machine tools of the given type. Brief "interventions" by the operator in the work process and the adjustment of the machine tool, when provided for in the servicing instructions and resulting from the relative imperfection of the machine tool itself, should not be included under the heading of "failure" (breakdown).

Thus, for example, the adjustment and replacement of a tool, the adjustment of individual mechanisms and preventive maintenance are included in the standard running adjustments and between-overhaul servicing of many present-day machine tools.

The more highly perfected a machine tool is, the fewer such "legitimate" stoppages it will have and the more suitable it will be for continuous operation. In order to assess the reliability of a machine tool, therefore, we have to take into account all interruptions of its operation (stoppages) which are not provided for in the servicing plan.

The most convenient period of time to select for the operation of the machine tool with a given degree of reliability is the period between two scheduled overhauls. The higher the guaranteed probability of operation without failure (p), the more reliable the machine tool.

Of great importance for machine tools is reliability from the point of view of output quality, that is, from the point of view of ensuring the desired precision of machining and quality of surface finish.

The ***production reliability of a machine tool***, which is an index of its capacity to continue to satisfy the qualitative requirements of the production process for a given length of time, can also be evaluated from the probability that the machine tool will satisfy those requirements throughout the period between overhauls or for the period before intermediate overhaul, at which any loss of precision by the machine tool is made good.

Reliability and durability are the characteristics which define a machine tool's capacity to realize its technical potential in actual operation, its serviceability and its degree of perfection. To improve the reliability and durability of machine tools, we have to combat the harmful influences which result in loss of efficiency.

The designer, the technician and the operator always have at their disposal a number of ways of achieving high indices of reliability and durability.

First of all, the machine must have *high resistance to external influences*. The units and mechanisms which make it up must be sufficiently sturdy, must be built on the frame principle, must have the smallest possible number of members, etc., so that they will withstand loads, undergo the least possible deformation and be as free as possible from vibration. Wear-resistant anti-friction materials must be used for friction couples, while all points of friction must be protected from dirt and thoroughly lubricated. Observance of these rules lays the foundations for good wear-resistance.

The causes of possible failure must be borne in mind in the design of the entire machine tool and its units, and precision mechanisms must be protected from shocks and other influences.(4)

The correct placement of driving gear, symmetry of design and the use of materials with low coefficients of linear expansion help to improve a machine tool's resistance to temperature deformations.

Corrosion is combated by protecting the machinery with special coatings and paints and by the use of additives in oils and coolants.

The above and other similar measures will result in the production of highly perfected machine tools of advanced technical performance.

The latest advances in mechanical engineering, materials and chemistry (lubricants and plastics) are continually being brought into use in up-to-date machine construction.

The possibilities of combating harmful processes are not unlimited, however. There are no completely wear-resistant materials, it is practically impossible to exclude all but liquid friction in all mechanisms and there are no materials which do not suffer deformation and do not change their dimensions with temperature fluctuations.

When it is also borne in mind that the sources of internal and external influences on the machine tool remain and that increasingly exacting demands are being made as regards output quality, it will be seen that the above methods of combating harmful influences, while essential, are inadequate, being limited by the level of development of one or another field of technology—for example, by the possibilities of producing wear-resistant materials.

The second way to increase the reliability and durability of machine tools is *to use the most highly rationalized methods of operating and maintaining equipment*.

The method of operation of a machine tool to a great extent determines its rate of wear and the rate of development of other processes resulting in loss of efficiency.

Systematic supervision of the functioning of the machine tool and of the lubrication of its moving parts, prompt adjustment of its various mechanisms, regular care and protection from accidental blows and damage are all essential conditions if the machine is to have the durability for which it was designed.

The system of planned preventive maintenance in operation in Soviet factories embraces not only overhaul operations proper, but also a complex of preventive operations which form part of the inter-overhaul servicing system.

Both the machine tool operator and the members of the maintenance staff (fitters, greasers, belt-drive servicemen and electricians) take part in the inter-overhaul servicing operations.

Inter-overhaul servicing includes checks to ensure that the equipment is in good condition, that it is being operated correctly, that necessary adjustments are being made and minor faults corrected and that proper lubrication is maintained.

In addition, the services included in the periodical overhauls, such as cleaning, changing the oil and flushing the lubrication system, and checking the equipment for precision and rigidity, also help to create proper conditions for correct operation.

In the operation of equipment, the protection of friction surfaces from dirt is of great importance.

The protection of friction surfaces from atmospheric dust, abrasives and chips from the work material considerably affects their wear-resistance.

It is particularly important to protect the surfaces if the surrounding atmosphere has a high abrasive content. For example, when polishing machines are in operation abrasive particles from the polishing discs accumulate in great quantities in the air and on the surfaces of the machines.

In such working conditions, therefore, rational operating procedures are extremely important, i.e., changing and filtering of lubricants, protection of mechanisms from abrasives, removal of dust from the working area, removal of the products of grinding and polishing, for example, by magnetic separation, and others.(5)

The nature of the material being worked is an important factor in the fouling of the machine surface.

When cast iron is worked on lathes, milling machines or other machine tools, damage is caused by scale or particles of grit falling on to the mechanisms; in the case of aluminium alloys, the harmful elements are hard aluminium oxides. Thus, the rate of wear of lathe slides in light machining operations, even with shields (which only partially protect the slides), is three to four times higher in the machining of aluminium alloys than in that of steel or cast-iron parts.

This demonstrates the need for more effective ways of protecting the slides in the machining of aluminium.

In some factories machine tools may be seen operating without slide shields, the slides being protected only by felt padding. Measurements have shown that in such cases slide wear is two to three times greater.

In machine tool operation, therefore, careful attention should be given to the use of various protective devices to prevent fouling of key parts.(6)

It is of great importance when operating machine tools to ensure that the lubrication system functions without interruption. Defects in the lubrication system may cause accelerated wear and the breakdown of key parts of the machine. For example, if the flow of oil to the spindle of a polishing machine is cut off, not only are the sleeve bearings damaged but the spindle is often heated to the point where heat cracks appear on its surface and it breaks down. While working with machine tools, operators have noticed that abrasive and other dusts in a state of suspension in the air settle on the bed guides and combine with the oil to form an abrasive mixture.

This accelerates the process of wear, especially if the machine with oiled slides has been idle for a time. The extent of wear may increase by 30 per cent. For this reason experienced workers clean the slides thoroughly at the beginning of their shifts, particularly after non-working days.

Wear depends on the hardness of the abrasives falling into the lubricant. In ascending order of abrasive capacity these particles may be rated as follows: steel and cast-iron filings; scale; grit; and cutting particles from polishing discs.

It is also desirable when operating machine tools to check the wear of their key parts, particularly the slides. This may be done with special wear gauges developed in the USSR, (7,3) which measure precisely the amount of wear of the slides in industrial operation. The extent to which deterioration can be corrected depends on the methods and technological processes employed in machine tool maintenance. In wear-resistance, accuracy and other characteristics, reconditioned parts or units should be as good as new ones.

The system of maintenance should be so organized that the restoration of the efficiency of equipment requires a minimum expenditure of time and resources.

A third way of improving and maintaining the technical characteristics of a machine tool is *to isolate the machine from harmful external influences*. This method is particularly applicable in the case of precision machines which are required to turn out a high-quality product.

Thus, in order to reduce temperature deformation, precision machines are placed in special temperature-controlled rooms or shops equipped with special devices to maintain the desired temperature, usually 20° C.

For example, co-ordinated boring machines, which are required to be exceptionally accurate in performance, are generally operated in temperature-controlled rooms; where that is not possible, each machine is placed in a separate room, where is can be better isolated from temperature changes, dust in the atmosphere and the vibrations of other machines.

Insulating machines from vibrations is also one of the methods of increasing their precision. Many machine tools and other machines and equipment operating in any part of a factory subject the bed on which they rest to periodic stresses. The resulting vibrations are transmitted to other machine tools and if they reach a certain degree of intensity and frequency they can lower the quality of performance of the latter substantially.

The usual method of insulating machine tools from vibrations it to set them on individual beds, 2 to 3 metres deep in the case of medium-size precision machines and up to 5 to 6 metres deep in the case of some heavy and special-purpose machines.

Although placing the machine tool on an individual bed considerably improves its resistance to vibration, the process is a laborious one and makes it difficult to move the equipment about in the shop.

To an increasing extent machine tools are being placed on special resilient supports or vibration dampers. The resilient component consists of steel springs or grids, plastic packing, rubber, cork, etc. If they are given the proper degree of rigidity, they damp vibrations transmitted from other machines and equipment.

Devices for removing dust from the air and strict atmospheric dust control are other widely used means of improving the accuracy of performance of machine tools. In some cases standards are set specifying the permissible quantity of dust particles per cubic centimetre of air. This procedure not only is essential in connexion with the manufacture and assembling of certain key parts of instruments but also helps to maintain the efficiency of the machine tools themselves, since it considerably reduces the quantity of abrasives which can fall on their friction surfaces.

Isolating the machine tool from temperature changes, vibrations, dust and other external influences increases its efficiency but this method, too, has its limitations.

First, internal causes of error remain, such as the heat generated by the working mechanism of the machine tool, abrasive particles produced by wear of the machine's parts, and vibrations produced by cutting and by the operation of the mechanisms of the machine itself.

Secondly, complete isolation is difficult to achieve because external influences are variable and to a certain extent indeterminate in nature. Thus, the intensity and character of external vibrations affecting the tool depend on the operation of other machines and vary quite widely, while insulation from vibration is most effective only for vibrations of certain frequencies.

Thirdly, and lastly, the very principle of isolation from external influences stems from an old non-cybernetic view of mechanical error as something which can be eliminated.

For these reasons there has been a growing tendency in recent years to use a fourth means of improving the efficiency of today's complicated machine tools, namely, *the use of special mechanisms which automatically regulate the parameters of the machine*. The use of these mechanisms makes it possible to maintain the fundamental characteristics of the machine over a long period of use, through interaction with the environment, through the automatic reaction of the machine to changes in its operating conditions.

Like a living organism, a complicated machine should possess the function of automatically recovering its lost efficiency.

Such mechanisms are already being used on machine tools, ranging from the simplest devices which automatically eliminate gaps produced by wear, break the kinematic circuit in case of overloading and ensure uniformity of stresses within the mechanism, to systems which restore accuracy of performance, replace worn-out tools, react to the effects of temperature, etc. For example, the following are coming into use: automatic regulation of the kinematic precision of the rolling chain in gear-cutting machines; automatic regulation of the thickness of the oil layer in the slides in vertical boring and turning machines; active control and automatic minor adjustments in polishing machines; automatic elimination of vibration and imbalance in lathes; automatic compensation for wear in the tables of certain types of machine tools, and other self-regulation systems.(8) These automatic regulation systems are opening up broad prospects for the development of reliable and long-lasting machines, but they require that even closer attention be paid to the methods of maintaining and operating them. The more complicated the equipment used and the better its quality, the more important the correct organization of machine tool servicing and maintenance becomes.

ORGANIZATIONAL PRINCIPLES FOR MACHINE TOOL MAINTENANCE AND SERVICING SYSTEMS

In order to keep equipment permanently in working order with the minimum expenditure of time and resources, it is necessary to institute a maintenance system with strict rules concerning the basic measures to be taken for this purpose.

In the Soviet Union, a uniform planned preventive maintenance system has been specially worked out for and is applied in all branches of industry. Now thirty years old and steadily improved, this system has shown its great possibilities and the correctness of the underlying organizational principles.

The basic principles are as follows.

1. All operations necessary to keep equipment in working order are divided into two groups: (*a*) servicing in the intervals between overhauls, which includes regular checking of the equipment and correction of faults, preventive measures, adjustment of mechanisms, and sometimes replacement of quick-change parts, and (*b*) periodic overhauls, which are carried out in accordance with a plan laid down in advance and which represents the bulk of maintenance operations.

2. The latter are subdivided into various types depending on the scale of the operations. There are usually three types of overhaul: minor (type I); intermediate (type II), and major (type III). A machine tool which has undergone major overhaul must be able to meet all the basic demands placed upon a new tool.

3. All overhauls of a particular model of machine tool under the plan are carried out at regular intervals, the intervening periods being called "intervals between overhauls". The length of the interval is one of the main characteristics of the maintenance system and depends on the type of machine tool and its operating conditions.

4. The maintenance system also fixes the pattern of the maintenance cycle, that is, the number of planned overhauls and the order in which they are carried out. Most machine tools now have a cycle of nine planned overhauls, in the following order: I–I–II–I–I–II–I–I–III.

This pattern is the same for all types and models of metal-cutting lathes and all operating conditions. The period of time over which it is completed, i.e., the period from one major overhaul to the next, is known as the maintenance cycle.

5. The expenditure of labour for a given type of overhaul is indicated by the number of machine-hours and man-hours allocated for it under the plan.

The relationship between the volumes of major, intermediate and minor overhaul work is the same for all machine tools.

6. Machine tools are broken down into different categories according to their degree of complexity. Each category is assigned a conventional coefficient which compares the labour consumed by a machine tool in that category with the amount consumed by a standard tool. The tool taken as the standard was a general-purpose turning-lathe of average complexity, whose labour consumption is indicated by a complexity coefficient R 10.

7. The standard values for the volume of overhaul work are average figures and are used to plan the total volume of overhaul work in a workshop or enterprise. Deviations are allowed for, depending on the actual state of a machine tool when overhauled.

The basic idea behind these principles underlying the maintenance system is that by establishing a maintenance cycle with a permanent pattern, preserving average ratios between the volumes of work involved in the different types of overhaul and comparing different types of equipment by placing each in a maintenance complexity category, it is possible to plan maintenance in advance and to calculate the labour, equipment and time required.

On the other hand, the system allows for the variety of equipment and working conditions to be found in industry. It provides for different intervals between overhauls, allows for deviations from the average values for labour consumption and lays down a whole complex of preventive measures to prevent sudden breakdowns and cumulative wear.

Standard rates have been worked out in the Soviet Union for determining the expenditure of labour in maintenance of technological equipment.(1) From the standard rates it is possible to calculate in advance the periodicity of maintenance, the amount of time and resources to be expended on it, the amount of labour and equipment required, the cost of maintenance operations, the quantity of spare parts, and other necessary data.

The standard rates are drawn up in such a way that the labour consumption in the overhaul of each unit of complexity is determined; this value is then converted for the tool in question. Thus, according to the 1962 rates, the time to be spent per maintenance unit should not exceed the figure shown in table 3.

These standard time rates are intended for planning and calculating the labour force required. In order to determine from them the number of hours required for maintenance of a given model of machine tool, the figures given

Table 3

Overhauls and preventive maintenance operations	*Number of hours*	
	Mechanics, etc.	*Machine tools*
Cleaning	0·35	
Checking accuracy	0·4	
Minor overhaul (I)	0·75	0·10
Intermediate overhaul (II)	4·1 16·5	2·0 7·0
Major overhaul (III)	26	10·1

Thus, the labour consumption ratio for planned overhauls is:
I:II:III = 6·1:23·5:36·1, or approximately 1:4:6.

must be multiplied by the complexity coefficient for the machine tool concerned. For example, in the case of a thread-grinding machine with complexity coefficient $R = 17$, $17 \cdot (26 + 10{\cdot}1) = 615$ hours should be planned for major overhaul, 400 hours for intermediate overhaul, and so on. The standards give examples of how to make the calculations and tables of complexity coefficients for different types and models of machine tools.

Table 4 gives the most characteristic complexity coefficients for certain types of machine tools.

Table 4

Type of machine tool	*Complexity coefficient*
Lathes, medium-sized	9–13
Heavy lathes	17–19
Vertical drilling machines	3–8
Radial drilling machines	6–12
Open-side jig borers	20–35
Horizontal borers, medium-sized	16–18
Cylinder-grinding machines	10–15
Gear-cutting machines, medium-sized	10–12
General-purpose horizontal milling machines	8–14
Planing machines, medium-sized	12–15

The length of the maintenance cycle in hours is calculated from formulas in which the operating conditions of the tool are expressed by empirical coefficients.

For metal-cutting lathes the value of T can be calculated from the formula:

$$T = 24{,}000\,\beta_1\,\beta_2\,\beta_3\,\beta_4 \text{ hours,}$$

where β_1 is the coefficient for the type of production, with values $\beta_1 = 1$ for mass and large-series production, $\beta_1 = 1{\cdot}3$ for series production and $\beta_1 = 1{\cdot}5$ for small series and unit production. The coefficient β_2 relates to the type of material worked on the machine tool, with values $\beta_2 = 1$ for structural steel, $\beta_2 = 0{\cdot}7$ for high-strength steel, $\beta_2 = 0{\cdot}75$ for alluminium alloys and $\beta_2 = 0{\cdot}9$ for cast iron and bronze. The coefficient β_3 relates to operating conditions, with values $\beta_3 = 1$ for normal operating conditions, $\beta_3 = 0{\cdot}7$–$0{\cdot}8$ for dusty and humid conditions, $\beta_3 = 1{\cdot}1$–$1{\cdot}2$ for high-precision tools in machine shop conditions and $\beta_3 = 1{\cdot}3$–$1{\cdot}4$ for tools housed separately. The coefficient β_4 relates to the size of the machine tool, with values $\beta_4 = 1$ for light and medium-sized tools, $\beta_4 = 1{\cdot}35$ for heavy tools and $\beta_4 = 1{\cdot}7$ for especially heavy and special-purpose tools.

The formula for the interval between overhauls t, with nine planned overhauls per cycle, is $t = \dfrac{T}{9}$ hours.

When equipment is worked on a single-shift basis, its rated annual working time is 2,000 hours.

The inter-overhaul period can be determined roughly from these functional relationships and then corrected in accordance with the specific operating conditions and methods.

Suppose, for example, that it is necessary to determine the duration of the maintenance cycle for a heavy turning-lathe (complexity coefficient $R = 17$, $\beta_4 = 1{\cdot}35$) working two shifts in small-series production conditions ($\beta_1 = 1{\cdot}5$). The tool processes mainly high-strength steel and cast iron $\left(\beta_2 = \dfrac{0{\cdot}7 + 0{\cdot}9}{2} = 0{\cdot}8\right)$ and humidity in the workshop is very high ($\beta_3 = 0{\cdot}7$).

$$T = 24{,}000 \times 1{\cdot}5 \times 0{\cdot}8 \times 0{\cdot}7 \times 1{\cdot}35 = 27{,}000 \text{ hours, or}$$

$$T = \frac{27{,}000}{2 \times 2{,}000} = 7 \text{ years}$$

$t = 9{\cdot}5$ months = the inter-overhaul period.

On the basis of these data, the machine's maintenance schedule can be drawn up and the labour consumed and the time spent idly in maintenance can be determined as above.

There are three main systems of maintenance at industrial enterprises—centralized, decentralized and mixed.

Under a centralized maintenance system, all maintenance work is carried out at the factory with the labour and resources of a chief mechanical engineer's section and its maintenance machine shop. This kind of organization is typical for plants with a small amount of equipment.

Under a decentralized maintenance system, all kinds of maintenance operations—servicing between overhauls and periodic overhauls, including major overhauls—are carried out under the direction of shop mechanics by so-called "shop maintenance units", which are general maintenance squads. The maintenance machine shop under the chief mechanical engineer carries out only major overhaul of complex units. In addition, it manufactures and reconditions equipment parts for the shop maintenance units when this requires special technology.

Under a mixed maintenance system, all kinds of maintenance, except major overhauls, are carried out by shop maintenance units, and major overhauls (and sometimes intermediate overhauls of large assemblies) by the maintenance machine shop.

SCOPE OF EACH TYPE OF OVERHAUL AND DETERMINATION OF THE SERVICE LIFE OF MACHINE TOOL PARTS

The scope of the planned periodic overhauls depends on the design of the machine tool and the conditions under which it is operated.

Table 5

Maximum permissible variation in diameter of workpiece (microns)	*Class of Precision at* d 50–80 mm	*Maximum permissible wear of slides when turning workpieces with lengths of up to:*					
		25 mm	*50 mm*	*100 mm*	*200 mm*	*300 mm*	*400 mm*
13	1	0·16	0·08	0·04	0·02	0·013	0·01
20	2	0·24	0·12	0·06	0·03	0·02	0·015
30	2a	0·40	0·20	0·10	0·05	0·035	0·025
60	3		0·40	0·20	0·10	0·07	0·05
120	3a			0·40	0·20	0·13	0·10
200	4			0·65	0·32	0·21	0·16
400	5				0·65	0·43	0·32

A *minor overhaul* entails the replacement or reconditioning of a small number of worn parts and the adjustment of the machinery, and checks that the machine tool is in satisfactory condition and that its lubrication system is functioning properly.

An *intermediate overhaul* entails a greater amount of maintenance work, including the partial truing up of the machine tool and the restoration of any precision which has been lost. It is carried out without removing the machine tool from its bed.

A *major overhaul* entails the complete restoration of the efficiency of the machine tool. The tool is normally completely dismantled and degreased and its parts are sorted, on the basis of measurements and visual inspection, into three categories.

The first category covers serviceable parts which do not need reconditioning and are fit to serve for another maintenance cycle.

The secondary category covers parts which require reconditioning because of surface wear, deformation or other reasons. The most suitable reconditioning process is specified for each part (building up the part by welding, chromium plating or other methods, grinding to the reconditioned dimensions, and so forth).

The third category covers parts which it is impossible or uneconomic to recondition. Such parts are replaced with new ones made to the same technical requirements. Typical parts which fall into this category are roller-contact bearings and friction clutch plates. In order that the various parts may be correctly sorted into categories and their suitability for further service in the machine tool properly evaluated, it is essential to set maximum permissible limits of wear for them and establish their service life.

This is an extremely complicated matter, as the parts of any machine tool have to satisfy the most varied requirements. So far, no completely satisfactory method of calculating maximum wear levels has been developed.

The criteria (characteristics) of the maximum wear of machine tool parts may be divided into two groups.

The first group comprises criteria relating exclusively to the proper functioning of a given assembly or part. This covers cases such as the breakage of parts as a result of wear (the teeth of slow-speed worm gears), the wearing away of the case-hardened layer, resulting in a sharp increase in the rate of wear (the slide blocks of link gear), and the breakdown of liquid friction (slider-type bearings).

In many cases, however, the functioning of an assembly cannot be considered in isolation from the functioning of the mechanism or the machine tool of which it is a part.

The criteria in the second group relate to the performance by the machine tool or mechanism of the functions for which it is intended. The most typical criterion of this group, as far as machine tools are concerned, is precision of machining.

Table 5, for example, gives lists of figures calculated by the author which show, for various degrees of machinery precision, the maximum wear of lathe slides (measured at the point of greatest wear) which will permit those precision requirements to be satisfied. The figures show only the reduction in precision due to wear of the slides and do not take into account the influence of other factors, such as the rigidity of the slide rest, the spindle and other parts and wear of the cutting tool.

It will be seen from the table, that there is a direct connexion between the permissible wear of the slides on the one hand and the desired precision of machining and the dimensions (length) of the workpieces on the other hand. When the workpieces are short and a large allowance is made for variations in their diameter the permissible wear may be very considerable. However, operational and overhaul considerations and the need to avoid vibration of the slide rest make it inadvisable to allow the wear to exceed 0·2 mm.

In many cases the maximum permissible wear of key parts of each model of machine tool can be established on the basis of practical overhaul and operating experience.

In order to determine the service life (T) of a part it is necessary to know the nature of the wear process in the part as a function of time and the maximum permissible value of wear ($U_{\max}$). As in the majority of cases normal wear takes place at a constant rate ($\gamma = $ const.), for known values of γ and $U_{\max}$ the service life of a part will be:

$$T = \frac{U_{\max}}{\gamma}. \qquad (2)$$

The value of the rate of wear (γ) is determined either on the basis of measurements or from experience of operation of machine tools of the type in question.

Formula (2) for determining the service life of machine tool parts is applicable to parts which are replaced only when they become unserviceable, that is, when their wear has reached the value U'_{max}. Quick-change parts which are replaced when the machine tool is serviced between overhauls fall into this category.

In the case of parts which are reconditioned or replaced during the periodic planned overhauls, the acceptable values of wear (U'_n) will be equal to or less than the maximum permissible values(U'_{max}) as the parts must not become unserviceable in the interval before the next overhaul. If the period between overhauls, that is, the period between two planned overhauls, is T_1, then over that period of time the wear of the part will increase by an amount γT_1. The maximum acceptable amount of wear (U'_n) after which it is essential to replace or recondition a part at the current periodic overhaul will therefore be:

$$U'_n = U'_{max} - \gamma \cdot T_1. \tag{3}$$

Bearing in mind that $\gamma = \frac{U'_n}{T}$ (where T is the service life of the part before overhaul), we have:

$$U'_n = U'_{max} - \frac{U'_n \cdot T_1}{T}, \tag{4}$$

whence

$$U'_n = \frac{U'_{max}}{1 + \frac{T_1}{T}}. \tag{5}$$

If a given periodic overhaul is the K^{th} since the last overhaul of the part, then the service life of the part will be $T = KT_1$ and the formula for calculating the acceptable wear will take the form:

$$U'_n = \frac{K}{K+1} U'_{max}. \tag{6}$$

For example, a part has a case-hardened layer 0·8 mm in depth and the maximum permissible wear is $U'_{max} = 0{\cdot}65$ mm (80 per cent of the depth of the case-hardened layer). Should the part be reconditioned if, when measured at the third periodic overhaul, its wear is found to amount to 0·55 mm?

If we calculate U'_n according to formula (6):

$$U'_n = 0{\cdot}65 \frac{3}{3+1} = 0{\cdot}49 \text{ mm},$$

we find the part must be reconditioned; although its wear is less than U'_{max} it will not last until the next periodic overhaul.

If the maximum permissible amounts of wear and the service lives of the main parts of the machine tool are known, the scope of the various types of overhauls can be defined more accurately, the durability of the machine tool increased and the cost of maintaining it reduced.

THEORETICAL BASES FOR ESTABLISHING THE MAIN PARAMETERS OF A MAINTENANCE SYSTEM

The main parameters of a maintenance system are a maintenance cycle pattern applicable to all machine tools and an inter-overhaul period which takes into account the special features of the equipment and the way it is operated.

The maintenance cycle pattern and the interval between overhauls must be such that through fuller utilization of the service lives of the machine tool parts and assemblies, other things being equal, the equipment is idle for overhaul for the shortest possible time, and expenditure on its overhaul is kept to the minimum.

In order to select the best values for these parameters, it is necessary to determine how their values influence the durability of the machine tool—the coefficient η_D (see formula (1)).

When using formula (1) in connexion with periodic overhauls it must be borne in mind that:

1. The periodicity of overhauls will be defined by the minimum service life T_1 of the parts subject to periodic overhaul;

2. At each overhaul, all parts whose service life will expire before the next overhaul must be replaced.

In order to analyse the maintenance cycle pattern, all machine tool parts which are subject to periodic overhaul must be divided into groups according to length of service life.

Each group comprises parts whose service life, T_i, is within the range $n \cdot T_1 \leq T_i < (n+1) T_1$, where n is the ordinal number of the group of parts in question and T_1 is the minimum service life, which determines the periodicity of overhauls. For the n^{th} group of parts, the periodicity will be $n \cdot T_1$, as parts of the first group will be overhauled after T_1 hours, parts of the second group after $2T_1$ hours, and so forth. The number of groups of parts (n) overhauled at the periodic overhauls is determined from the relation

$n = \frac{T_{max}}{T_1}$, where T_{max} is the service life of the most durable part.

If the maintenance cycle patterns used are analysed from this point of view, more advantageous variants than the nine-period pattern may be found.

It is a fact that although the pattern shows the first two periodic overhauls as being of the same type (minor overhauls), this is an index only of their average scope. In reality these two overhauls will be different from each other, as after the period T_1 (the period between overhauls) the first-group parts will be overhauled, while after the period $2T_1$ both the first-group and the second-group parts will be overhauled. The amount of overhaul work carried out on the second occasion will consequently be greater, although both are classified as minor overhauls and the time and resources allocated for them are identical.

It can similarly be shown that the volume of overhaul work involved in the first and second intermediate overhauls in the cycle will be different in each case.

In the interests of more accurate planning of maintenance it is therefore desirable that there should be not three but four types of overhaul (the fourth type being termed a complete overhaul).

As the author's calculations show, (3,6) it is more advantageous from the point of view of reducing equipment idle time to use a six-period pattern with a I-II-III-II-I-IV cycle and a ratio of volumes of overhaul work of I:II:III:IV = 1:2:4:6.

The change to a cycle pattern with four types of overhaul requires a higher level of maintenance organization and will constitute a further development of the maintenance system.

Attempts are now being made in the Soviet Union to introduce optimum maintenance cycle patterns which take into account the work which has been done in this field. The existing maintenance system, which has been of great economic value to industry, will thus be further developed and perfected.

The length of the period between overhauls (T_1) is that basic parameter of the maintenance system which reflects the special features of the equipment in question and the nature and intensity of its operation. It must be determined after the maintenance cycle pattern has been selected, and is thus the second task in establishing the basic parameters.

The aim in determining the length of the period between overhauls and the maintenance cycle pattern must be to achieve the highest possible durability of the equipment. The optimum period will be that which, other things being equal, gives the highest coefficient of durability (or the minimum loss of machine time on overhauls, which amounts to the same thing).

The main consideration in selecting the optimum period between overhauls ($T_1 = T_{opt}$) is to establish such a ratio between the amount of work carried out at the periodic overhauls and the amount carried out in the course of servicing between overhauls as will make possible the minimum expenditure of labour on overhauls in the given conditions.

When the length of the inter-overhaul period is extended, a larger number of parts will be replaced in the course of the servicing between overhauls. The result of this is that, while the durability of individual parts is more fully utilized during the servicing interval, the amount of assembly and disassembly is increased.

On the basis of these considerations, the author proposes the following formula for calculating the optimum interval between overhauls:

$$T_{opt} = \frac{1 \cdot 8}{K} \cdot \left(\frac{\tau_k}{\tau_1} + 1\right)\left(\beta - \sqrt{\beta^2 - 1}\right) \cdot T, \qquad (7)$$

where: T is the length of the actual interval between overhauls established in practice;

K is the number of overhauls in the cycle ($K = 6$ or $K = 9$);

τ_k is the the actual time required for a complete overhaul (in hours) for a length of cycle $K \cdot T$;

τ_1 is the actual amount of time required for a minor overhaul (in hours);

$\beta > 1$ is a coefficient which indicates the increase in the amount of time spent on the overhaul of machine tool parts and assemblies in the course of inter-overhaul servicing because of increased assembly and disassembly work.

β is normally between 1·5 and 3. This formula permits the calculation of the value of $x = \frac{T_{opt}}{T}$, which is an index of the advisability of lengthening or shortening the period between overhauls in the given operating conditions: in other words, it makes possible more accurate correction of the value of T established from the norms.

The coefficient β greatly influences the value of T_{opt}.

If the time spent on assembly and disassembly work can be reduced by using quick-change parts and introducing wear compensation adjustments, the interval between overhauls can be lengthened advantageously.

If changes are made in the overhaul and operating conditions of the equipment, the inter-overhaul period should also be adjusted accordingly.

Improvements in overhaul methods, in the durability of the individual parts, and in the design of machine tools will be fully effective in increasing the durability of the equipment provided that the main parameters of the maintenance system — particularly the maintenance cycle pattern and the length of the inter-overhaul period — are correctly selected.

ORGANIZATION OF MAINTENANCE SERVICES AT THE PLANT

The organization of maintenance work at the plant must provide for the execution of all technological processes necessary for maintenance operations, receipt of spare parts from the machine tool factory and overhaul of individual assemblies or machine tools at special maintenance centres.

As shown above, such organization depends upon the types and number of machine tools at the plant.

The plant's maintenance machine shop usually comprises the following sections or units: (1) a machine tool section, (2) a fitting shop; (3) a welding shop. In large maintenance machine shops there is a further department for restoring and increasing the wear resistance of parts, with sections for metalization, chrome plating, cementing, heat treatment and so forth.

The machine shop is headed by a superintendent, subordinate to the factory's chief mechanical engineer, and the various sections or units are headed by foremen, under the shop superintendent. Also under the latter's authority are a technological office, a planning office and other administrative units.

Shop maintenance units, as has already been shown, form part of production shops. Their purpose is to carry out servicing between overhauls and to perform individual repair work on all the various types of equipment installed in each workshop. The scale of operation of a shop maintenance unit depends on the system of maintenance followed at the plant.

Under a centralized system of maintenance, in which work is carried out exclusively with the labour and resources of the appropriate workshops of the chief mechanical engineer's section, the shop maintenance unit is responsible only for inter-overhaul servicing. Where the workshops of the chief mechanical engineer's section have insufficient work, they are also made responsible for this type of servicing.

Under a decentralized system, the shop maintenance units carry out inter-overhaul servicing of mechanical equipment and all types of overhauls, except major overhauls of the most complex units. They are also responsible for servicing between overhauls and for minor and intermediate overhauls of electrical and diesel equipment.

Under a mixed maintenance system, major overhauls of production shop equipment are carried out by mechanical and electrical repair shops.

The *Model Regulations* (1) recommend the establishment of shop maintenance units in workshops where the total number of maintenance and repair operations runs to upwards of 600–700. In small workshops independent maintenance units are not set up. Such shops are served by so-called central district units (one unit for several shops), headed by district mechanical engineers, who are subordinate to the chief mechanical engineer.

Central district units are staffed by squads of fitters, attached to production sections, bays or shops. The size of each squad is established according to the labour requirements for the projected maintenance operations according to an annual schedule and for carrying out the inter-overhaul servicing of the equipment assigned to the squad.

In choosing the particular system of maintenance for the factory as a whole, account is taken of its effect on the structure of the central maintenance service apparatus—the chief mechanical engineer's section. With a decentralized system of maintenance, when the bulk of the work is undertaken by the shop maintenance units, it is advisable to augment the latter's planning and accounting staff and correspondingly to simplify the structure of the central maintenance service apparatus, making the latter responsible only for the methodical direction and supervision of the shop maintenance units' work.

The structure of maintenance services in the chief mechanical engineer's section also depends on whether there is an independent chief mechanical engineer's section at the plant. If there is such a section, one of its functions is to ensure the correct use and planned maintenance of all power equipment.

An independent chief power engineer's section is usually set up at large plants which have a large amount of equipment and use substantial quantities of power. In factories using small amounts of electricity and having small power installations, a combined chief mechanical engineer's and power engineer's section is formed, which includes a power engineering office and is responsible for the work of the electrical and diesel shops.

In plants with large numbers of machine tools of the same kind and in mass production factories, it is advisable, in order to cut down machine idle time during repair, to carry out repairs by the unit system.

The essence of the unit system of repair is the removal of machine tool units requiring repair and their replacement with spare units, either previously repaired, rebuilt or newly purchased. In metal-cutting machines, such interchangeable units include the headstock, the apron and the carriage saddle, the drive mechanism, the spindle casing, the grinding and turret heads, etc. The range of interchangeable units and interchangeable parts must be made more and more comprehensive, and the rebuilding (repair) of these units and parts must be centralized.

In addition to the unit system, there is the successive-unit system of repair and overhaul, in which the units of the assembly are overhauled in a particular sequence during normal breaks in the operation of the equipment. During meal-breaks and on rest-days and non-working shifts, different units requiring overhaul are dismantled and their worn-out parts replaced. The succesive-unit system is particularly well-suited for the repair of standard-unit machine tools and other tools where the various sub-assemblies are individually designed.(9)

The more equipment is standardized and the more its individual units and assemblies are unified, the simpler will the organization of maintenance services become. It is expedient, therefore, in equipping any given factory, to use the minimum number of machine tool contractors.

In the Soviet Union, efforts are now being made on a broad front to produce machine tools in various technological versions and types on a single base, to standardize regular machine parts and assemblies, and to unify construction. These measures not only reduce the cost and increase the quality of machine tool production but also simplify their repair and maintenance substantially.

TECHNICAL PROBLEMS OF MACHINE TOOL MAINTENANCE

In the maintenance of machine tools and other equipment, correct choice of the technical processes to be used to restore the impared efficiency of the various units and parts is important.

This is a somewhat complex problem because, first, the range of repairable parts is extremely wide; secondly, the parameters of the parts have to be fully restored in repair, and in many cases increased wear resistance and toughness are called for, and, thirdly, expenditure on repairs and idle time during repair must be kept to a minimum.

In addition to the ordinary methods of mechanical machining, extensive use is made of electroplating, metal improvement processes, pulverization and other technical processes to restore the dimensions of the worn parts. (10) Processes to harden the surface of parts and increase their wear resistance and fatigue strength are also used. These include heat and thermo-chemical treatment, electric spark surface toughening, and surface toughening by rolling and shot-peening.

Table 6

Maximum machining diameter of machine tool (mm)	100	200	400	800	1,600
Force applied (kg)	70	200	500	1,600	4,500
Maximum displacement relative to mandrel (mm):					
Spindle	0·04	0·10	0·21	0·47	1·05
Tailstock	0·05	0·13	0·27	0·61	1·40

In repairing equipment, it may also become necessary to modernize individual units, replace some materials by others, and economize in the use of non-ferrous metals. In some cases, therefore, bimetallic parts have to be made—slider bearings, worm wheels and lead screw nuts, for example, using bronze for the friction surface and steel or cast iron for the main body of the part. Metallo-ceramic parts are also used—for example, iron-graphite bushings and plastic parts.(11) All this calls for special equipment and skilled labour.

In the repair of machine tools, particular attention has to be given to the technical processes for reconditioning or repairing certain parts, since their quality determines the precision of the machine tool. Normally, the most labour-consuming operation is the repair of machine tool slides, since these determine the precision of movement of the basic units of the machine and the accuracy of their relative positions. The technical processes for repairing worn slides are varied, and, depending on the circumstances, may be carried out by machining at the lathe, by the use of suitable appliances or by hand. The machining of slides by planing, milling or grinding is the most exact and productive method of reconditioning worn slides. However, its use is not infrequently limited by the factory's lack of machine tools of suitable size and adequate precision.

The repair of bed slides with the help of suitable appliances necessitates no special equipment; the appliances used for the purpose are of simple construction and can be made at any machine-building plant. But the drawback of this method is its high labour consumption as compared with machine work, since treatment with appliances normally takes place at a slower tempo, and usually necessitates a certain amount of manual labour in preparing the setting bases and some rather labour-consuming work in installing and setting up the appliance. Nevertheless, it is often preferable, because it can be carried out at the site of the machine tool, so that the bed does not have to be dismantled and reassembled, and time is saved on transporting it to the repair shop and back. This method is best suited to the repair of particularly large bed slides.

The repair of slides by hand (powdering, scraping, etc.) is the most labour-consuming and outdated method, and is permissible today only in one of the following cases: (1) when the wear on the slides is so slight that hand reconditioning requires less time than mechanical methods; (2) when the equipment for mechanical treatment (machine tools and appliances) has not yet been obtained or made.

The Soviet Union has developed portable appliances for grinding and clean planing machine tool slides in the process of repair, mechanized scraping tools and technical processes and methods for machining slides with the use of machine tools.(10) Model technical processes have also been developed for repairing spindles, lead screws, precision worm couples and other key machine tool parts.

The overhaul of the hydraulic equipment of machine tools presents special features of its own, including technical processes characterized by the use of precision and finishing work in the repair of hydraulic cylinders (honing) and hydraulic pump parts (grinding), and by checking to ensure precise clearances and relative positions in reconditioned parts returned to use.

Units are assembled with the help of universal and special appliances ensuring correct and efficient assembly.

In order to make sure of accurate assembly we have to apply the theory of dimension sequences and compensators,(12) since the method used to restore precision can then be selected on rational grounds; for example, we can regulate or adjust the part, use trial and error or fit a compensator in one of the members of the sub-assembly.

Great importance for high-quality assembly attaches to the checking and testing of the machine tool after an overhaul.

Besides the familiar tests for geometrical precision, efficiency, machining precision and surface quality obtained, methods of checking to determine the quality of separate sub-assemblies are also being introduced into the practice of machine tool overhaul.

We may mention first the rigidity standards and methods of checking the rigidity of machine tools worked out in the Soviet Union.(13) For example, in the case of lathes a load is applied to the spindle and tailstock into which the mandrels are inserted. Force is created with the help of a special dynamometer, which exerts pressure on the mandrel at an angle of 60 from the horizontal (in the direction of total cutting thrust). Under the standards applied for normal precision lathes, the permissible displacements of the slide rest in relation to the mandrel are as shown in table 6.

By means of rigidity testing we can ensure a high repair quality and detect any couplings requiring more careful adjustment.

In the case of gear-milling, thread-grinding and other precision machines, it is also desirable to check the kinematic accuracy of the mechanisms linking the rotation of the blank to the movement of the tool. For this purpose universal and specially developed tools are used.

The use of technically advanced repair and testing processes is essential to achieve high efficiency and economy in the overhaul of machine tools.

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Interregional Conference on the Development of Petrochemical Industries in the Developing Countries

The first United Nations Interregional Conference on the Development of Petrochemical Industries in the Developing Countries was held in Tehran, Iran, from 16 to 30 November 1964. The meeting was organized by the United Nations Centre for Industrial Development, in co-operation with the Bureau of Technical Assistance Operations of the Department of Economic and Social Affairs, and the Economic Commission for Asia and the Far East (ECAFE), the Economic Commission for Europe (ECE) and the Economic Commission for Latin America (ECLA), and was sponsored locally by the Government of Iran. The Conference was attended by seventy-four participants nominated by governments from twenty-eight countries, eighty-three participants from industry, academic and research institutes, twenty-three observers, and twenty-three representatives of the United Nations, the specialized agencies and other international organizations.

As part of the Conference programme, participants from developing countries took part in field trips to the Abadan refinery and Shiraz fertilizer plant in Iran, and petrochemical facilities in the South of France.

The Conference held a total of twenty-one working sessions, in which one hundred and fifteen working papers and fifteen information papers were presented. Presentations were followed by floor discussions after each session or substantive item. The agenda of the Conference was organized along the following main subjects: characteristics of the petrochemical industry and prospects for its development; aspects of demand and supply of petrochemical products; recent trends in research and technology in the petrochemical industry; industry studies on raw materials and basic intermediates, nitrogenous fertilizers, plastic materials, synthetic rubbers, synthetic fibres and selected end-products; country studies, regional development, financial and legal aspects of the petrochemical industry, and location factors in the petrochemical industry and prospects for regional development. The following are some of the important conclusions and considerations of the Conference:[1]

CHARACTERISTICS OF THE PETROCHEMICAL INDUSTRY AND PROSPECTS FOR ITS DEVELOPMENT

Although petrochemical industries are still concentrated in the industrialized countries, developing countries have shown increasing interest in the development of petrochemical industries, and efforts at industrialization seem to have coincided with a planned high rate of investment in the petrochemical industry. The Conference observed that petrochemical industries are being planned and installed by those developing countries which have a large enough market to absorb domestically a good part of the output, and also by some developing countries with abundant petroleum and natural gas resources which provide a cheap source of raw materials for the industry. In this case, export markets are expected to provide an important outlet for the production of these resource-based petrochemical plants. Market-located petroleum refineries, which are now being established in a number of countries, also provide a basis for the establishment of petrochemical complexes. Finally, there are countries with an already existing organic-chemical industry, which are substituting oil and gas for other traditional inputs, such as raw materials derived from coal or vegetables.

The Conference was of the view that the petrochemical industry is of strategic importance to induce further industrial development because of its high productivity and its many links with other industries, characteristics which are common to other industries of intermediate manufacture like iron and steel, pulp and paper and industrial

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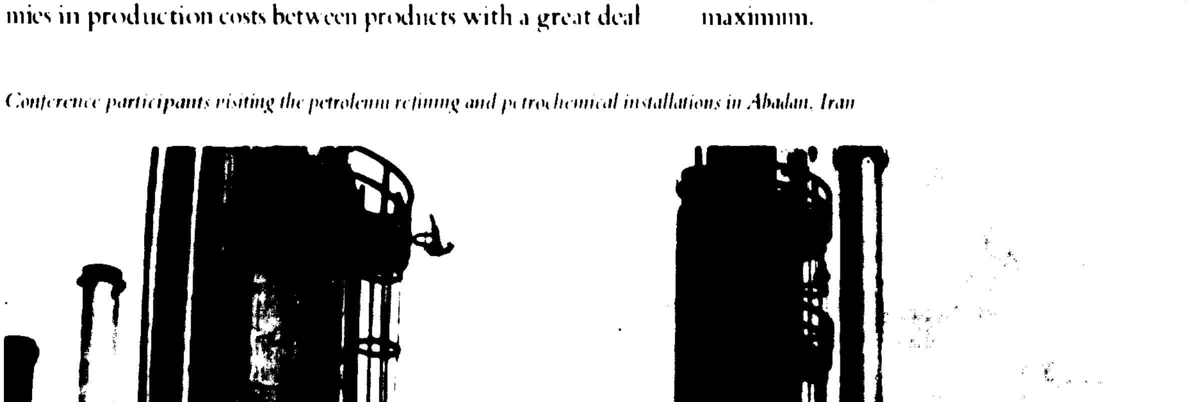
[1] The report of the Conference is available as a United Nations publication (Sales No.: 66.II.B.14). A separate United Nations publication, *Studies in Petrochemical Industries* (Sales No.: 66.II.B.5) includes most of the papers delivered at the Tehran meeting.

machinery. It has recently grown at an impressive rate in the world economy, leading in the growth of other manufacturing sectors, supplying new consumer products and intermediates to a number of other industries and providing substitutes for traditional materials such as steel, lumber, paper, natural fibres, soap, and the like. Other characteristics of the petrochemical industry that were stressed at the Conference are the high degree of homogeneity and standardization of its products, owing to the continuity and stability of its operations, its high capital intensity, the high proportion of skilled labour, including the scientists and technicians that it requires, the availability of many alternative processes and initial raw materials, and the high rate of technological change prevailing in the industry.

The petrochemical industry is characterized by high capital requirements and large scale of operations. The relatively large size required for economic operation is a limiting factor in the establishment of petrochemical plants in countries where domestic demand is limited. Economies in capital investment typically range from 20 to 45 per cent according to the type of production, when output is tripled. Economies in production costs also arise from the reduction in unit costs of labour and capital when output increases. There is a great range of variation in the economies in production costs between products with a great deal of value added, for example, plastics and resins for synthetic fibres, and basic intermediates, such as ammonia or ethylene, obtained by one or two processing steps from oil or natural gas raw materials. While economies in production costs will be around 10 per cent for the first group, they will range between 15 and 40 per cent for the second group, when output is increased by three to five times.

The Conference observed that the greatest economies can be achieved when output is increased from the low to the medium size capacity range, whereas they tend to disappear after large capacities are reached. Accordingly, some developing countries could benefit to a large extent from potential scale economies while operating in the medium size capacity range. Another important consequence for developing countries is that, when economies of scale are operative, the relative share of raw materials in total unit cost rises with the increasing scale of production. So, while the capital cost per unit of output is reduced, the contribution to the unit production costs of raw materials—in which many developing countries can claim a comparative advantage—increases. Thus, while total absolute capital requirements are higher with the increased scale of production, per unit capital cost will be minimized and the potential comparative advantage in raw materials exploited to the maximum.

Conference participants visiting the petroleum refining and petrochemical installations in Abadan, Iran



Labour requirements in the petrochemical industry are rather low for unskilled workers, whereas a high proportion of engineers, technicians and skilled operators is required. This could act as a major deterrent to the application of modern petrochemical technology, since specialized skills are in very short supply in most developing countries. Even in countries where there is a relatively large, university-trained professional élite, the engineers will have to undergo specialized training in order to learn the operation, control and maintenance of petrochemical installations. Moreover, in most developing countries there is a shortage of intermediate skills such as those of mechanics, electricians, tool makers, welders, draftsmen, foremen and so on, which are in relatively high demand for petrochemical plants.

Special skills and know-how are also embodied in the three technical phases of constructing petrochemical facilities: process design, mechanical design and construction. While process design would seldom be available from domestic sources, many developing countries do have a pool of engineers and technicians competent enough to undertake locally part of the mechanical design and construction engineering. The same is true of the engineering and industrial facilities required for the fabrication of a major portion of the plant equipment.

Some of the major components of the cost and steel weight of equipment requirements for petrochemical production are rather simple items, such as piping, valves, storage tanks and structural steel, which could be produced in many developing countries. At more advanced stages of industrialization, the construction of more sophisticated pieces of equipment, such as compressors, pumps and generators could be added.

The Conference observed that the co-operation of constructors, licensers, foreign investors and engineering companies with potential local suppliers was necessary in order to provide for the possibility of local supply of such equipment. Provisions have to be made during the mechanical design phase so as to adapt drawings, raw materials and construction specifications to the specific possibilities present in each country. Governmental policy should also play a role in stimulating these arrangements. Furthermore, the Conference recommended that the United Nations, through its appropriate organs, assist developing countries in establishing national or regional mechanical design institutes with the objective of promoting local manufacture of industrial equipment for the petrochemical industries, thus reducing the foreign exchange burden of the countries concerned.

The meeting noticed that the majority of the existing and projected petrochemical plants in the developing countries are for the production of ammonia and nitrogenous fertilizers, and only a few for the production of synthetic rubbers and fibres. Fertilizer plants rank first on account of the growing demand for nitrogenous fertilizers to increase food production and the easy availability of the necessary technological "know-how", whereas the production of synthetic rubber and fibres, although it does not call for higher capital investment, requires a more complex technology. Also, in many developing countries their development would imply the substitution of traditional industries sometimes based on domestic raw materials.

Although there are many limitations and difficulties in establishing a petrochemical industry in developing countries, these countries also have some advantages over industrialized countries. In this respect, the Conference observed that in most developing countries there is a simpler structure of consumer demand; consumers can be supplied with a more limited variety of products, subject to less rigid specifications. When this situation prevails, relatively lower production costs are possible. Also, with regard to raw materials, some countries have abundant and cheap raw materials for the petrochemical industry, such as natural gas and the energy to be derived from it. These countries could pursue their own pattern of industrial development, account being taken of the availability of petrochemical substitutes for glass, paper, steel products, wood and natural fibres.

The meeting also called attention to the fact that countries now developing a petrochemical industry could benefit from being late-comers to the field by making use of the latest available technology. It was stressed in this connexion that developing countries should try to avoid the pitfalls of uneconomic size of plant and obsolescent products and technology by giving due consideration to the latest technologies being made available in the industrialized countries. The Conference noticed that recent technological improvements make possible the production of similar industrial and consumer products with lower investment and production costs. Attention was called to the following specific points. In the field of synthetic rubber, the construction of polyisoprene and cis-polybutadiene rubber plants should be carefully considered as an alternative to the more traditional SBR rubber supplying the synthetic rubber needs of the tire industry in developing countries. In synthetic fibres, if a single fibre is to be selected, the choice will probably favour nylon as the most versatile and highly sought synthetic fibre for industrial and consumer uses. Polyester fibres require a higher capital investment and more sophisticated technology; the availability of know-how is at present limited. Acrylic fibres are in less demand because of the climate prevailing in many developing countries. With reference to nylon fibres, the production of caprolactam-based Nylon-6 instead of Nylon-66 was suggested, because it requires a smaller economic scale, lower investment and production costs, and the raw materials and know-how are readily available. The field of detergents was also mentioned as another instance where care should be exercised in making a basic technological choice. While the trend in the more advanced countries is towards biodegradable detergents because of water pollution problems, in developing countries dodecylbenzene sulphonate may still be a good choice as a detergent for some time to come.

The Conference was of the opinion that the United Nations should make an effort to help the developing countries decide what kinds of plants and processes they should adopt in their petrochemical projects, and help them obtain know-how and process design so as to reduce the capital investment and cost of petrochemical production.

ASPECTS OF DEMAND AND SUPPLY OF PETROCHEMICAL PRODUCTS

The petrochemical industry has been characterized in the recent past by a very high rate of growth. In all industrial areas of the world, chemicals based on petroleum and natural gas have exceeded the growth rate for the chemical industry as a whole, as well as that of total industrial production. This high growth rate may be explained, on the supply side, by the increasing demand of the chemical industry for basic raw materials and the subsequent substitution of oil and natural gas for traditional raw materials such as coal. On the demand side, a number of these products show a very high income elasticity of demand and have been expanding by substituting and supplementing other products: substitution in certain end-uses for lumber, glass, metal and paper; synthetic rubber for natural rubber; detergents for soap; supplementing as well as substituting natural fibres by synthetic fibres, and so on. Gains from substitution have been greatly enhanced by improvements in the properties and development of new applications for petrochemical products, as well as by the introduction of new products with specialized properties and extensive promotion activities with respect to both industrial users and consumers. Furthermore, prices for a number of these products have declined in absolute terms or relative to competing products, thus giving further impetus to the substitution process.

Although the first commercial chemical based on petroleum (isopropyl alcohol) was produced in 1919-1920, during the early part of the century world chemical production grew at a very modest rate, reaching an estimated total production value of $10 billion* in the late nineteen thirties. The trend of rapid growth did not become significant until after the Second World War. By 1955 world production reached $50 billion and by 1965 it probably exceeded $100 billion. Although in 1950 the United States produced about 50 per cent of total world output, owing to the resurgence of the chemical industry in Europe and Japan this share has now been reduced to slightly under 40 per cent. By 1960-1962, eight countries—Canada, the Federal Republic of Germany, France, Italy, Japan, the Union of Soviet Socialist Republics, the United Kingdom and the United States—accounted for three-quarters of the total production; and the percentage of the total world market held by these eight countries has been increasing in the last few years.

With regard to international trade, total export of chemical products throughout the world has grown from over $6 billion in 1959 to almost $8 billion in 1962. More than 90 per cent of the world's chemical trade is conducted by the European Economic Community (EEC) and European Free Trade Association (EFTA) trade groups, the United States, Canada and Japan. While chemical exports as a percentage of total production run at about 9 per cent, considerable variation exists among the different producing countries. The Federal Republic of Germany and the United Kingdom export about 25 per cent of their output.

Product-wise, recent trends in the most important sectors of petrochemicals, namely, plastics, synthetic fibres, synthetic rubbers and nitrogenous fertilizers, were analysed as follows. For plastics and synthetic fibres, the major consuming centres are Australia, Japan, the United States and western Europe, which account for about 80 per cent of total world consumption. For nitrogenous fertilizers, the above group of countries have a lower share, namely 66 per cent, with the remaining share going mainly to the centrally planned economies (18 per cent) and Asia (14 per cent). With respect to synthetic rubbers, the above-mentioned consuming centres, with the addition of the Soviet Union, now also a major producer of synthetic rubber, consume over 90 per cent of the world's total.

With regard to trade, available data for these four sectors indicate a rather high share of trade in total production, ranging between 20 and 30 per cent. This rate becomes even higher, ranging up to 50 per cent, when individual products within these sectors and individual countries are considered. Western Europe is the major importing region and has increased its share over the last decade in all four sectors except nitrogenous fertilizers, which share was kept approximately constant. North America, on the other hand, recorded a relatively small share of imports for all products excluding nitrogenous fertilizers, and Asia is developing as an important market for these products.

Exports issue from a small number of countries: plastics from the Federal Republic of Germany, France, Italy, Japan, the United Kingdom and the United States; synthetic fibres, from these countries and from Switzerland; and synthetic rubber from Canada and the United States. Exports of nitrogenous fertilizers, however, are less concentrated. This pattern of exports reflects the concentration of production facilities in the same countries. With respect to developing countries, a number of them have already begun to produce petrochemicals, but their share is relatively low.

The Conference considered estimates of potential consumption of petrochemicals based in income elasticity of demand and certain assumptions about annual rates of growth for gross national product and population. It was emphasized that, while these methods for estimating future demand are useful, for a more accurate assessment in individual countries or regions of potential need, they would have to be supplemented by additional projections which would take into account substitution factors and changes in the pattern of end-uses. While these factors have greatly

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* The term "billion" signifies a thousand million.

contributed in the recent past to the growth of consumption, particularly with respect to plastics, synthetic fibres and synthetic rubbers, they are usually difficult to quantify and project. In this respect the experience of the industrially advanced countries may be used in part by the developing countries in the application of market research techniques, in order to determine the extent of the market, identify the consumers and evaluate their needs. This is particularly important in the petrochemical industries because of the need to match demand with the multiplicity of products that exist in each sector of the industry.

The Conference recommended that the Centre for Industrial Development continue its studies, as well as projections of production, demand and trade in petrochemicals in various parts of the world, so that the developing countries could undertake their petrochemical projects with full knowledge of the developments taking place in this field. It also recommended that studies be undertaken on the substitution of traditional materials by synthetics and or improving their quality with the help of synthetic products, as well as on the new uses of such products, to assist the developing countries in widening their markets and providing a larger basis for the development of petrochemical industries.

While the more predominant pattern for the development of the industrial sector in developing countries has been primarily concentrated on import substitution, this policy is likely to result temporarily in the development of high-cost industries under an umbrella of heavy protection. This is particularly the case in those industries characterized by significant economies of scale and for which the local market is too small to permit economic exploitation. Within this pattern of industrial development, the export-oriented industries are also concentrated in the field of light and labour-intensive industries, such as textiles, which have been characterized by stagnant demand. An alternative to this pattern of development has been suggested in a paper presented by the Centre for Industrial Development to the United Nations Conference on Trade and Development (UNCTAD), held in Geneva.[2] It is maintained that in the long run developing countries may attain faster industrial growth and hence economic development by concentrating through specialization on the development of certain dynamic industries.

The importance of economies of scale in the petrochemical industry cannot be over-emphasized, especially in view of the small market of the developing countries for a number of petrochemical products. One approach to the efficient development of this industry may be through pooling of regional, subregional or country demand. This pooling of demand may be conceived on a partial integration basis for a number of dynamic industries, such as steel, chemicals, metal-working and so on, or on a broader level of economic integration. This would make it possible to take advantage of the economies of scale obtaining in this industry and may provide an economic production base for entry into the international market.

An important export outlet may be represented by the major consuming centres, particularly western Europe, which is also a major importer of petrochemical products. This is of interest to potential exporters from North Africa and the Middle East. However, the progress of western Europe towards economic integration presents certain disadvantages to new entrants from outside the region; multilateral or bilateral trade agreements may be entered into as ways to secure markets.

Markets outside the economically advanced countries may also be sought, as in the case of possible export of nitrogenous fertilizers to Asia. Another outlet for these products may be the centrally planned economies. Trade between these and the developing countries has developed primarily through bilateral trade and assistance agreements. Further expansion of trade between centrally planned economies and developing countries may be possible for certain petrochemical products.

The entry of developing countries into the international market poses a number of problems. In the short run many factors, which may be attributed primarily to lack of experience on the part of labour and management in new production and marketing techniques and operations, tend to increase production and marketing costs. Until the industry acquires experience in production techniques, management and marketing, direct and indirect measures involving protection and promotion of industry, including promotion of exports, may be required over a specified period.

Plant investment is also higher in developing countries, as compared to advanced countries, because of higher capital cost. Additional investment in infra-structure may be needed. This investment may be substantial and beyond the means available to single enterprises. Another important infra-structure activity that requires additional capital and trained personnel is that of research and development. Such factors contribute further to the higher cost of production. Here again, recourse may be had to both national and international assistance.

Another problem for new entrants is that the international market in petrochemicals at the present time is largely controlled by a small number of companies. As stated earlier, a breakthough requires a concerted effort in securing and promoting markets, including such measures as international trade agreements. Various forms of joint ventures between developed and developing countries may provide access to the international market and a solution to some of these problems, including the supply of experienced personnel for a transitional period, technical know-how, research and development and experience in marketing techniques, and training of local labour and personnel.

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[2] United Nations, "General Study of Exports of Manufactures and Semi-Manufactures from Developing Countries and their Role in Development", *Proceedings of the United Nations Conference on Trade and Development*, vol. IV (Sales No.: 64.II.B.14).

Asia and the Far East

The consumption of petrochemical products in the ECAFE region has increased sharply in the recent past. Between 1953–1954 and 1960–1961, the annual rate of growth for nitrogen fertilizers was 7 per cent. In 1960–1963, the annual rate of growth for plastics and synthetic resins was 21 per cent, that of non-cellulose man-made fibres, 23 per cent, and that of synthetic rubbers, 23 per cent.

The production of petrochemical products in the region has also grown rapidly. In 1960–1963, the annual rate of growth of nitrogen fertilizer output was 14·5 per cent, that of plastic and synthetic resins, 24 per cent, that of non-cellulose man-made fibres, 26 per cent, and that of synthetic rubbers, 65 per cent. Both production and consumption of petrochemical products, however, are still concentrated mainly in Japan.

The ECAFE region has been a net importer of nitrogen fertilizers, plastics, and synthetic resins and rubbers. It was a net exporter of non-cellulose man-made fibres. Japan is the only principal exporter of non-cellulose man-made fibres. The region is characterized by very low levels of consumption and production of petrochemical products, with potential for expanding both consumption and production. In 1961 the *per capita* consumption of nitrogen fertilizers in the region was 1·4 kilogrammes, compared with 14·9 kilogrammes in the United States, 10·8 kilogrammes in the EEC, 3·7 kilogrammes in the EFTA and 3·5 kilogrammes in the Soviet Union, in terms of nitrogen. For plastics and synthetic resins, it was 0·96 kilogramme in the ECAFE region, as against 14·4 kilogrammes in the United States, 9·7 kilogrammes in the EEC and 8·86 kilogrammes in the EFTA. For non-cellulose man-made fibres, it was only 0·16 kilogramme in the ECAFE region, compared with 1·7 kilogrammes in the United States, 1·04 kilogrammes in the EFTA and 0·9 kilogramme in the EEC.

On the production side, the *per capita* production of nitrogen fertilizers in the region was 1·3 kilogrammes, compared with about 14·9 kilogrammes in the United States, 18·7 kilogrammes in the EEC, and 11·7 kilogrammes in the EFTA, in terms of nitrogen. For plastics and synthetic resins also, it was only 0·81 kilogramme in the ECAFE region, compared with 11·5 kilogrammes in the EEC, and 9·4 kilogrammes in the EFTA. *Per capita* production of non-cellulose man-made fibres was 0·17 kilogramme in the ECAFE region, compared with 1·86 kilogrammes in the United States, 1·03 kilogrammes in the EEC and 0·87 kilogramme in the EFTA.

Various factors impede the growth of petrochemical industry in countries of the ECAFE region. Factors responsible for the slow growth of the fertilizer industry were brought out at the United Nations Conference on the Development of the Fertilizer Industry in Asia and the Far East, which was held at Bombay, India, in 1963. The price relationship between crops and fertilizers, lack of credit and of adequate distribution facilities were considered to be the factors responsible for the low level of consumption in most countries of the region.

Although India, Iran and Pakistan are in the process of establishing petrochemical complexes within their borders, at present only two countries in the ECAFE region, namely Japan and Australia, have developed a petrochemical industry. The major problem faced by these two is the competition from overseas suppliers, which have solid advantages of size, technology, access to cheap raw materials, and highly efficient financial and organizational structures. In Australia, with the elimination of import licensing, the local chemical industry including petrochemicals, became vulnerable to dumping by overseas suppliers. Japan, which has attained international stature in the petrochemical industry, has its own problems. The small size of production units and the high price of naphtha, which is the basic material for the petrochemical industry in Japan, were listed as major problems. For example, the capacity of Japan's maximum unit of ethylene in 1964 was 120,000 tons per year, as against 250,000 tons in the United States, 200,000 tons in the United Kingdom and 150,000 tons in the Federal Republic of Germany. Price comparison of selected petrochemical products showed that in Japan, in 1962, the domestic price per kilogramme of polyethylene was about $0·58 compared with the imported price of about $0·51, that of polystyrene, about $0·69 compared with $0·36, and that of SBR about $0·53 compared to about $0·48 for the imported product.

The basic obstacle to the development of an integrated petrochemical industry is the limited market in most countries of the region for the major petrochemical products, such as plastics and synthetic resins, non-cellulose man-made fibres and synthetic rubbers.

Some countries of the region have already started to make nitrogenous fertilizers from natural gas or naphtha. Most of the countries have plans to establish naphtha-cracker complexes for the production of basic petrochemicals. The Conference examined country studies reflecting the experience and future plans in Burma, China (Taiwan), India, Indonesia, Iran, Japan, Malaysia and Pakistan.

Africa and the Middle East

Taking into account the vastness of the African continent the Economic Commission for Africa (ECA) has divided the continent into four subregions, namely, North, West, East and Central. Branch offices of ECA have been opened in three of these subregions. In this connexion, it was mentioned that with a view to promoting the industrial development in the subregions of Africa, a conference on Industrial Co-ordination in West Africa was held in Bamako, Mali. The Conference has recommended the development of industries such as basic chemicals, fertilizers and some petrochemicals, based on imported intermediates. It was envisaged to hold similar meetings in East and Central Africa in the near future.

Some countries in Africa, especially those in North and West Africa, which have huge reserves of oil and natural gas, have already initiated feasibility studies for the development of petrochemical industries within their borders.

The potential for petrochemical development in some countries of North Africa and the Middle East is based on the existence of proved and abundant sources of hydrocarbon raw materials, which at present are not being utilized to any great extent.

In the discussions that followed the presentation of the country papers and statements, there were indications that it would be more beneficial to plan petrochemical development on a regional basis, rather than for each country individually. Furthermore, it was evident that, in countries with abundant natural gas resources, the question of export markets outside the area looms large in the planning efforts. It was mentioned that regional co-operation is being seriously considered by some of the countries in this area with a view to developing a common market. Country studies and statements for Israel, Kuwait, Libya, Morocco, Saudi Arabia, Syria and the United Arab Republic were presented.

Europe

The growth of the petrochemical industry in Europe was slower immediately after the Second World War than it was in the United States. The reconstruction problems which arose during that period, the time lag in technological progress; the policy of the oil companies in locating the refineries near the oil or natural gas reserves, in order to avoid adding transport costs to the heavy capital costs, and the existence of a well-developed chemicals-from-coal industry were cited as factors responsible for the slower growth in Europe. At the end of the Second World War, nearly all European countries were still dependent for their organic chemical products on coal and raw materials of vegetable origin. After modest beginnings, the petrochemical industry made great strides in the past decade in western Europe. Production registered an almost eightfold increase during the period 1953-1960, and investment is estimated to have reached $3 billion in 1964. Increases in the fields of plastics, synthetic rubbers and synthetic fibres were significant.

Although refinery gases and natural gas are the most important sources of raw material in the United States, naphtha would be the major raw material for the petrochemical industry in Europe. From the experience of the European countries, it is evident that there is a close interrelationship between the development of the petrochemical industry and industrial development and technological progress. In fact, the most rapid growth in the petrochemical industry has taken place in the highly industrialized countries, and it is only now that less industrialized countries such as Spain, Portugal and Greece are beginning to build their petrochemical plants.

Concerning the structure of the European petrochemical industry, there is a strong tendency towards vertical integration to provide for diversification and ensure adequate sources of raw materials, as well as outlets for sales. There is also a considerable concentration of capital in the most important producer countries of Europe to support the heavy investment necessary not only for fixed assets, but also for the research required to keep pace with technological progress. In the Federal Republic of Germany, for instance, 75 per cent of petrochemical production comes from only five companies, two of them combined with oil companies; in the United Kingdom, about 25 per cent is in the hands of one major enterprise; in Italy, the industry is largely controlled by three firms and their subsidiaries and joint ventures. Even in France, where the most striking feature of the petrochemical industry is its apparent dispersal, most of the basic feed-stocks are supplied by five firms only.

Nevertheless, Europe's petrochemical industry has not reached a state of maturity. In spite of current overcapacity in some areas, investments continue to be high in research and development. Construction activity is rising strongly; petrochemicals are considered the most promising sector within the chemical industry.

With respect to Europe, the experiences of Poland, Romania, the Soviet Union, Turkey and Yugoslavia were were presented.

Latin America

Although a few small petrochemical plants were already established in the region twenty years ago, the petrochemical industry in Latin America really got started only after the Second World War. The industry has attempted to supply continuously expanding domestic markets, but because of the limitations in market size and the big investments required, there are relatively few plants in the region.

A trend is noticeable toward the installation of complexes or groups of plants which concentrate different units of production in one site. Examples were mentioned, in Mexico, Argentina and Brazil. The structure of the industry in Latin America is characterized by the concentration of production in state enterprises and foreign ventures.

With reference to raw materials for the petrochemical industry, in Argentina and Mexico the consumption of natural gas has been growing steadily and long gas pipelines have been constructed. In other countries of the region, which have big supplies of natural gas, different proportions of the gas are still being flared according to different patterns of utilization. There are 4,518 million cubic metres of oil reserves and 1,211 billion cubic metres of natural gas reserves. The refining capacity of Latin America in 1963 was 2·5 million barrels per day, 92 per cent of which is accounted for by refineries located in seven countries. The consumption forecast for refinery products in all of Latin America is 2·28 million barrels per day for 1970. However, not all the volume refined can be considered from the point of view of petrochemical raw materials, owing to the existence of relatively small distilleries dispersed over a wide area in a number of countries. Projects in preparation have taken this into account; a number of countries are planning to erect new and bigger units, especially for catalytic cracking and reforming. Also, in some cases, special steam-cracking units will be installed, especially where there are no refining facilities or supplies of natural gas. Steam cracking is already being installed in Mexico and Brazil.

Consumption forecasts were presented for a sample of twenty-four petrochemicals for 1970. For these products, 75 per cent of the total demand will be absorbed by Argentina, Brazil, Mexico and Venezuela. The main fields of growth will be plastics, synthetic fibres, synthetic rubber and detergents. Special attention is being paid to the production of fertilizers, and it is expected that in 1970 Latin America's production will be about 900,000 tons (N) of nitrogenous fertilizers.

In the last decade, an accelerated process of import substitution of chemical consumer goods took place, but owing to the relative completion of this stage, emphasis must now be transferred to that sector of the industry able to produce the primary and intermediate materials necessary to achieve higher rates of growth. It is in this respect that the petrochemical industry may play a very important role. Indeed, it can be expected that petrochemicals will become the main area of development in the chemical industry of Latin America.

Apparent consumption of chemicals in Latin America was estimated by ECLA to be of the order of $3 billion in 1959, with imports accounting for about 30 per cent of this total. For 1970, demand was projected to be of the order of $8 billion. The share of petrochemicals in the total was rather limited in 1959, but is expected to increase substantially by 1970. Since the proportion of imports of petrochemicals was much higher than the 30 per cent average for the entire chemical industry, the necessity of a considerable import substitution effort is foreseen for petrochemical raw materials and intermediates.

Participants from the Latin American countries represented in the Latin American Free Trade Area (LAFTA) expressed the following view: "While petrochemical industries are capital-intensive industries, there is a scarcity of domestic capital in the area; a high foreign exchange component of investment is required; economies of scale prevail in the development of petrochemical industries; full utilization of the locally available technology and skills is necessary; a better allocation of resources and markets is desirable; and the possible solution rests in the concept of complementation and integration of the petrochemical industries in Latin America, which has already been recommended by sectoral meetings to the Executive Committee of LAFTA in 1963 and 1964."

State oil companies in Latin America have already taken the initiative and some have signed agreements to study the complementing of their industries in all its aspects, especially in the field of petrochemicals, starting immediately with the exchange of technicians and technical information, utilization of idle capacities and exchange of products.

This trend towards integration has found recent expression in the meeting held in Buenos Aires under the auspices of Yacimientos Petrolíferos Fiscales (YPF), where all Latin American state oil agencies were represented and the basis for joint action was discussed. The establishment of a permanent organization was expected to be achieved during 1965.

The Conference reviewed country studies for Argentina, Brazil, Chile, Colombia, Ecuador, Mexico, Peru, Trinidad and Tobago, Uruguay and Venezuela.

FINANCIAL AND LEGAL ASPECTS OF THE PETROCHEMICAL INDUSTRY

Financial aspects

The scarcity of capital in developing countries, coupled with the fact that plants built on new sites there cost much more than they do in the more highly industrialized nations, where they can be integrated with existing manufacturing units and infra-structure, and the immensity of these infra-structure needs, poses particular problems for the financing of petrochemical ventures. The public sector would have to weigh investment in petrochemicals against a number of alternatives, especially those where public funds are essential, that is, investment in social and economic infra-structure. However, availability of funds for petrochemicals from the private investor may likewise be limited, because the bulk of such funds follows an investment pattern aimed at producing liquidity and a high rate of return. Thus, the foreign investor, private or public, may be called upon to play an important part in the industrialization of developing nations, especially since he has access to technical skills and research upon which sophisticated investment projects depend.

Since 1955, the flow of private capital from the main highly developed countries has been around $4 billion yearly, and by now is approximately equal to the total volume of public aid. The direction of the two flows is, however, quite different. Private investors have preferred Latin America to Africa and Asia: in 1957, Latin America's net long-term foreign capital inflow was $1·5 billion, as against $100 million in ten Asian low-income countries, with a population 3½ times that of Latin America. The gap has been filled, to an extent, by public funds. As of 1957, total United States direct investment in ventures involving less than 95 per cent ownership was about $1·7 billion in developing countries, compared with about $4·7 billion in industrialized countries. These figures may be taken as representative of the extent to which United States business participated in joint ventures abroad.

State concerns like the Ente Nazionale Idrocarburi (ENI) in Italy and the Institut français du pétrole (IFP) in France are favourable to entering joint arrangements with other state enterprises abroad and seek the participation of local governments. As a rule, companies in the United Kingdom and the Federal Republic of Germany are better disposed towards joint ventures than their American counterparts. However, it is the smaller capital exporting countries, notably Japan and Italy, which have the strongest preference for this type of investment. Also very important are licensing and technical assistance agreements, even in the absence of capital participation by foreign firms.

The importance of joint ventures in developing countries has recently increased and foreign investors tend to shift more and more to minority commitments. Among the developing countries, Latin America is the area where joint ventures constitute the largest proportion of foreign investment: as of 1958, in Brazil they made up over 20 per cent of $3 billion worth of total direct foreign investment; in Mexico, 11 per cent of M$5·555 billion of foreign investment in 1950-1957 was in joint ventures, and important partnership arrangements also exist in Colombia.

Joint ventures are generally predominant in manufacturing, typically the newer activities, which require extensive funds and technical know-how; petrochemical industries, of course, are very much included in this category. Participation by the local general public has so far been scanty, owing to the characteristic thinness of the capital market in developing countries, but the situation has been improving as financial institutions and capital market mechanisms have developed.

Developing countries have a tendency to prefer joint ventures because they permit local capital to participate in the benefits of economic development, generate a faster transmission of technical and organizational know-how and lessen the danger of foreign economic domination. It is sometimes argued that these motives contrast to some extent with the goal of maximization of foreign capital inflow in those cases where local capital could have found alternative means of productive employment; and that the requirement of joint partnership will have the effect of reducing the inflow of foreign capital without generating offsetting benefits for local capital. However, even if this proposition were correct, it underestimates the economic importance of rapid transmission of technical and managerial know-how.

In general, the governments of industrialized countries have set no definite policy with regard to joint ventures of national companies abroad. Private industry leans more and more towards acceptance of joint agreements in developing countries. As for the changing trend towards foreign minority participation, some companies in the industrialized countries feel that majority holding of an enterprise abroad implies the loss of those fiscal and public relations advantages which are derived from local identification of the venture.

The number of joint ventures in petrochemicals is relatively higher than in other industries, partly because there has recently been a general shift towards this form of investment, and partly because joint arrangement schemes are highly suitable to petrochemical projects. An analysis of the forms of ownership of petrochemical projects in developing countries as of 1963 showed that 35 per cent of foreign investments in all areas was in the form of joint local foreign ventures. The percentage was relatively higher in Asia (41 per cent) than in Latin America (32 per cent); no participation of local capital in foreign enterprises existed in Africa at that time.

Wholly foreign ventures constituted 32 per cent of all private ventures arranged according to specific classifications. They were relatively less important in Asia (23 per cent) than in Latin America (36 per cent). The proportion of wholly local ventures was, instead, similar in both regions; 36 per cent in Asia and 32 per cent in Latin America. Oil companies sponsored 12 out of 62 projects listed (19 per cent), and chemical companies sponsored 49 projects (78 per cent), oil companies were relatively more active in Asia than in Latin America.

State-owned and/or state-controlled projects comprised 36 per cent of all classified projects; the proportion was relatively much higher in Asia (42 per cent) than in Latin America (30 per cent), despite the extensive activities of state enterprises in the latter (notably PEMEX in Mexico, PETROBRAS in Brazil and YPF in Argentina).

The greater frequency of joint petrochemical ventures in Asia is not to be attributed to a higher preference of foreign investors for this form of venture; on the contrary, oil companies, which are generally less favourably disposed towards joint ventures, sponsor a relatively greater number of projects in Asia. The explanation lies in the regulations of national governments. The same factor is probably responsible for the lower number of projects wholly owned by foreigners in Asia than in Latin America. The role of state enterprises and national public intervention in the petrochemical field in developing countries is very significant and tends to increase in importance.

In general, the ability of a petrochemical concern in a developing country to finance its own expansion out of retained earnings will be greatly influenced by the economic policy of the government concerned and by the purpose which lay behind its very establishment. The experience of Japan was presented as a case study of a country that was able, over a short period, to bring about through financial and other measures a fast rate of development in the petrochemical industry. The significant growth of the Japanese petrochemical industry began in July 1955 with the initiation of the Ministry of International Trade and Industry's development plans. The total investment in the chemical industry up to that time was only about $90 million. Within a decade the investment in petrochemicals rose to about

$900 million. An additional $320 million in industries was expected for 1964.

The petrochemicals output in Japan in 1963 was valued at $500 million, with a sales turnover relative to fixed asset investment of about 70 per cent. Fourteen new companies, of which seven entered the field for the first time, were included in the First-term Programme for the development of petrochemicals in 1955. In the last five years, twenty-four new enterprises were established, of which six were joint ventures with foreign manufacturers. The total number of joint ventures at the present time is about ten.

Of the total investment of $900 million, $180 million (20 per cent) was in the form of capital and capital surplus; the balance of $720 million (80 per cent) was borrowed, mostly in the form of loans. In comparison, the average for manufacturing industries in Japan was 30 per cent capital and 70 per cent borrowings. The financing of new ventures still tends to rely heavily on outside sources, although the relative share is declining as more and more internally generated resources become available from the accelerated pace of growth of existing enterprises.

The Government of Japan encouraged the implementation of the First-term Programme for petrochemicals by providing Treasury funds, principally through the Government-sponsored Japan Development Bank. Though this source of funds amounts on the average to only about 6 per cent of total investments, and was as high as 10 to 15 per cent in individual cases, it was a sufficient stimulus to bring about joint or co-operative financing in the form of loans from financial institutions, such as the Industrial Bank of Japan, the Long-term Credit Bank, and the like, in combination with commercial banks and trust banks. In addition, sizable investments were made by the Japan Life Insurance Syndicate. The role of government-sponsored funds has tended to decrease, relatively speaking, in recent years, once the initial objective of launching the new industry was more or less achieved. This source of funds is expected to continue to be available, however, on a more highly selective basis.

The raising of funds in overseas capital markets for petrochemical development has assumed increasing importance in recent years, particularly in view of the somewhat tight domestic capital market. The growth potential of the industry, the quality of the available technical resources and world-wide scope of marketing activities have tended to attract foreign funds. Out of $900 million invested in petrochemicals, $132 million was of foreign origin, most of which was used for facilities and fixed assets. Actual foreign investment amounted to about $50 million representing $20 million in know-how subscribed as capital, $10 million in cash subscriptions and $20 million in loans. Joint venture companies with foreign participants, who as shareholders must hold less than 50 per cent of the voting rights, require governmental approval. Separate government authorization must be sought to convert know-how into non-cash share subscriptions, and, as in the case of regular fees and royalties, taxes are imposed on such payments.

In relation to other major industries in Japan, petrochemical development depends less on the securities market, that is, stocks and bonds, and relies much more on borrowings. The major stockholders are corporations and financial institutions; only a few petrochemical companies offer stocks on the open market. Thus the tendency has been for loans and internally generated resources to provide the bulk of funds for petrochemical ventures. In order to encourage greater utilization of internally generated resources, the petrochemical industry has been allowed liberal depreciation schedules, which also reflect the need to depreciate the assets relatively rapidly, in view of the inherent high rate of obsolescence of petrochemical technologies.

The discussion at the Conference indicated that a simple evaluation of petrochemical projects on the basis of projected commercial profitability, does not take into account problems of a national character, such as foreign currency shortages, unemployment, exploitation of natural resources and the more dynamic consequences resulting from the development of an industry, such as the spread of initiative, know-how, industrial skills and so on. The use of shadow prices instead of market prices was suggested as a means of arriving at a satisfactory solution. For example, if labour is unemployed, the social cost of unemployed labour is lower than existing wage rates. Similarly, if problems of foreign exchange shortages are of major importance, shadow prices could be used in the form of a higher exchange rate in the evaluation procedure. This could be developed further in terms of net cost to the economy per unit of foreign exchange earned.

Discussion then centred on foreign exchange problems, the shortage of foreign currencies and exchange control. It is clear that investment decisions cannot be based solely on considerations of foreign exchange savings, but for many developing countries with an adverse balance of international payments, the question of net foreign exchange savings necessarily plays an important role in investment decisions. Imports of finished goods involving an outflow of foreign exchange, which many developing countries cannot afford, should be balanced against possible domestic production of the products, even if this entails production at higher cost in local currency.

There was some debate as to whether public international sources of funds could be made available to develop petrochemical industries at lower interest rates than currently available. In the private sector, the International Finance Corporation is by its charter prevented from providing loan funds at rates lower than those prevailing in the established capital markets. The question was raised as to whether public international funds should not be looked upon as needed for development of petrochemical industries in the same light as roads, dams, harbours, and other infra-structure developments. No answer was given at the Conference; it was suggested that the International Bank for Reconstruction and Development (IBRD) be approached by interested parties. In this connexion, the meeting noted the efforts being made by the developing countries to set up within the United Nations family an international finance institution to provide long-term, low interest rate development loans to industry in the developing countries, since at the present time such assistance is not available from international institutions. It recommended that efforts be continued and intensified in that direction so as to realize this objective. The need for long-term development loan finances for developing countries for the promotion and rapid growth of petrochemical industries is very urgent. The Conference recommended that no efforts be spared to set up such an international institution at the earliest possible date.

PATENTS AND LICENSING AGREEMENTS

Since the available technology in the petrochemical field has been almost exclusively developed in the more industrialized countries, it will have to be transferred in some form of patent and licensing agreement in the course of implementing such industry in the developing countries.

The basis for any such agreement is the mutual recognition of the nature of the exclusive ownership of a new technology, and the need to guarantee the owner that the time, money and effort invested in developing it will be protected from competition by imitators as soon as it becomes public knowledge.

The matter of concern to all, and particularly to the recipient developing countries, relates to assurances and measures to avoid over-exploitation of the almost total technical and financial dependence of the developing countries on the transfer of an exclusive property. In the transfer of technology by licensing agreements, essentially two forms of technical properties are involved. The first of these is commonly referred to as a "patent"—an industrial property right confirmed by an individual government by deed, for a fixed number of years, to make a product or use a process. This right lies not in the possession of the scientific or technical knowledge incorporated therein, but in the exclusive right to use, and prevent others from using, that knowledge.

The second form of property rights involves "know-how", "technical data" and similar technical knowledge resulting from the accumulated skills and experience of the owner. Such rights, which have commercial value in the adoption of new technology, are not defined by government deed or document as in the case of a patent.

Licensing agreements are concerned with defining the mutual rights and obligations between the licensee and licenser, arising out of the proposed transfer of industrial property rights. It must be emphasized that the licensing of patent rights is determined solely by national laws, and that these laws vary from country to country in the extent to which certain products or processes are eligible for patenting and the degree to which the patent owner may exercise his monopoly. The provision of monopolistic power can be abused and misused, as in fixing, patent pooling and compulsory package licensing, which cannot be justified in the public interest. National patent laws are directed at control of such restrictive practices.

It seems doubtful that the legal strength of patent laws in any particular country affects to any great extent the decision to obtain patents. The available data also seem to indicate that patent owners rarely resort to litigation to enforce their proprietary rights. In the United States, for example, the 500 largest corporations were, on the average, involved in less than two law suits each during the period 1949–1958. The large disparity between the number of patents granted in developing countries, as compared with the industrialized countries, can probably be ascribed to the limited economic gains. There appears to be little interest in establishing a patent portfolio in a country where there is little likelihood of developing the technical potential for producing or using a product in the immediate future. This is particularly true in the petrochemical field, with its relatively high degree of technical obsolescence.

In any case, it is unlikely that a patent for petrochemical products or processes could be advantageously introduced into a developing country without the technical co-operation and collaboration, that is, the proprietary know-how, of the foreign licenser. This supply of know-how, particularly with reference to developing countries, could include not only the establishment of the plant and putting it "on stream", but also assistance in operation during the initial years, in the form of management contracts.

The tendency to participate in licensing arrangements covering both the patent and the know-how is prevalent in the petrochemical industry in the industrialized countries. These arrangements often include cross-licensing involving third parties and make it possible to enlist within a reasonably short time the most up-to-date research and development efforts of competing organizations. Petrochemical technology is subject to rapid changes, and there are pressures on the owners of proprietary knowledge to exploit a process promptly, or face the possibility that the process will be outmoded and replaced by newer ones.

Although there may be wide variations in the actual form of a license agreement, there are certain common provisions. These include: definition of processes, patent rights and proprietary knowledge, exclusive or non-exclusive nature of license, provisions for exchange of technical information, secrecy, time factor, royalties and compensations, engineering services and assistance, guarantees, warranties, liabilities and penalties, arbitration, *force majeure* and assignability.

In the assessment and evaluation of proprietary technical processes, the licensee from the developing country should attempt an evaluation in terms of capital investment, operating requirements, product specification, royalty and compensation, status of process development, commercial application, prior record of licenser, services offered and so on. Given the fundamental importance of technology in the industry, licensing agreements generally entail a very sizable financial burden on the licensee. In this connexion, the Conference noted the efforts now being made by the developing countries and the appropriate United Nations organs in connexion with know-how licensing problems and transfer of new technology. It recommended the following for consideration by these organs, particularly with reference to the rapid promotion of petrochemical industries in the developing countries:

(i) Licensing know-how fees now being charged should be reviewed so as to be levied commensurately with the size of the project, and not irrespective thereof.

(ii) To provide incentives for lower licensing fees, it is recommended that governments of developed countries provide to the licensers some form of income tax relief from know-how fees and royalties originating from the transfer of technologies to the developing countries, especially in the field of petrochemicals.

(iii) In view of the developing countries' need to export some of their new petrochemical industry products, it is recommended that petrochemical licensing agreements for developing countries should not be restrictive in the above respect. The developed countries should encourage such imports from the developing countries by sharing their own export markets with their licensees in the developing countries, such measures are essential to the rapid promotion and growth of the petrochemical industries, as well as to the reduction of the burden of payment in foreign currency through such export earnings.

With respect to patent and licensing agreements, the discussion centred on evaluation of the cost of a licence as compared with the total investment needed for a project. While some measure of the relative cost may be obtained by comparing the offers of alternative licence vendors, much reliance will have to be placed on the reputation, prestige, experience and good faith of a particular vendor. Royalty rates do vary a great deal from process to process. They may be directly based on actual expenditure incurred in the development of the process technology appropriately amortized over a period of years, or on a percentage of the sales price of the producers; or they may be evaluated in terms of the share of projected profits over the life of the licensing agreement in the event that a joint venture partnership is involved.

One representative then argued along the following lines. In most developing countries, the agricultural sector, principally food production, plays an important role in the development plans. Fertilizers are considered necessary to increase food productivity, and the aim of most developing countries is to make fertilizers available to the farmers at the lowest possible cost. This means that the capital cost of fertilizer projects should be brought down to a minimum; the latter includes royalty fees, which must be paid to a licenser and should also be minimized. It was pointed out that licensing is one of the important factors in developing petrochemicals, and that the transfer of technology to the developing countries should be made at relatively low cost. This would, in fact, constitute a realistic means by which the industrialized countries could help the developing countries.

LOCATION FACTORS IN THE PETROCHEMICAL INDUSTRY

THE MAJOR FACTORS to be considered in deciding on the location of petrochemical industries were summarized as follows: potential demand, domestic as well as export; availability of raw materials; possibility of by-product utilization; markets and distribution centres for the products; facilities for transport of raw materials and finished products; availability of facilities such as water, power and effluent disposal; prospects of expansion in the future and availability of skilled labour.

Availability of raw materials and markets are considered the most important factors in determining a suitable location for a petrochemical plant. With natural gas it is preferable to locate the plant near the source of raw material. If, however, liquid petroleum feed-stock is available, it may be possible to set up the units near the principal market or distributing centres. The ideal location, of course, would be where the raw material is easily available in the neighbourhood of a large market.

A recent tendency in the more advanced countries is to concentrate the production of petrochemical industries near a large refinery, because the investment per unit weight of the product is thereby reduced considerably. However, it may not be possible to set up units of comparable size in the first stage of industrialization in a developing country, because the delivered cost, say, per ton of nitrogen, to the farmer, as well as the cost of production, are economically determinant. The difficulties and costs of transport often dictate that in a large country, petroleum refineries with capacity of the order of 2 million tons a year may have to be set up in a dispersed manner. This would itself set a limit to the capacity for fertilizer or ethylene production that can be set up in the vicinity. For this reason, it may not be possible initially for developing countries to have units for ammonia synthesis with capacities of the order of 600 tons per stream, per day, and more, or naphtha crackers for about 200,000 tons of ethylene per year, now regarded as optimum in advanced countries. The actual size and location may have to be decided after making an economic balance of the economies of large-scale operation and the lower delivered cost obtained by decentralization.

One of the most important petrochemical products is synthetic ammonia utilized to produce nitrogenous fertilizers, demand for which is increasing in all countries. All countries also have a tendency to make this basic chemical within their borders to the extent that they possess the main raw material for the synthesis of ammonia, namely, natural gas or naphtha. One or both of these raw materials are available from natural sources in a number of developing countries, although in some countries petroleum naphtha is derived from refineries operating on imported petroleum crudes.

In selecting a site for a fertilizer factory, it is necessary to ensure that water to the extent of 20,000 gallons per day is available per daily ton of nitrogen capacity. It is also necessary to see that an adequate supply of water will be available when the capacity of the unit is doubled or trebled in time. If the steam-reforming process is used for the production of synthesis gas for ammonia, the requirement of power from an external source is not large. The use of electrolytic hydrogen may be avoided in ammonia synthesis, unless there are special reasons for its use. The reason is, to begin with, that electrolytic hydrogen is more expensive than hydrogen obtained from other sources. Also, a fertilizer factory based on electrolytic hydrogen ties up a large amount of power that is far more valuable for other industrial purposes, particularly in a developing country. The effluent from a fertilizer factory which uses hydrocarbon feed-stocks contains materials that are harmful to human and cattle health. Such effluents must therefore be rendered harmless by biological or other treatment before they are discharged into a river stream or estuary.

Among other petrochemicals, plastics, synthetic rubber and synthetic fibres are most important for developing countries. In many of these countries, some demand for plastics already exists. It is possible that this demand would increase considerably if local production were available, particularly in countries where, for instance, packing materials such as paper-board and tin-plate are not available locally. The three main plastics, polyethylene, PVC and polystyrene, require ethylene for their production. At the present time, units for the production of these plastics have been set up in some developing countries, with capacity as low as 5,000 tons a year. However, ethylene has been generally obtained from alcohol or other raw material rather than from a petrochemical source. If ethylene is derived from a petroleum source, it is much cheaper, particularly in the case of large-scale production. Some developing countries might find it profitable to make reciprocal arrangements, whereby only one plastic is produced in each country to supply all others taking part in the agreement. Whenever a cracking plant is set up for production of ethylene from petroleum feed-stocks, propylene, as well as higher olefins, are produced at the same time; and where the amount of propylene available is substantial and ammonia is also available in the same location, circumstances are favourable for the production of acrylic fibre. Similarly, under certain circumstances, it is possible to set up the production of nylon. However, since in the advanced countries, production of this fibre is already organized on a very large scale and at low cost, the units set up in the developing countries would have to be based essentially on local requirements.

With respect to labour, fertilizer and other petrochemical industries are capital-intensive and require a high proportion of skilled labour. However, their numbers are not large, and usually it is possible to draw personnel from existing industries, such as steel fabrication or refineries, and train them for their new responsibilities by organizing short-term courses. It is also desirable to depute some engineers abroad for training in similar factories, during the period of fabrication and erection of imported and local plant and equipment. Machinery manufacturers are usually able to provide assistance in making the necessary arrangements.

The Conference took note of recent developments in the transport technology of liquid ammonia and ethylene produced in large units. It was mentioned that a unit for production of anhydrous ammonia has already been set up in Trinidad, with a production capacity of 230,000 tons; this capacity will shortly be raised to 500,000 tons of ammonia per year. This large unit is being set up in order to produce ammonia at a very low price for export. The ammonia is stored in tankers at atmospheric pressure and a temperature of minus 28 F. Special ships, as well as receiving terminals in the importing countries, are provided to ensure that individual shipments of 9,000 tons of ammonia can be made. It is claimed that this system will assist the developing countries to produce nitrogen fertilizers in a shorter time: ammonia would be imported and either used as such or in the form of fertilizer compounds.

The position is similar with respect to the transport of liquid ethylene. It was stated that the transport cost of liquid ethylene decreases considerably when the total amount of ethylene transported to a single point increases from 10,000 to 50,000 tons a year. At the latter rate the cost of handling per ton of ethylene is as low as $4 per ton. It was also mentioned that the advantage of transport of liquid ethylene increases with distance. While in the case of much larger demand it would be more economic to produce ethylene in a naphtha cracker, a developing country requiring small amounts might find it useful to import liquid ethylene, in the initial stages.

In accordance with the above, it was suggested that gases associated with petroleum crudes that are now being flared in Iran, for example, could be used to establish an ammonia unit with a capacity of 150,000 tons or more in a single stream; it would then be profitable to transport the ammonia to India, for instance, at a delivered price lower than the cost of production in the importing countries. While this would not provide an outlet for the entire volume of gases that are flared today in Iran alone, it might be one method of utilizing part of the gas. It was also claimed that, not only would the cost of ammonia transported in this way be lower, but also there would be a foreign exchange saving in such imports. On the other hand, it was pointed out that in India petroleum crudes are imported to feed refineries set up mainly for the production of kerosene, diesel oil and furnace oil, with a light fraction supplying motor gasoline as well as surplus naphtha. If kerosene and diesel and furnace oil were imported separately, they would cost much more than the crude from which they are produced in a refinery. Under such circumstances, the surplus naphtha has no foreign exchange cost. Therefore, any calculation which purports to show that it is cheaper in terms of foreign exchange to import ammonia than to make it from locally available surplus naphtha is based on an erroneous assumption. It is therefore unlikely that a country which has a surplus of naphtha would be interested in importing ammonia, since this would aggravate the problem of surplus naphtha disposal.

The Conference has before it two papers which described petrochemical complexes developed in Japan and Mexico, respectively. In the case of Japan, it was indicated how a unit started out with a very low capacity for ethylene and was gradually converted into a unit with capacities comparable to those of the present day in advanced countries. It was also stated that, although in retrospect it would appear that the original unit was too small and therefore uneconomic in size, it created the necessary preliminary conditions for the subsequent building up of a larger petrochemical complex. The units established in Mexico also exemplify how local requirements were met by establishing these complexes. The general conclusions drawn by a study of these papers were that the concentration of several producing units in a well-planned petrochemical complex, sharing raw materials, infra-structure and overhead facilities, as well as the utilization of resulting by-products, tends to counteract the necessity of very large-scale capacity for economic production in single, isolated petrochemical plants; and that the requirements for each country must be thoroughly evaluated before the size and complexity of a petrochemical unit to be set up in a particular location can be determined.

Considerable discussion took place in the Conference about the possibility of establishing units with large capacity for production of ammonia at locations where natural gas or associated gas are available at a very low cost. In this respect, reference was made to the case of Trinidad, where anhydrous ammonia plants have been set up essentially for export. It is possible, however, that the example of Trinidad and Tobago will not be generally applicable. The success of ammonia manufacture in Trinidad is due largely to its location near a very large and cost-conscious consumer market. If similar circumstances were available elsewhere or if it were possible to make barter arrangements between importing and exporting countries, ammonia units of large size could be established in locations where low-priced hydrocarbon gas is available. However, it is likely that in many developing countries foreign exchange requirements would be higher for imported ammonia than for ammonia obtained from domestic production, where only a small portion of the cost of production would require foreign exchange. In some developing countries there would be an additional problem, since the existence of substantial refinery capacity set up for meeting local requirements for petroleum products gives rise to a substantial naphtha surplus; under these circumstances, imports of ammonia would not only create a problem of disposal of the naphtha surplus, but would also aggravate the problem of foreign exchange.

Finally it was stated that since the production of ammonia does not really provide an outlet for a large proportion of gases that are flared today in the Middle East and North Africa, some other solution must be found for the utilization of these gases. One solution would be to use them to produce cheap power for energy-intensive industries.

Interregional Symposium on Industrial Project Evaluation

Held in Prague, Czechoslovakia, from 11 to 29 October 1965

INDUSTRIAL PROJECT EVALUATION is of strategic importance to industrial growth under any economic system. Careful and systematic scrutiny of proposed projects based on a thorough investigation of their economic and technical feasibility is indispensable in selecting viable projects and in committing financial and technical resources to them. Poorly conceived or poorly timed projects inevitably result in considerable waste of investment capital. In addition, unless new projects are conceived to attain full utilization within a reasonable time, the invested capital simply remains frozen in the form of unproductive capacity, rather than being used more effectively elsewhere. In developing countries where the investment effort is by necessity correspondingly greater, and where investment capital and savings are limited, it is essential that the available resources be applied in the most productive way possible. Industrial project evaluation is, therefore, of crucial importance in these countries because of the need to select only those projects having the greatest growth potential. Keeping the above considerations in mind, the United Nations Centre for Industrial Development has already embarked upon a sustained programme of research, training and technical assistance in industrial project evaluation, as a substantial part of its programme of work in the field of industrial planning and programming.

As the first stage of this continuing effort, the Interregional Symposium on Industrial Project Evaluation was held in Prague from 11 to 29 October 1965, under the joint sponsorship of the United Nations and the Government of the Czechoslovak Socialist Republic. This Symposium constituted the first international gathering exclusively devoted to the consideration of issues and problems in industrial project evaluation.[1]

Participants from thirty developing countries in Africa, Asia, Europe, Latin America and the Middle East attended the Symposium on a fellowship basis under the sponsorship of the United Nations Bureau of Technical Assistance Operations. In addition, there was substantial representation of other countries as well as of regional organizations, national financial corporations and planning organizations. A large number of specialists in the field of industrial project evaluation also attended the Symposium in the capacity of observers.

The symposium examined all revelant aspects of industrial project evaluation. Among the subjects dealt with were: the relation of the proposed project to the general strategy of industrial development; essential elements in the preparation of a project; data and other information required for industrial project evaluation, and the institutional aspects of such evaluation. The core of the discussion included the issues and problems connected with commercial profitability and national economic profitability, inter-industry linkages, managerial and technical skills, etc., survey of current practices and theories in the field of industrial project evaluation, pricing problems with special reference to foreign exchange and foreign trade considerations, and financial planning and its appraisal. The various procedures and tools required for the follow-up and supervision of approved projects were surveyed. The criteria and methods of industrial project evaluation followed in developing countries, case studies illustrating them, and the problems encountered in the evaluation of industrial projects were highlighted in the course of the discussion. This discussion helped to clarify the scope of improving existing evaluation procedures and practices in the developing countries, and to formulate the programme of research, training and technical assistance recommended, including also guide-lines for the future work of the Centre for Industrial Development.

The various items of the agenda were examined against the background of the specific goal of developing countries to accelerate their industrial development. Understanding of the proper criteria and techniques of project evaluation was considered vital to the realization of this objective. With this in mind, the Symposium made a comprehensive review of the state of the art and in particular the experience of developing countries in industrial project evaluation, including a survey of the organizational framework available for project evaluation and an account of different criteria used and techniques adopted in their application. In

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[1] The Report on the Interregional Symposium on Industrial Project Evaluation, is available as a United Nations publication (Sales No.: 66.II.B.II). Selected Studies submitted to the Symposium will also appear as a United Nations publication.

the course of the deliberations, several issues and problems were highlighted leading to a number of conclusions.

It was found that the considerations applied in evaluating industrial projects in different developing countries varied in accordance with the availability and quality of data, availability and skills of personnel and computing facilities, which also were largely a reflection of the different stages of their development. It was agreed that there was wide scope and urgent necessity for improving existing practices and procedures of industrial project evaluation in all developing countries. It was also evident that there was no single uniform set of criteria and techniques that can be applied in all developing countries. Criteria adopted in developing countries would depend on development goals and relative weights attached to them, while techniques of their application would depend mainly on data, skills, computing facilities, etc. on the one hand, and economic systems and the forms of planning and stages of development on the other hand.

An industrial project should be evaluated within the framework of the general strategy of industrial development which, in essence, means the formulation of industrial priorities for a given period of time. These priorities should take into account potentials for import substitution as well as export promotion. Industrial sectoral programmes should be elaborated on the basis of these priorities. Internal consistency is of vital importance in formulating and co-ordinating the sectoral programme. In examining the relation of the proposed project to other projects, two types of relationships, i.e., competitive and complementary, should be distinguished and carefully appraised.

Appraisal of a project as well as its success depends partly on the thoroughness and reliability of project preparation, which must necessarily include exhaustive investigation of its technical, economic and financial feasibility. In addition, a project report should point out how the proposed project fits in with the broad national objectives and the development programme of the country, and should detail the various uncertainties and margins of error in estimating costs and benefits. Although blueprints and construction schedules are a part of the final (engineering) project report, the choice of a well-tried and commercially successful process of production and provisions for sound designing of the plant and scheduling of construction at minimum cost should be clearly laid down in a project report.

A project report should incorporate comprehensive data on private and social costs and benefits, foreign exchange effects, engineering and financial aspects, availability of technical know-how, availability of and arrangement for training technical and managerial personnel, infra-structural requirements, inter-industry effects, arrangements for the even flow of raw materials, intermediates, components and spare parts, retooling and servicing facilities, etc. The degree of detail and comprehensiveness required may vary with the size and complexity of the project.

The systematic assessment of data and information contained in project reports requires a wide range of skills, especially in the fields of engineering and technology, economics and accountancy and financial planning specifically conceived for project appraisal. It was recognized that there was a shortage of those skills in developing countries as well as of facilities for imparting such skills.

The Symposium considered that there were certain issues pertaining to the functions of evaluating agencies and their organizational set-up which required further research. These issues are mentioned below.

Commercial profitability alone is not a sufficient criterion in developing countries seeking accelerated industrial development. National economic profitability occupies a central place in various considerations applied in appraising an industrial project in developing countries. This is especially true in conditions of inflationary pressures, generated by the development process where most of the proposed projects may appear commercially successful.

Three methods, i.e., discounted cash flow method, payback or recoupment period and average return on investment, are available for estimating commercial profitability. In selecting different methods of estimating commercial profitability in developing countries, the earning streams at different points of time should be taken into consideration.

The vital importance of national economic profitability arises from three sets of factors. First, the market mechanism in developing countries (and even in developed countries) does not always reflect relative scarcities and consequently true social costs of various inputs. Market prices should not therefore be relied upon exclusively to allocate resources among various projects. The official exchange rate represents not infrequently an overvaluation of the currency. The market wage rate in economies with surplus labour does not reflect accurately the social opportunity cost of labour. The prevalent rate of interest often does not reflect the relative scarcity of capital or the productivity of capital investment. National economic profitability is designed to correct such distortions in input prices. Second, commercial profitability, as conceived by the single entrepreneur, does not necessarily take into account various development objectives such as stepping up the rate growth, expansion of employment opportunities, reduction of inequality among various income groups and regions, etc. These objectives are not only partially complementary with one another. It is therefore necessary to attach relative weights to the defined objectives. Third, the rate of interest in perfectly competitive conditions is supposed to represent the time preference of the community attaching relative weights to present consumption as compared with future consumption. However, perfectly competitive conditions are not to be found in any country and least of all in developing countries. In addition, in developing countries seeking to accelerate development, the vital issue of deciding the social time preference between present and future consumption cannot be left to the market mechanism.

The functions of attaching relative weights to defined development objectives and to the contributions of these objectives belong to the highest planning and political authorities of the country. It is necessary to bring home to these authorities the importance and imperative necessity of making these judgements without which it would be impossible to measure and assess adequately the national economic profitability of the proposed project.

Once the weights are given, it is operationally feasible to assess and measure adequately the national economic profitability of the proposed enterprise. The introduction of the measurement of national economic profitability will be a major advance in improving evaluating practices in developing countries.

In addition to the measurement of commercial profitability and national economic profitability, there are other important considerations in the evaluation of industrial projects which may or may not lend themselves easily to quantitative measurement. One of these considerations is the inter-industrial aspect or linkage effects. It includes on the cost side new supporting or servicing facilities, particularly infra-structural facilities such as transport and power, that may be required. On the benefit side, the output of the proposed project may meet the input needs of some other industries or sectors of the economy. In addition, the proposed project may give rise to new economic activities in the form of either forward or backward linkage.

The importance of carefully examining the required technical and managerial personnel for the proposed project arises from the fact that the realization of expected results depends on the efficient operation of the enterprise. This appraisal essentially consists of an assessment of the manning table of the proposed projects, scrutiny of the organizational plan and examination of the availability of skilled personnel, arrangement for training of nationals, and hiring of foreign experts on a temporary basis, and their respective costs. This appraisal is especially important in respect of functional managerial cadres (e.g., production manager, sales manager, etc.)

The shortage of skilled personnel in many developing countries is a serious limiting factor to industrialization. This can be solved satisfactorily only on the basis of long-term planning of human resources. The available evidence indicates that there is a direct relationship between the value added per employed person in a given industry and the skill composition of the work force in the same industry. This relationship worked out on the basis of international comparative data and long-term industrial sectoral programmes may be employed to forecast the skill composition required for various industries in the future. Measures can be devised to adapt and expand facilities for formal education, vocational training, in-plant training, etc. to meet these demands.

It is possible and necessary to evaluate the contribution of the proposed project in accumulating technical know-how and in creating a pool of managerial and technical personnel capable of operating other projects with similar production processes. For this purpose it is helpful if industries are classified on the basis of production processes.

The issue of the choice of location of industrial plants is complex and inevitably intertwined with issues of regional and urban development. It therefore needs to be tackled in a separate seminar or symposium.

It is also necessary to take into account other considerations such as the health of operatives, safeguards against accident, air and water pollution, etc. The minimum standards for them are or should be laid down by the government in the form of legally binding obligations.

Accounting prices are an instrument for applying the criterion of national economic profitability. It may be advisable, pending additional research and accumulation of experience and data, for the developing countries to adopt partial solutions, working out accounting prices by means of very simple methods for only those inputs (e.g., foreign exchange and capital) which are in acute short supply.

The evaluation of industrial projects in inflationary conditions remains unaltered if the relative rate of increase in all prices is uniform. However, if there is a change in the composition of relative prices under inflationary pressures, prices based on forecasts of changes in relative prices for important commodities and services should be used in working out cost-benefit ratios.

It is important to take into account foreign exchange cost and earnings in the evaluation of industrial projects. In making these estimates and calculating net foreign exchange earnings or savings, it is often advisable to use an accounting foreign exchange rate in place of the official foreign exchange rate.

The objective of systematic follow-up is to ensure that the project follows agreed lines. Since no project is likely to follow forecasts exactly because of changing conditions, follow-up should be made through continuous reappraisal of the project in the course of implementation. Two issues arising from follow-up deserve careful attention: the commercial success (or failure) of a project is not necessarily a valid guide to its success (or failure) in achieving national economic objectives; and a project may earn satisfactory or even high return in certain local conditions even though it is operated inefficiently.

There is a genuine need to improve in the shortest time possible the existing practices and procedures of industrial project evaluation. An effective way of increasing the competence of developing countries in this area would be through the organization of training workshops at national or subregional levels, under the sponsorship of the United Nations and the governments concerned. The basic objective of these workshops would be to impart instruction in the methodology of industrial project evaluation to individuals responsible for choosing among alternative projects.

There is also a shortage in many developing countries of trained personnel who can adequately perform the task of industrial project evaluation. The training of local cadres for this purpose and accumulation of experience by them will take considerable time. In view of this, the United Nations' future activity in the field of technical assistance should concentrate in part on:

(*a*) Providing the governments of developing countries, at their request, with assistance in evaluating existing or incoming industrial projects;

(*b*) Assisting governments of developing countries in setting up specialized institutions or departments for industrial project evaluation.

The deliberations of the Symposium brought forth several issues in industrial project evaluation on which further research and investigations were felt to be highly desirable. It is recognized first of all that it is important to link the procedures for project preparation, evaluation and selection to an explicit and operative concept of over-all industrial strategy. Secondly, in order to ensure thoroughness and reliability in project preparation, it is necessary to adopt sound methods and techniques which best suit the requirements of developing countries. Thirdly, data and information presented in support of a project should integrate the results of a thorough investigation encompassing the engineering, economic, and financial aspects of that project. Fourthly, a system for follow-up must be devised to secure timely detection and correction of shortcomings of the project as well as to ensure continued support for it. In view of the above premises, and taking into account the more detailed considerations of the final report, the Symposium felt that future activity of the Centre should be concentrated in part and on a continuing basis on the investigation of the following problems:

(*a*) Factors underlying the formulation of the general strategy of industrial development for developing economies at different stages of development and with different sizes of domestic markets;

(*b*) Methodologies of sectoral (branches of industry) industrial programming, evaluation criteria for sectoral programmes, evaluation techniques for individual projects within the setting of the sectoral targets, and elaboration of capital and other input coefficients for the principal branches of industries as a tool of sectoral programming;

(*c*) Functions and organization of work of evaluating agencies with special reference to their responsibility regarding project development and implementation;

(*d*) Comparative evaluation of the period of recoupment, or pay-back period, and discounted cash flow methods in estimating commercial profitability;

(*e*) Pilot studies in co-operation with developing countries in the application of the criterion of national economic profitability;

(*f*) A study clarifying the role of value judgements in the calculus of national economic profitability and relationship between these judgements and the possibilities for fulfilling different objectives;

(*g*) Treatment of uncertainty in the evaluation of industrial projects and possible solutions;

(*h*) methods of evaluating management, requirements and standards for the proposed projects;

(*i*) Required skill patterns for sectoral (branches of industries) development programmes or projections;

(*j*) Pilot studies designed to test the suitability of alternative techniques of using accounting prices in developing countries;

(*k*) The use of international prices for inputs and outputs and other methods for evaluation of export industry projects with a view to integrating them in international specialization, and

(*l*) Studies on follow-up practices in countries with different economic systems.

In addition to the long-term and continuous programme of work outlined above, the gap in the literature on industrial project evaluation makes essential the preparation of a Manual on Industrial Project Evaluation which can be used by evaluating agencies and educational and training institutions in developing countries.

The problems of location of industries in the evaluation and selection of industrial projects and the increasing relevance of this matter in the industrial development strategy of developing countries, as a result of the formation of common markets and other forms of economic unions all over the world, should also make it essential for the United Nations to hold at the earliest time possible a separate seminar or symposium on the complex problems of the choice of location for industrial projects. The corresponding agenda in this case should give special attention to the problems of locations of industries in the context of regional economic integration schemes.

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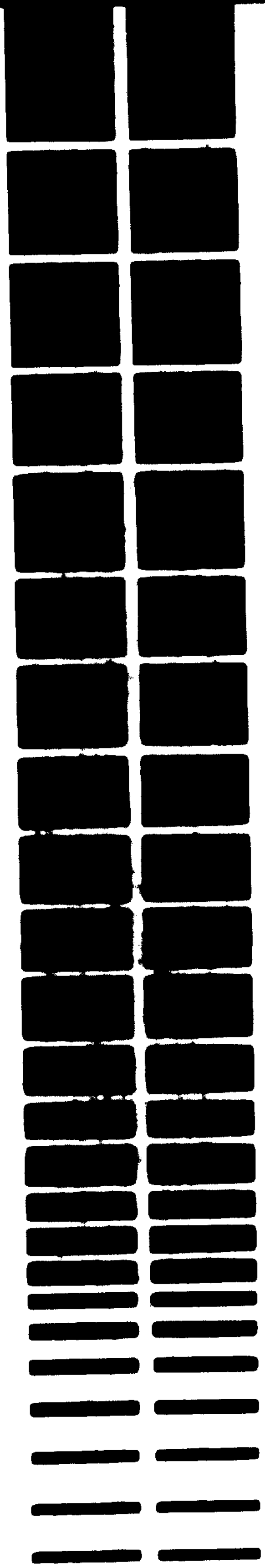

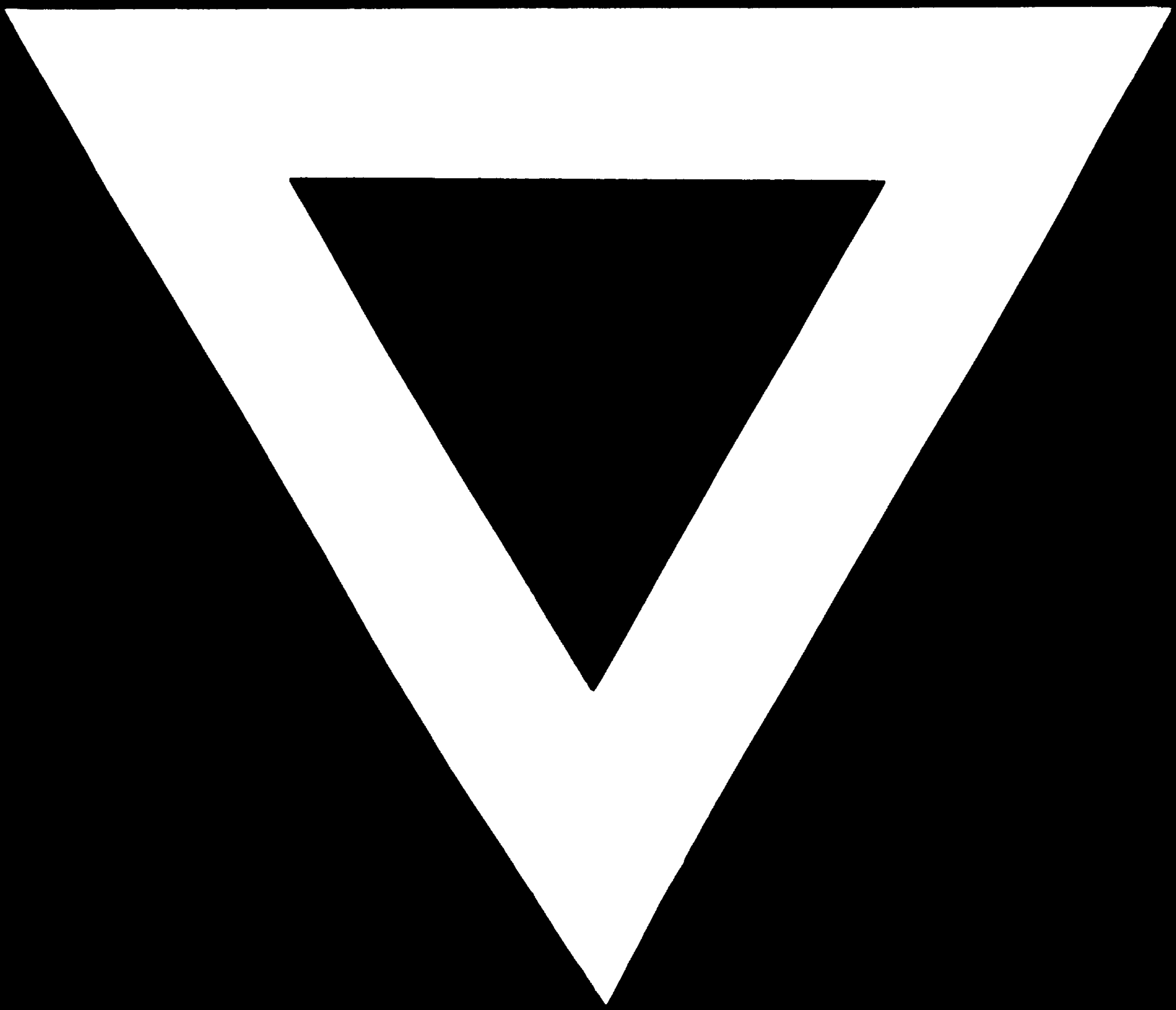

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