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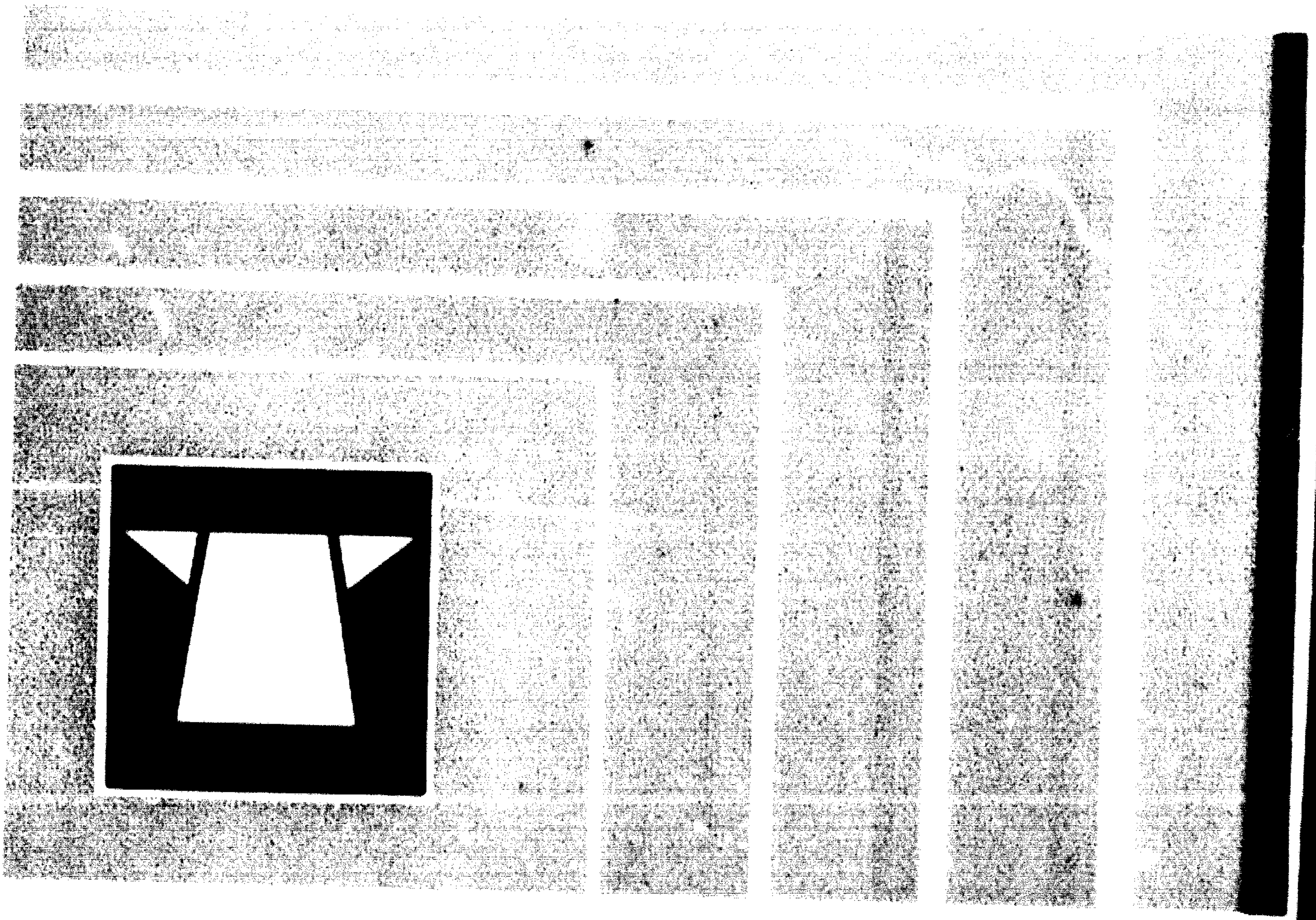
UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

# PLANNING AND PROGRAMMING OF THE METALWORKING INDUSTRIES WITH A SPECIAL VIEW TO EXPORTS



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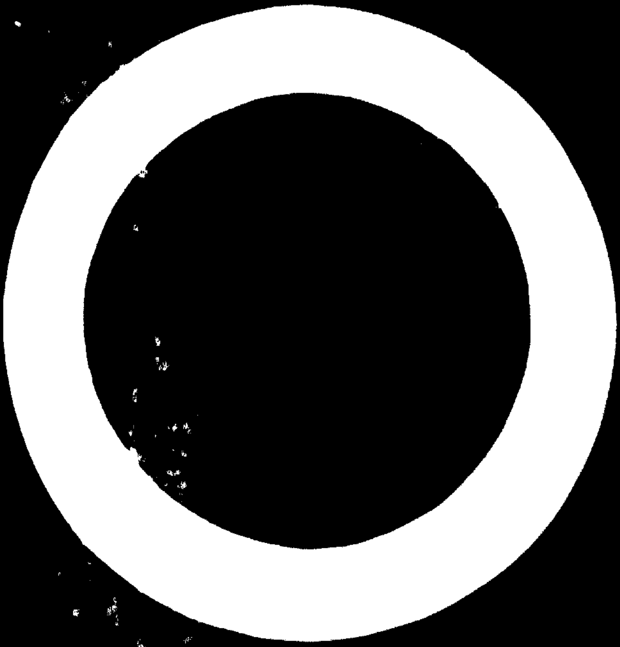

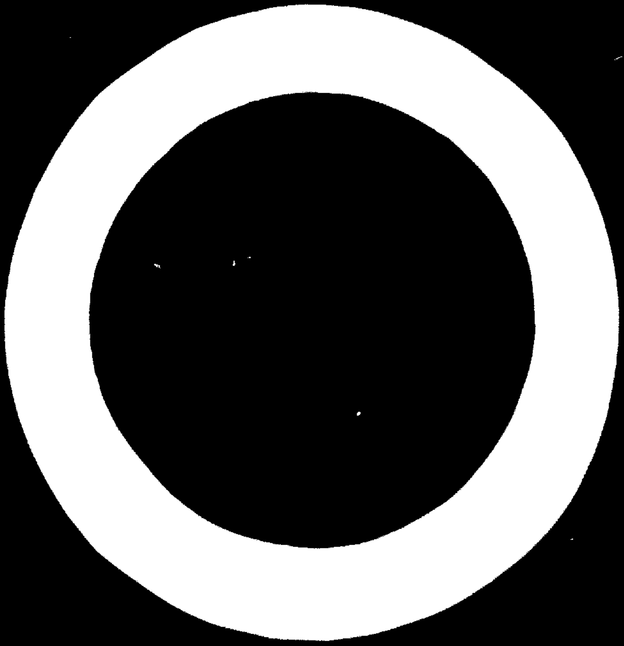

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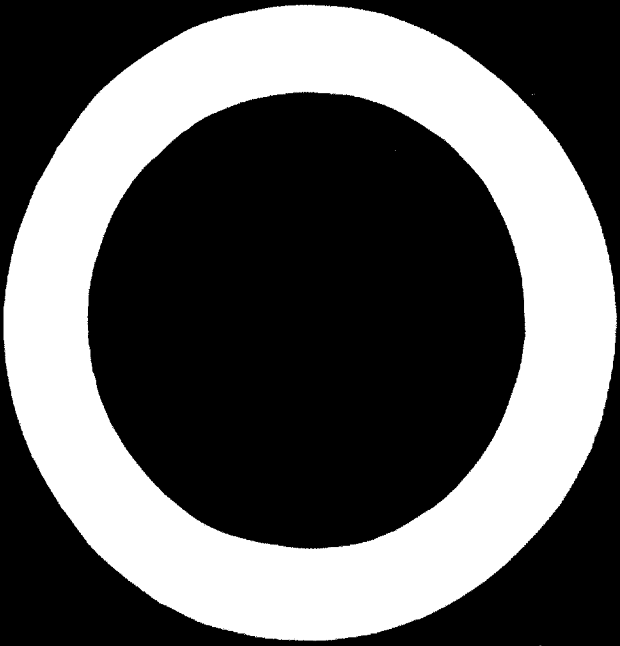

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
VIENNA

# PLANNING AND PROGRAMMING OF THE METALWORKING INDUSTRIES WITH A SPECIAL VIEW TO EXPORTS

UNITED NATIONS
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# *Preface*

This study is a part of a broader project undertaken by the United Nations Industrial Development Organization (UNIDO) concerned with the industries of the metalworking sector as potential export industries in developing countries. The key role of this sector as well as its export potential for developing countries were recognized in Resolution 1178 (XLI) of the Economic and Social Council of the United Nations on industrialization policies including policies for the promotion of export-oriented industries. The resolution specifically referred to metalworking industries in developing countries as examples of industries with export potential in the development of which "concurrent opportunities for import substitution . . . might be achieved".

The two studies reproduced in this publication were prepared for an Expert Group Meeting[1] on Metalworking Industries as Potential Export Industries in Developing Countries held in Vienna, 12–19 December 1969. Part I, "The Planning of Production and Exports in the Metalworking Industries", is by Mr. Thomas Vietorisz and Mr. Richard Lissak. Part II, "Programming of Production and Exports for Metalworking: Models and Procedures", is by Mr. Vietorisz.

The aim of the study was to develop a workable approach to the planning and programming of the metalworking sector in developing countries with a special view to exports. Given the general lack of orientation with regard to an effective planning approach to this sector, the study represents a significant advance. The conceptual orientation that has been achieved and the experience that has been gained through the collection of programming data now make it possible to recommend as a next phase an approximate but comprehensive technical-economic description of the key features of the sector as a whole in order to provide an over-all view of developmental possibilities and the identification of main lines of advantageous growth in individual countries. Since the completion of the present publication, a start has been made in this direction. A pilot study to survey the heavy electrical equipment manufacturing industry in Mexico, undertaken by the authors under the

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[1] The report of this meeting was published under the symbol ID/23, Volume I: *Metalworking Industries as Potential Export Industries in Developing Countries* (Sales No.: E.70.II.B.16).

auspices of the Basic Research Centre of the International Bank for Reconstruction and Development (IBRD), confirmed that the conceptual framework proposed in the present publication is viable.

On the other hand, several major problems remain without adequate solutions. One of them is the development of a practical short-cut to the problem of costing, that is, the provision of a system of success indicators for potential projects and product categories without full immersion in quantified technological detail.

A wide range of problems are associated with labour training, productivity, research and development, and innovations of technological change. Future progress in the solution of these problems must be grounded in concrete case studies of the proposed planning approach.

Part I of the study covers problems of planning methodology, the experience gained in the collection of empirical materials on a pilot basis, and the suggested application of selected concepts and empirical materials to over-all sectoral planning decisions in individual countries. The data for chapter 4 were compiled and organized by Mr. Nathan Ginsburg with the co-operation of Mr. Peter Bearse and Mr. Richard Lissak and the assistance of Mr. Robert Baker. Mr. Bano Fahrenstock was consultant on problems concerning transformers. The basic approach of semi-quantitative programming data was introduced by Professor Van Court Hare, Columbia University, a consultant on the study, who also organized the data collection effort at this level of detail and drafted the text of chapter 5.

The contributions of Mr. Martin Kenner and Miss Rachel Strauber were indispensable in providing a well-rounded background for the study. Mr. Peter Bearse was responsible for co-ordinating the computer programming work involved in the updating, indexing and selective output generation of the bibliography; he contributed also to the over-all integration of the methodology.

In the stage-by-stage development and refinement of the over-all methodological approach of the study, periodic staff discussions proved to be invaluable. The participation of Professor Van Court Hare, Mr. Stedman Noble, Professor Paul Medow and Mrs. Florence Krupa in these staff discussions and their fundamental contributions are gratefully acknowledged.

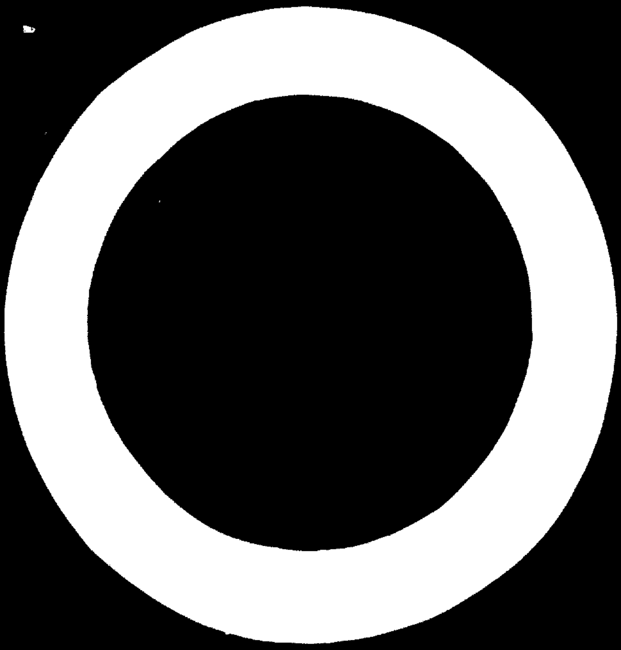
For the clarification of problems relating to the method of approach and the practical execution of the country studies, grateful acknowledgement is extended to the following individuals:

*In Israel:* Professor Abraham Ber, Technion, Haifa; Mr. Y. Merzel, Ministry of Commerce and Industry; and Mr. N. Pardo, Israel Investment Authority;

*In Hungary:* Mrs. János Deák, Ministry of Finance; Mr. Ferenc Nemes, Ministry of Metallurgy and Machine Building; and Mr. József Drecin, National Planning Board. Mr. György Cukor, Mr. János Kornai, Mr. László Csapó, Mr. András Bródy and Mr. György Kondor, Economic Research Institute of the Hungarian Academy of Sciences contributed to discussions of methodological issues in planning for the metalworking sector. Mr. Béla Martos, Economic Research Institute of the Hungarian Academy of Sciences, contributed to the evaluation of the project methodology in its final stage.

A number of contributions were made by staff members of UNIDO in discussions concerning both theoretical and practical problems of planning for the sector. The classification of the sector by industrial branches, given in the appendix to Part I, was prepared by the Export Industries Section of UNIDO. The co-operation of the United Nations Computing Centre was indispensable in reference work in connexion with the study, that of the Regional Commissions Section of the Department of Economic and Social Affairs of the United Nations is also gratefully acknowledged.

Part II is an extension of Part I into the sphere of programming models with attention centered on the handling of economies of scale. Three simple programming models are presented; they are based on some of the main features of the method discussed in Part I. While the models do not cover all the complexities involved, they provide a basis from which generalizations and modifications may be drawn.



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## Explanatory notes

The following symbols have been used throughout this publication:

The use of a hyphen (—) between years, e.g., 1963—1966, signifies the full period involved, including the beginning and end years.

References to "tons" indicate the short ton (0.907 metric tons) unless otherwise specified.

References to "dollars" indicate United States dollars.

Symbols of United Nations documents are composed of capital letters combined with figures. Mention of such a symbol indicates reference to a United Nations document.

Figures in square brackets [ ] refer to the list of references at the end of this publication.

*Part I*

# THE PLANNING OF PRODUCTION AND EXPORTS IN THE METALWORKING INDUSTRIES

*by Thomas Vietorisz and Richard Lissak*

## 1. The nature of the problem

The problems arising in the metalworking and engineering products sector are the most interesting as well as the most exasperating of the sectoral planning problems. They are of great practical significance because the metalworking sector is the key producer of capital goods and thus a strategic agent for growth. This sector is also a centre of innovation and a focus of the cultural change signalled by the upgrading of skills and organizational abilities at all levels that characterize economic development. At the same time, it is the most exasperating of the economic sectors since the problems that arise in it call into question many of the comfortably entrenched notions of the economist about matters such as the aggregative description of the phenomena connected with production, the role of the price system in decentralized resource allocations and the constancy of technical input coefficients. For this very reason, it is also the most challenging sector; progress toward solution of the problems it presents offers a hope of obtaining a new and clearer picture of the key characteristics of the economic process.

It has long been evident that the planning problems of this sector must be attacked at a fundamental level if progress is to be achieved toward the compilation of programming data and the definition of proper methods of planning procedure. Several attempts [1] to solve these problems have been made recently. However, none of the studies[1] seems to be entirely satisfactory. The present study attempts to synthesize these earlier approaches and extends their best features.

Much of the study is dedicated to the clarification of conceptual problems. Empirical work was originally to have been undertaken entirely in separately commissioned country studies but, due to major delays on

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[1] Some of the studies are discussed in a review of the reference literature in chapter 2.

the latter, some data have been gathered on a pilot basis in the United States primarily as a test of the methodological concepts.

The present study is part of a broader effort undertaken by UNIDO to promote the growth of new and dynamic export industries in the developing countries. Its specific aim is to improve the techniques of production and export planning in the metalworking and engineering products sector. For the purposes of the study, the sector is defined as including classes 35 through 39 of the International Standard Industrial Classification.[2]

In particular, the efforts of the study are focused on the objective of providing policy-makers with factual tools that will help them to answer such vital questions as:

The kind of investments that would be economically justified in new or expanded productive resources;

The branches of production and, within these branches, the product assortments that should receive the principal emphasis;

Taking into account the potentialities of the world market, the exports that deserve serious promotion;

The guiding principles to negotiate desirable foreign trade agreements.

### *Linkage between domestic production and exports*

The metalworking and engineering products sector presents both great opportunities and particular difficulties in the development of new, high-grade exports linked with systematic import substitution in a developing country. The opportunities are connected to the key role of this sector in economic development, as pointed out above. By simultaneous consideration of exports and the domestic market, economies of scale can be attained that would otherwise be impossible to achieve, and a source of foreign exchange earnings can be provided that is far less subject to price instabilities in the international market than the typical primary exports of the developing countries.

The close relationship between domestic production and exports in this sector is further underlined by the following institutional considerations. Exports in any sector, but particularly in the metalworking sector, which show marked dependence on technological advance and on a high degree of efficiency in regard to production methods and inspection techniques, will generally be very difficult to promote effectively unless

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[2] A classification of the activities of the sector into twelve major groups and 92 branches is given in the appendix. This classification has been prepared by the Export Industries Section of UNIDO.

they are based on a broad experience of sales on the domestic market. Foreign purchasers are understandably reluctant to commit themselves to a source of supply that has not passed the practical test of acceptance in its home market.

At the same time, potential domestic purchasers of newly introduced import-substituted metalworking products will show a similar distrust in regard to such considerations as the expected quality, performance, reliability of continuing service and spare-parts supply for the domestic production. The hesitancy can be most readily overcome by a simultaneous promotion of the products for export. The esteem of the products in the home market will rise in proportion to their acceptance in foreign markets.

This psychological acceptance of domestically produced metalworking products to the extent that they are accepted abroad is, of course, further supported by the requirements for quality and performance that are inevitably imposed on export products, as compared to the possible carelessness and even shoddiness of import-substituted products in their protected, isolated and non-competitive, small home markets. Temptations in this direction on the part of producers may be difficult to resist even with the best of intentions, since small crises that might appear to justify an erosion of quality are ever present in the daily operation of the industries. When a firm must produce for export in order to survive, it simply cannot permit the quality of its products to deteriorate.

The principal difficulties with regard to the metalworking sector are organizational rather than strictly technical. While much of the requisite technical know-how can, in principle, be readily obtained by any country that desires it, the proper individual and collective attitudes toward the organizational requirements of the modern production processes and the adoption of adequate planning procedures are also indispensable. These attitudes and procedures are required in the many activities of the metalworking and engineering sector in a manner to allow either competitive entry into the world markets or planned international specialization.

## *Difficulties of planning for the sector*

The diversity of metalworking machinery is well known; the number of sizes and types of just metalcutting machine tools has been recently estimated [2] to be more than 1,500. Such machines can be organized into shops or production departments in the most diverse ways. The number of different kinds of manufactured metalworking-engineering products is about 250,000 for a medium-sized country, which is defined as a country with a population of 10 million and annual *per capita* income of $400 and a fairly well developed metalworking sector. In the United States, procurement agencies of the federal government list over 4 million items; a majority of the items is produced in the metalworking sector (this includes military items).[3] In comparison to the diversity in this sector, the planning for the basic chemical industries is relatively simple: a United Nations study of the entire Latin American region encompassed a significant fraction of the production value of the sector by an investigation of about 70 products and 90 production processes. [3]

In the basic chemical industries a given plant generally produces only one kind of output (for example, an ammonia plant normally produces only ammonia); in the metalworking sector, on the contrary, a given piece of equipment characteristically turns out a wide variety of products. In principle, a lathe can turn out components for an unlimited range of end-products and even in practice its yearly capacity will be divided among many inidividual items. Forges or foundries are capable of an equally diverse output. As a result important economic connexions are established between the jointly produced products that make it impossible to "cost out" a given product independently of all other products. Thus, since there exists a great diversity of both productive resources and products, the consequences would appear to be that the metalworking sector cannot be adequately dealt with except by the simultaneous consideration of hundreds of thousands of interconnected details. This conclusion evidently reflects an inappropriate approach. It will be the task of this study to point the way toward a drastic simplification.

Decreasing costs in the metalworking sector appear in two guises. First, the real costs as measured in resource inputs decrease with the seriality (lot size) of production and second, independently of the former phenomenon, costs also fall with the scale of total yearly output of a productive facility. The result of these two effects is that there frequently exists a sharp lower limit to the feasible seriality or the total yearly production scale. The technology precludes the proportional subdivision and averaging of inputs for distinct production facilities and creates large mathematical difficulties for any programming effort; it excludes the possibility of an exact decentralization of production and investment decisions by any linear system of prices or other incentives. Thus, in the presence of a decreasing-cost technology, linear and even non-linear programming fail, and any cost analyses of individual enterprises in the sector can be built only on very shaky foundations. In such a situation the only known way of constructing an efficient plan is to define alternative industrial complexes based on individual combinations of the fixed

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[3] Estimate based on items listed in United States Government procurement catalogues.

costs that are implied by the lower limits on serialities and on total production scales and to choose the most favourable of these complexes.[4] Unfortunately, when comparing this requirement with the implications of the other difficulties, it becomes clear that an astronomical number of possible combinations exists. The common virtue of mathematical programming and of a decentralized market mechanism, provided that they are capable of operating in a given situation, is exactly that they cut through the combinational jungle of possible alternatives and lead directly to the optimum. Unfortunately, in the present situation these short-cuts are not applicable; this is the crux of the third difficulty that arises from decreasing production costs.

Owing to the three sources of difficulty discussed above, no suitable planning procedure exists that provides guidance in regard to the basic problems faced by the sector. The planning methods customarily employed are inadequate in one of two ways. (*a*) Each product or small group of products is investigated individually and the broader connexions are neglected. Then the cost estimates are excessively high and the prospects of capacity utilization are poor. Therefore too many production activities appear to be uneconomical. (*b*) Efficiency factors are not explored. Instead the emphasis is placed upon the elaboration of a single, coherent feasible plan. In either case it remains doubtful if a given plan has adequately succeeded in exploiting existing potentialities. The application of such methods in the absence of better alternatives often results in a sense of uncertainty about the appropriateness of basic planning decisions.

### *The requirements of a suitable planning methodology*

A planning approach is most urgently required that will yield an approximate but essentially correct over-all view of the entire sector. As long as this need has not been met, no amount of conscientious compilation of detail—of which there is no lack in many cases—will resolve the doubt as to whether the sector as a whole is moving in the right direction. In line with the objectives of the present study, such a direction must strike a mean course between the extremes of insufficient and underutilized capacities, between uneconomic diversification and overspecialization and between undue risks in production for the open world market and excessive rigidities in commitments to long-term trade agreements.

The definition of a successful planning methodology presupposes both an adequate technical-economic description of the sector that is not lost in detail and a programming technique that is applicable to the case

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[4] Fixed costs represent a simple approximation to more general types of decreasing-cost functions. The programming problems posed by decreasing costs are discussed in detail in chapter 3.

of decreasing costs and can thus handle the ensuing combinatorial problem of alternative industrial complexes. The two considerations are closely related since it is impossible to cut through the welter of technical data unless there already exists an awareness of the type of detail that will play a key role in the programming. At the same time, however, the task of programming cannot be formulated unless resources and activities are already suitably grouped and specified to suppress all but characteristic detail.

In the course of the present study, it became evident that the entire question of the level of detail at which the technical-economic description of the sector is attempted plays a key role both in the cost and speed of data collection and in the definition of the fundamental approach to be used for planning. It has been found best to specify three distinct levels of detail, the first two of which have been explored empirically: first the "semiquantitative" level which is suitable for preliminary orientation and preselection of the project; second the "fully quantified" level, which provides programming data for costing purposes, is the basis for feasibility studies; third, the level of concrete project engineering and blueprinting preparatory to the final go-ahead decision in plan execution.

The three levels are typical, but the possibility of additional intermediate levels that might become useful at some stages of programming need not be excluded. The threefold classification corresponds closely to the one employed in general for project evaluation and sectoral-level planning in the United Nations and in other studies.

The data for the present study have been collected on a pilot basis both at the semiquantitative and fully quantified levels. The third level of concrete project engineering is completely excluded by the adopted terms of reference. Programming strategies have also been explored primarily at the first two levels.

### *Organization of the study*

The study is organized as follows. After a survey of the literature in chapter 2, the key features of the approach adopted are given in chapter 3. The rationale of fully quantified programming data is discussed in chapter 4 and semiquantitative programming data in chapter 5. The application of the concepts to planning decisions and further studies in individual countries are discussed in chapter 6.

## 2. PREVIOUS PLANNING AND PROGRAMMING OF THE SECTOR

While there is a great deal of accumulated know-how in relation to the planning and programming of the sector, no satisfactory integrated approach exists for a fundamental attack on the difficulties described in chapter 1. Prior approaches to the problem of planning for the metalworking sector in developing countries have been largely concentrated in two areas. The first is the aggregate estimation of the desired growth of the sector, which is loosely coupled with product-by-product or, at best, branch-by-branch, feasibility studies or project analyses. The latter are intended to provide estimates of local production costs that can be compared with world market prices as guides to the decision whether a given project has a chance of success in the country under study. The other approach is the construction of the material balances that are characteristic of centrally planned economies in which most decisions concerning domestic production and foreign trade are prejudged on the basis of prior experience. Project-by-project cost studies enter only afterwards, primarily to complete the details of a plan for which the major aspects have already been determined.

The two approaches share the inability to relate organically the resource-allocation side of the planning process to the side of precise cost evaluation of individual activities in the framework of the plan as a whole. With the first approach, the neglect of technological interconnexions between commodities and branches of production leads to an overestimation of costs and an underevaluation of development possibilities: in so far as a process appears feasible at all, it tends to be oriented toward import substitution, and there is only a minimal consideration of the export market. With the second case insufficient attention is given to evaluation problems, with a resultant tendency to become excessively autarkic or at least not properly related to foreign trade potentials.

## *Centrally planned economies*

The metalworking and engineering products sector of the economy, like all other sectors, is necessarily subject to continual, practical decision-making in all centrally planned economies. Until very recently the focus of these planning efforts has been mainly upon the preparation of a consistent plan. The official descriptions [5] of the planning process present established practice. The details of recent methodological innovations [6] have been obtained in large part from the professional economic literature.[5] Questions concerning the efficient allocation of resources have been handled by the assignment of over-all priorities and the application of a variety of evaluation criteria to individual

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[5] A comparison of these sources reveals a tendency toward a great increase in emphasis upon formal analysis of efficiency problems in resource allocation.

projects. [7] As a result many technical details concerning the sector have been embodied in planning norms, manuals of engineers and designers and technical articles, while the procedures of plan preparation as well as the formulation of policies designed for increasing productivity and technical progress have been developed into a complex art. [8] This material is very useful as a source of reference, primarily in regard to practical problems of development policy and the kind of costing information that is subject to commercial secrecy in market economies. It does not, however, lend itself readily to summary but accurate technical descriptions of the sector that would be reasonably transferable from one country to another. Furthermore it does not directly permit a quantitative analysis of the problems posed by the process indivisibilities, product interrelations and economies of scale that must underlie the formulation of policies under the widely diverging conditions of different economies.

A good idea of the scope and content of the technical-economic materials from sources of the Union of Soviet Socialist Republics can be gained from a series of studies by the University of North Carolina [9], which contain very detailed literature citations up to approximately 1961. The studies are discussed in detail below. Another convenient guide to sources from the USSR and Eastern European countries is available in English through the translations of the Joint Publications Research Service, United States Department of Commerce. Even though some of those sources address themselves directly to the problem of planning in the sector [8], they do not give an integrated quantitative approach that is suitable for consideration of both the resource-allocation and the cost-evaluation aspects of sectoral planning.

During the course of the present study there have been a few limited opportunities to gather spot information on planning practice in the metalworking sector in centrally planned economies. The literature [6] indicates that planning for the metalworking sector in these countries is at present done largely in a pragmatic fashion [10], relying on detailed engineering information and the preparation of material balances but with little formal attention to problems of efficient resource allocation and cost evaluation.[6] The key quantitative features of the techniques used in centrally planned economies are: (*a*) principal reliance on material balances, (*b*) the prejudgement based on experience of proportions between domestic production, imports and exports, and their distribution among branches of the sector, (*c*) the use of technical norms for drawing up the material balances, (*d*) the necessarily broad aggregation in the balances characterizing this sector even though the material-balances approach

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[6] The valuable source survey of reference [10] discusses process-analysis type models applied to a number of industries in the USSR; however no model dealing with any metalworking industry is mentioned.

generally aims, in so far as possible, at homogeneous resource and product categories, (*e*) the existence of detailed project studies, (*f*) the lack of coherence between the material balances and the project studies owing to the fact that the latter are drawn up in terms of far more detailed product classes than the resource and product classes for which balances are prepared, (*g*) the use of project studies to complete the framework provided by the material balances, which is done in the course of detailed programming for the sector as the plan is executed and the consequent almost complete lack of feedback from project studies to the broad production, import-substitution and export decisions embodied in the plan.

The above characterization does not, of course, approach the inclusion of all features of the planning approach used in the sector; rather, it concentrates on those features that are of particular interest to the present study and omits a great deal of additional significant information. In order to adequately consider current practice, a description should include, for example, the organized flow of communications between the central, ministerial and enterprise-level planning organs, detailed production scheduling at the plant level and its relation to the planning process, the institutional features of policy concerning innovations, productivity and incentive systems, details of supply, financing, control of enterprises and many others.

It has been found that the quantitative features of the current over-all planning practice for the sector enumerated above do not reflect a general satisfaction with the method; on the contrary, the shortcomings of the existing, largely pragmatic approach are well recognized and deplored. No alternative is presently available; in particular, the current types of mathematical programming models were specifically rejected as direct decision-making tools because of the wide range of unacceptable oversimplifications that were known to be invariably involved in their construction. None the less, such models were considered as useful sources of background information provided that their results were viewed with proper critical reservations and placed in a broader perspective.

A very large linear-programming planning model for the entire economy is being built at the Economic Research Institute and the Computing Techniques Centre of the Hungarian Academy of Sciences. [11] It has two levels, which correspond to central and sectoral planning decisions, and is organized for computer solution by means of the well-known Dantzig-Wolfe "decomposition" technique. [12] There are 50 submodels [11] at the sectoral level; eleven of them in the broadly defined metalworking sector of the present study include 133 individual products. The model is an outstanding example of process analysis applied to the economy as a whole and to the individual sectors.

### *Process-analysis studies*

The two major academic process analysis studies[7] are by Markowitz and Rowe [13] (hereafter MR) and the University of North Carolina Center for Social Studies [9] (hereafter UNC). The term "process analysis" has been defined as follows:

> ". . . analysis of industrial capability through models reflecting the structure of industrial processes." [14]
>
> "The models are generally based upon relationships well known to the industrial engineer . . . The aim is to cast these relationships into a form usable for the analysis of economy-wide capabilities. In most cases the models are of the activity-analysis type . . ." [14]

A summary description and evaluation [15] of the two studies as well as an analytical comparison [16] with suggestions for generalization are available.

The two principal parts of the MR study are a "requirements analysis" and a "substitution analysis". Both are aimed at the definition of the capabilities of an existing set of productive facilities in the United States rather than at the construction of a set of investment policies for optimizing economic growth. In the requirements analysis, the input coefficients of about 50 types of metalworking and auxiliary machinery into 1,000 dollars' worth of the output of the major branches of the metalworking sector constitute the basic information.[8]

The knowledge of such input-requirement coefficients and an estimate of the existing machine-park of the sector permit the prediction of maximum productive capability in a particular line of output given the production levels of other outputs. In turn, this prediction can be refined by means of the second part of the study: that is, by substitution analysis. In the latter, the rigid one-to-one correspondence between outputs and input classes is relaxed by permitting alternative input combinations to occur (substitution between machines as between a lathe and a milling machine) in producing given outputs.[9]

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[7] Undoubtedly some relevant studies, particularly in Eastern Europe, have been omitted in the literature survey. Programming studies of rail transport, cement and ceramic pipe industries are known to have been undertaken in the USSR; and of the cotton textile, synthetic fibre and aluminium industries in Hungary, in addition to the two-level planning model referred to above.

[8] In the original version, there had been 25 major and 14 additional subclasses for a total of 39, while in the later version 46 are given. The numbers of industrial branches covered in these two versions are 51 and 45, respectively.

[9] The substitution analysis in the MR study is only outlined. Coefficients have been derived only for metalcutting machine tools and not by industrial branch but at a level of much greater technical detail than in the present study. This would have to be complemented by an analysis of demand, branch by branch at the same level of detail. Such a demand has never been actually estimated.

The UNC study covers heavy machine building in the USSR and is quite similar to the MR requirements analysis in its rigid association of inputs with outputs. The inputs are, however, not individual machines but co-ordinated groups of machines called "resource elements", which roughly correspond to a production shop, such as a forge, casting shop or machine shop, while the outputs are typical but highly specific individual end-products such as a particular tractor or a railway freight car. Several classes of such products are chosen as representative of each industrial branch, and the capital and flow inputs of each of these "representative products" are derived by a process of weighted averaging of the inputs of the "typical sample products". The coefficients thus constructed can be used for capability analysis much in the same way as the MR coefficients.[10]

The principal contribution of the two studies to the present study has been to help define the proper method and the proper level of detail for the description of technology in the sector. The concepts of resource element and typical product have been taken from the UNC study (see chapter 4 for exact definitions of these terms), while the analysis of substitution possibilities has been adapted from the MR study, even though at a lower level of technical detail. In general, the UNC study has been important in defining the core of the proposed fully quantified description of technology and in estimating that the required research task for completing a description of the sector, while onerous, is manageable.

In addition to the two studies, the Hungarian two-level planning model also contains a detailed process-analysis description of the metalworking sector. In the description, inputs are specified in terms of monetary costs rather than in physical units or in terms of resource elements. As in the other two studies, economies of scale due to aggregate output or lot size are left implicit; all the activities included in the model are permitted to vary in a proportional fashion. The detailed coefficients of the model have not been disclosed; information concerning it has been obtained from a published summary description [11] and personal communications.

With the exception of a model for Mexico [17] in which the metalworking sector was schematically sketched using American data from the MR study, the Hungarian model is the only instance of a technical-economic description of the metalworking sector in the context of an economy as a whole. Therefore, it is very important from the point of view of the programming tasks of the present study. Although the description of the sector is not sufficiently detailed, the use of costs rather than physical units reduces the operating significance of the input data.

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[10] Key characteristics of this study are discussed in detail in chapter 4.

Furthermore, economies of scale are not quantified; these defects of the model can be readily remedied by building a third, more detailed level below the two existing ones. This has reportedly already been completed for another sector of the model, namely, in mining. The existence of a comprehensive process-analysis type model for the economy as a whole permits experimentation with a variety of programming approaches to the metalworking sector and evaluation of the repercussions of either sectoral decisions on the rest of the economy or of changes in the rest of the economy upon the desirable structure and development of the sector.

### *Other process-analysis data*

In defining the suggested approach of the present study, the MR and UNC studies have been complemented by some technical-economic data that do not constitute complete process-analysis studies. However, because of the similarities in approach, they have provided particularly valuable details of technical description and programming methodology.

An interesting set of technical-economic studies pertaining to the sector was developed for the Latin American Meeting of Experts on Steel Making and Transforming Industries held at São Paulo, Brazil, in 1956. Unfortunately, the studies have not been included in the published proceedings, which concentrate on steel making. [18] They include technical and economic aspects of casting, forging and machining. [18]—[23] In an outstanding contribution, Podgorski attempts to integrate these aspects into a comprehensive method for the sector. [20] Two papers on economies of scale in steel tube-making and boiler shops reflect a similar approach. [24] All of the data are particularly valuable for secondary corrections for capacity and flow input coefficients based on resource elements when developing fully quantified programming data.

### *Programming of the sector by aggregate projections*

Aggregate projections of the sector do not attempt to directly describe technological relationships; instead various aggregative measures characterizing the sector are developed and are projected in simple ways after correlation with explicatory variables. There are statistical correlations with explicatory variables. There are statistical correlations for a number of industries. [25] Of particular interest are the projections of the United Nations Economic Commission for Latin America (ECLA), which employ a number of variations of this technique.

The scale of output of the sector and of its branches is quantified in terms of total value or total tonnage. Demand for the sector as a whole can be projected by input-output methods, as in the ECLA study for Peru in which the sector is treated as one grouping in a 20 × 20 table. [26]

The branches of the sector are subsequently projected by correlation with the scales of the industries that use their products; for example, tin cans with canned fish products and mining machinery with mining. A similar procedure for projecting demand is followed in an ECLA study in Brazil, [22] where the demand for chemical, petroleum-refining, cement-producing, power-generating and other equipment is projected on the basis of the estimated growth of the same industries complemented by the precise equipment inputs of known projects targeted for future realization. A study of the metal-transforming industry in Venezuela [21] follows an analogous procedure.

In each of these cases, however, the key economic decision concerns the division of total demand between domestic production and imports and cannot be taken on the basis of projections alone. To arrive at a decision, ECLA has followed a pragmatic but none the less useful technique. All available information is collected and organized branch by branch, beginning with production and import trends and complemented by indicators such as capital intensity, the level of skills and the share of domestic raw material inputs. While the data do not lend themselves to a direct computation of future import substitution percentages, after they are collected it is possible for small groups of experts (in addition to the personnel of the study, local businessmen, engineers, economists and government officials) to evaluate the data The required future percentages are thus found in an intuitive but potentially quite reliable manner. In the case of machine-tool production, [23], [27], [28] the demand estimate is somewhat different, but the appraisal of domestic production possibilities is similar. In no case is there a comprehensive quantification of product interrelations, resource indivisibilities and the influence of lot size on required inputs that would be necessary for a critical appraisal of the present structure and optimal growth characteristics of the sector; [19], [23] instead there is an ingenious and effective method to extrapolate the trend of development, assuming an increasingly efficient use of opportunities in the framework of given structural and institutional characteristics.[11]

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[11] The approaches of the MR and UNC studies are considered and rejected [19] for application to a study of the machine-tool industry in Brazil and other Latin American countries on the grounds that the available coefficients are non-transferable because they are incompatible with existing practice (regardless of efficiency) and that the development of suitable coefficients is impossible or excessively burdensome. In reference [23] a number of technical-economic norms are taken from the detailed study of five model machine-tool plants of progressively increasing size. There are three small models that are based on existing practices in Brazil. No consideration is given to the question whether the use of such small plants which is characteristic of widely dispersed production in an unplanned proliferation of small enterprises is inherently efficient or not. The remaining two models are based on Western European practice and are of larger sizes not yet encountered in Latin America.

In addition to the work of ECLA, aggregate projections of the sector appear in a number of economy-wide programming models in which domestic production and imports are explicitly considered as competing alternatives even though still at a highly aggregated level. Chenery's model is one of the first of the type. [29] It is based on an input-output table for Italy and Southern Italian data. The mechanical sector is one of fourteen industry groupings in it. A particularly interesting methodological feature of this model is the consideration given to the effects of increasing product diversity and other sources of increased costs as the degree of import substitution increases while total demand is constant. This feature allows the quantification of the diminishing returns that accrue to import substitution in various sectors and ensures that an efficient programme will push such efforts up to a common economic limit. The analogous device of a step function to quantify increasing costs has been used in a linear programming model [30] of the Greek economy.[12] The device of quantifying increasing costs as a function of the scale of the sector at an aggregate level is an important element of the methodology of using fully quantified programming data explored in the present study.

Among a number of similar models, two are mentioned. A model for India by Eckaus and Lefeber [31] treats the equipment sector as one of eleven industry groupings in a multi-period formulation that permits the introduction of the time lags and the exploration of efficient growth possibilities over a span of years. There are versions of this model with a more detailed sectoral breakdown. A model for the key sectors of the Mexican economy by Manne [17] merits special attention, since it considers the metalworking-machinery sector in a breakdown of 28 branches, each represented by a commodity row and by a corresponding production activity. The technical coefficients for the breakdown have been adapted provisionally from the coefficients of the MR study covering conditions in the United States. Subject to obvious reservations concerning the reliability of such data, it is interesting to note that the model projects domestic production rather than imports for each branch of the sector.[13]

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[12] In the model, the metalworking-engineering products sector is divided into two parts; transport equipment appears as one of the fifteen industrial groupings, while the rest of the sector is included in "manufacturing".

[13] The model contains no provision for increasing costs in each branch and thus exhibits the all-or-nothing behaviour typical of linear models. An independent estimate [32] based on an ingenious adaptation of United States census data on establishment size distribution to an extrapolation from the United States to the much smaller Mexican market (0.5 per cent of the United States market) gives the rough indication that two-thirds of imports in the sector could be reasonably considered for substitution.

## *Other previous work*

### *United Nations agencies and consultants*

An analysis of the sector based on statistics from a large number of countries was prepared for the Centre for Industrial Development (CID). [33] A series of important papers have also been published in the *Industrialization and Productivity* bulletins. A paper by Melman [34] is outstanding for its wealth of ideas and novel approaches. Descriptive studies are available for several areas; the most comprehensive are by the Economic Commission for Europe (ECE) [35] and the Economic Commission for Asia and the Far East (ECAFE). [36] Considerable work on the machine-tool industry was undertaken by CID. [2] Many papers were prepared for the Interregional Symposium on the Development of Metalworking Industries in Developing Countries [37] in 1966. The more than 2,000 papers prepared for the 1963 Geneva Conference on the Application of Science and Technology for the Benefit of the Less Developed Countries [38] include about 40 that are relevant to the problems of the sector because they offer qualitative insights rather than a basis for quantification.

### *Foreign-aid agencies and consultants of the United States*

The Agency for International Development and its predecessors have published hundreds of technical-economic papers and reports under several acronyms (MSA, FOA, ICA and, currently, AID). Of these, about four dozen refer to branches of the metalworking sector. In addition, a collection of Industry Profiles [39] organized according to United States census classes and containing extensive data compilations for branches of the sector is also available. While these sources contain valuable reference material, their general focus on establishment-by-establishment presentation of data, with no consideration given to broader product interrelations, resource indivisibilities and other factors crucial for a proper planning and programming of the sector, reduces their direct usefulness for planning purposes. There is also a tendency to stress consideration of the smaller establishments with consequently little information on economies of scale. None the less, they offer significant help in the technical-economic description of the sector.

### *Industrial economics literature*

Monographs and industrial economics textbooks focus primarily on institutional and market characteristics. In these sources, often economies of scale are measured in some reasonably aggregative fashion for purposes of analysing conditions of entry; for example, minimum economic scales for stampings, motor manufacture and assembly are given in reference [40] for the automotive industry. Work on capital-labour substitution in machinery by Boon deserves special mention. [41]

*Technical literature*

Industrial texts that contain process descriptions and estimating procedures have been very valuable for the present study.[14] They are essential aids in the technical-economic description of the sector. The periodical literature is too numerous to be considered here.

*Direct technical-economic information from industry sources*

Among the principal categories are: published standards, manufacturers' specifications available to users of their products, confidential production and costs data of private firms, which can sometimes be obtained indirectly by engaging the services of consulting engineers familiar with this material (such consultants can base conclusions on the data without revealing individual items), manufacturers' and retail catalogues and trade-association statistics.[15] Examples of the use of information drawn from the miscellaneous sources are given in chapters 4 and 5.

## 3. KEY FEATURES OF THE STUDY

### *Strategic considerations*

The present study is an attempt to consider the characteristic difficulties and complexities of the sector at a fundamental level and to evolve an integrated approach to the planning of both domestic production and foreign trade. The strategic considerations that underlie the choice of approaches in planning for the sector are multipurpose production facilities and capacity use, lot size and standardization, exports, specialization and trade agreements, a two-level planning framework and programming models and the description of technology and the information-system approach.

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[14] Reference [42] contains chapters on the machine-tool, motor, aircraft, shipbuilding and electronic industries and the cutlery trade. Reference [43] contains chapters on the automobile and tin-can industries. Reference [44] contains chapters on the engineering, motor-vehicle, and shipbuilding and marine engineering industries.

[15] Technical-economic data of a similar nature available in the planning norms of centrally planned economies have already been mentioned. Among published sources is the work of Fekete *et al.* [45].

### *Multipurpose production facilities and capacity utilization*

Although multipurpose production facilities are characteristic of the metalworking sector as a whole, there are branches of the sector that use special-purpose equipment. However the essential core of the sector contains a common set of resource-element inputs.

A multipurpose resource element is identical with a shop, that is, with a casting shop, a forge or a machine shop. The advantage of this concept is that detailed records of individual machines in the metalworking operations are not necessary. Thus lathes, drill presses, planing and boring machines of a certain size and accuracy are handled as a single machine shop, and input requirements for a certain product can be expressed in terms of tons or shop-hours. Resource elements such as casting and forging can be handled similarly. An industrial branch can then be analysed quantitatively by defining a limited number of typical products and investigating the input requirements of resource-element (shop) units in these products. The total required shop-hour or tonnage capacities of different shops can then be derived for an industrial branch by a weighted averaging of the various typical products.

The appropriate capacity of each resource element in the metalworking industries is a difficult planning problem for both maintenance and investment. Some resource elements such as heavy forges have very large annual capacities, and it is not feasible, except perhaps in the larger industrialized countries, to achieve full utilization of such a resource element on the basis of the input requirements of a single branch, such as agricultural equipment or electrical machinery. On the contrary, it is desirable that all the various branches of the economy of a developing country should participate in raising the use of the capacity of such a forge, since there is an inherent indivisibility. The forge is either established at the given yearly capacity or it is not; one cannot invest in one-fourth of a forge. The same problem exists with regard to other resource elements, especially those adapted to handling outsize or heavy workpieces, and those designed for specialized jobs. Therefore since the proper use of productive capacity requires the sharing of this capacity among various branches of the economy, the planning process for the sector must necessarily cut across these branches.

### *Lot size and standardization*

One of the key determinants of cost in metalworking is seriality: that is, the length of a production run of identical workpieces. The degree of seriality affects the total number of shop-hours required to produce a single workpiece, the necessary labour skills, tooling material, floor space and inputs. For example, to drill holes in the flanges of electical motors, it would be worth while to construct an elaborate jig to hold the workpiece in place and perhaps drill several holes simultaneously if a thousand units are produced in a single run, thereby reducing the shop hours per workpiece. The procedure requires a greater input of tool- and die-making skills than the hand production of single units. From the point of view of planning methodology, this phenomenon not only forces the subclassification of resource elements by seriality but also places a heavy premium on the widest possible use of standard end-products as well as standard components and subassemblies within the sector. The latter may range from nuts and bolts to more complex elements such as motors, clutches and transmissions. Such standardization has inherent disadvantages as well as advantages beyond a certain point, since it sacrifices the full adaptation of design to the particular requirements of an individual product. Only a sector-wide planning approach can balance all the advantages of increased seriality against the disadvantages of greater rigidity in the design, since the gains of standardization depend on total seriality that often may not be achieved except in the sector as a whole.

### *Exports, specialization and trade agreements*

Non-traditional exports from developing countries are, to paraphrase Mark Twain, like the weather: everybody complains about them but nobody does anything about them. The highly industrialized countries have thus far moved with glacial slowness in this area, and the developing countries lack the proper instruments with which to attack the problem effectively.[16] Why should a developing country purchase the potential surplus of another developing country when such items are likely to be more expensive, of lower quality, with poor or non-existent service facilities, without financing aids and other disadvantages, as compared with imports from a developed country? Clearly the overruling potential incentive for non-traditional exports is mutuality.

In other sectors the requisite joint planning of industrial growth encounters the very severe problem of the acceptable apportionment benefits. In the Central American Common Market, for example, there has been continuous discord over the location of the handful of very large plants (chemicals, petroleum refining, rayon and glass) intended to serve the market as a whole. In the metalworking sector, fortunately, the large diversity of products helps the kind of specialization that will maintain a continuously balanced allotment of benefits to all participants from the very beginning. This need not mean that trade must be balanced exclusively in the sector. Since production facilities are bulky and indivisible, the more advanced (large, heavier and more specialized) resource elements

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[16] The question of non-traditional exports from developing countries has been thoroughly reviewed. [46]

may well exist only in one member of the group at any given stage of growth, and the benefits may be partly balanced by other sectors.

There is an evident advantage in arranging trade agreements on a multilateral basis (possibly in the framework of a common market), since this increases the market and reduces rigidities and excessive dependence on individual partners. There is also, however, a corresponding increase in difficulties, not the least of which is the inability of policy-makers to predict confidently the potential benefits and costs of any given political-economic agreement. A better grasp of the economic realities in the sector will aid the negotiation of trade agreements.

An understanding of the economic realities also contributes to the implementation of the possibilities for sectoral trade with the industrialized countries either under special agreements or on the open world market. The experience of these countries in their trade in metalworking and engineering products with each other has been that technical and economic progress has contributed to specialization and increased trade. Thus the more economic growth the developing countries can achieve by means of multilateral trade agreements with each other, the greater the stimulus for expanded trade among these countries as a group and with the industrialized countries as a group. Trade agreements based on joint supranational planning of the sector in the developing countries are thus not competitive with increased trade with the industrialized countries: on the contrary, they are complementary to it. As a foundation for the evaluation of various trade possibilities, it is thus essential to define the range of appropriate resource combinations and product assortments in the sector for a number of stages of economic development.

## *A two-level planning framework and programming models*

An approach that considers planning and programming for the economy as a whole in which the planning problems of individual sectors are subordinate is indispensable for rational planning decisions. The metalworking sector should be placed in this context. Two-level (or multi-level) programming models are well-known conceptual tools [12], [47], [48] that permit experimentation with the key aspects of the interrelation between decisions for the entire economy and sectoral decisions. They establish channels of interaction between the upper and lower levels that may consist of steering prices or resource allocations communicated from the upper to the lower level and corresponding resource claims (in response to steering prices) or shadow resource evaluations (in response to specific resource allocations) communicated from the lower to the upper level. These models, however, cannot handle the economies of scale and indivisibilities that are particularly pronounced in the metalworking sector. In general, no price-type or other linear decentralizing system can be expected to give reliable results when those economies are present.

An exact programming solution under these conditions would require models of the integer type[17] that pose exceedingly burdensome computing problems whenever they are of a scale sufficient for practical use in planning. As far as is known, in a two-level planning model an exact integer programming solution would lose the advantages of decomposition into parts for the economy as a whole and for each sector and would thus represent a backward step from the sequential solution of several smaller models to the simultaneous solution of a single very large model.

If the claim to an exact solution is relinquished and approximations are accepted, some variant of full-cost pricing can achieve a partial decomposition of the programming problem. [52] Since such a programming decomposition is the counterpart of decentralized decision-making in planning organizations, any part of the problem that can be decomposed within a tolerable limit of error can also be made subject to administrative decentralization or merely indicative planning.

Decisions concerning a partial decentralization in a two-level planning system are thus based on considerations of the possibility to decompose a programming model; they in turn are based on a previous decision as to the importance of fixed costs and indivisibilities relative to the resources used in the sector as a whole. Some activities or resource inputs may thus indeed be sufficiently continuous to allow an allocation of their fixed costs on the basis of capacity or near-capacity production. Such a partial decentralization is inherently more complex than decentralizing schemes based simply on the use of shadow prices or other linear decentralizing instruments and depends upon an overview of the sector in the context of the economy as a whole. Consequently, no simple technique is satisfactory for branch-by-branch planning of the metalworking sector. The conclusion is reinforced that the proper planning technique treats the sector as an integrated whole in the framework of multi-level planning.

It is thus essential that the investigation be oriented as much to an over-all view of the problems of economic planning as to the application of detailed engineering or managerial judgement. While an adequate technological description requires a very broad coverage of engineering information, the proper use of all the information to obtain an optimal decision for the sector as a whole requires economic insights of a high order. Furthermore, despite the emphasis on the use of advanced analytical tools, the results of a purely formal analysis can never be accepted uncritically, particularly if they have been produced by mathematical programming models whose internal workings are not readily apparent. Thus the judgement of the economist-planner becomes crucial

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[17] Surveys of integer programming are given by Dantzig [49] and by Beale. [50] Gomory [51] gives an excellent summary, an appraisal of rounded continuous solutions and a new algorithm.

in implementing the results of formal analysis by practical planning decisions.

The description of technology for the metalworking sector raises problems that are not solved by some of the current methods that have been useful in the technological description of other sectors. The serious shortcomings of statistical techniques based on input-output data and any method based on aggregation are more apparent in metalworking than in other industries. One problem is that no classification scheme that describes the sector *ex ante* can be adequate for information requirements that typically arise at a later stage of planning. If, for example, an export project that requires an unusual and expensive input such as a rare metal used in a special steel, should appear advantageous, it is impossible to estimate the requirements of this new input on the basis of the old classification scheme of an interindustry table. The same may be true for certain intermediate products such as specialized ball-bearings. In other words, the individual detailed input that will become critical in the future can never be predicted from the point of view of the sector or even of the economy as a whole. Thus, any technological description based on a fixed classification and aggregation will be inadequate for planning needs. This limitation also applies to material balances that cannot avoid the use of aggregate categories in the metalworking engineering products sector.

The shortcomings of a fixed aggregated technological description as currently used in input-output models are particularly striking in connexion with the decision-making technique known as "management by exception": the underlying concept of the technique can be readily generalized from individual enterprises to entire sectors or economies. Management by exception operates on the principle that the highest decision-making level must avoid routine management problems and concentrate on exceptions to the regular operation of the organization. It is thus always the unusual or crisis situation that is referred to the higher decision-making level. Since a crisis can arise from bottle-neck conditions in any one of the detailed technical commodity categories, it is evident that an exhaustive *ex ante* technological description of any given industry or sector is not possible.

While these problems are encountered to some extent in all sectors of the economy, they are less troublesome in the sectors with homogeneous products. The basic chemical sector is a good example. However, these considerations become the crux of successful planning for the metalworking sector.

It is thus inevitable that an effective planning approach to the metalworking sector must be based on a more flexible concept of technological description than the mere compilation of rigidly defined input-output coefficients or technical norms.

Inputs expressed in terms of resource element units ("standard shops") instead of cost aggregates do not alleviate the aggregate problem and the limitations imposed by fixed classifications. If a representation of the technology in the sector is to be constructed from a manageable number of resource elements used as "building blocks", then these modular elements, for the very reason that they are typical of a wide range of practice (for example, a standardized heavy forge with given total output and seriality), will never be completely adapted to the production of any given assortment of output pieces. In other words, a technical-economic description of the sector based on standardized resource elements will never be able to handle the problem of specific technological adaptations and will necessarily overstate the required resource inputs. If the resource-element input coefficients were to be regarded as rigidly fixed, serious distortions would be present in any planning decisions based upon them. Accordingly, the programming process must provide not only for successive revisions that modify the combinations of activities that are included in a trial programme (as characteristically undertaken in the course of obtaining an optimal solution to an activity-analysis model) but also for revisions of the activity coefficients upon which these combinations are based. At this point, there is not the usual fixed sequence of data collection, model building, programming and practical decision-making but an integrated information and decision system in which data collection and decision-making become inextricably linked.

Variations in labour productivity that are attributable to different degrees of cultural adaptation to the production process at all levels from the individual shop to the economy as a whole pose more of a problem for the planning of the metalworking sector than for many other sectors. In the production of basic heavy chemicals, for example, productivity is paced to a much greater extent by the machine than by the operator, and problems of work-scheduling and organization are of minor importance except for maintenance, which is of course a metalworking operation. In the metalworking sector, productivity varies with learned skills at the following levels: the technical skill of the machine operator, the organizational and work-scheduling skill of the foreman or the manager in a job-shop, the higher-order managerial skills necessary to handle the inevitable interruptions of a continuous mass-production operation,[18] the interaction of firms through delivery, subcontracting and other institutional arrangements, and the stability and continuity of government policies or plans affecting the individual enterprises. All of these productivity variations are superimposed even on an unchanging technological basis. There are furthermore the continuous qualitative transformations of the

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[18] The logic of productive organization in a job-shop versus organization in a continuous operation is discussed by Abruzzi. [53]

production process through innovations. Given such variability, the use of rigid technical coefficients in planning is entirely illusory; an integrated information and decision system is indispensable.

Coefficients and norms are indispensable for attacking and solving any given planning problem, including the preparation of projections and perspective plans for the entire sector. These coefficients and norms must, however, be organized in files that can be readily revised or complemented by technical experts prior to use. If possible, a data system should incorporate modern information-processing methods; it should be kept up-to-date by small groups of technical specialists for particular branches or activities in the sector. The success of any planning method for the sector depends on the improved flexibility of the technological description in the information system.

### *Characteristics of the approach used in the present study*

In the present study it has not been possible to follow closely all lines of approach to the planning of the sector that have been suggested by the strategic considerations discussed above. The key features of the approach are summarized.

The sector as a whole was always the focus of attention. The aim was to develop a programming method that encompasses resource allocation problems for the entire sector and simultaneously provides guides for the evaluation of individual projects. The method was designed to overcome the present characteristic lack of linkage between aggregate branch-by-branch (or resource-by-resource) projections and detailed feasibility studies. For the sake of an integrated approach a rather wide margin of error in technical detail was accepted, for example, in the use of semiquantitative programming data.

An attempt was made to confront directly the problems created by product diversity, product interrelation in multi-purpose production facilities, indivisibilities in productive resources and economies of scale attributable to lot size. This was considered to be preferable to devising a method of approach that would bypass these difficulties. Although the results were not fully satisfactory, they have clarified many conceptual problems and have established the basis for further work.

The initial fully quantified description of the technology of the sector used the concept of resource elements to create modular units. Because of numerous difficulties and slow progress, a parallel effort was soon initiated to devise a semiquantitative method of description for a rapid if sketchy overview of the sector as a whole. The two efforts proved to be mutually supportive in data collection; they represent two initial stages of a sequential decision-making process in programming. The final stage of the process is project engineering.

Semiquantitative programming data should primarily define lists of products and productive processes and establish incidences between them; that is, specify whether a given productive process is used in the manufacture of an individual product. This kind of information can be assembled rapidly and at a low cost. Despite its elementary nature, it has a surprising range of planning applications. The effectiveness of this information can, moreover, be greatly increased by a few simple and low-cost extensions, including the identification of productive processes that are in some sense critical to the manufacture of a given product, the provision of footnotes containing incidental information in regard to critical processes or other features of production, the specification of product weights and their approximate percentage distribution between such major processes as casting or forging and the provision of rough quantitative indications with regard to processes that cannot be characterized by weight, such as machining or heat treatment.

Fully quantified programming data should specify the pattern of physical inputs and outputs associated with the production of an individual product or an assortment of related products in sufficient detail to permit approximate estimates of production costs on a comparable basis for potential products for import substitution or export. This effort requires first the decomposition of products into subassemblies and components; subsequently they must be related to basic production processes, such as machining or assembly. The endless variety of product designs is represented by a restricted number of typical products; the limitless range of alternative production facilities is then reduced to a combination of standardized modules referred to as resource elements. Together, these concepts permit a quantification of the technical-economic description of the sector.

From the point of view of data collection, the two levels of detail described above do not represent closed systems. On the contrary, the present study indicates that large economies of effort can be achieved by a close co-ordination of the two data-gathering tasks. Thus the construction of suitable resource elements needed for deriving fully quantified data was greatly facilitated by semi-quantitative work prior to or concurrently with it. Since semiquantitative data were not suitable to handle thoroughly the problems posed by economics of scale that originate either from aggregate output or from lot size, fully quantified programming data were necessary to indicate the decisive features of the technical-economic structure in the sector.

The two levels of detail are also interrelated with regard to the task of programming as distinct from data gathering; they are also related to the third level of project engineering. There are large advantages to a sequential decision-making process that progressively narrows the range of open alternatives through the use of more detailed information from semiquantitative data to engineering blueprints. The crucial issue is whether the sequential process leads to the best of all possible alternatives or simply to a local optimum. The question is discussed in detail below.

Despite some reservations about the ultimate direct applicability of a programming approach to the planning problems of the sector, activity analysis[19] has been a useful conceptual framework for the problems of technical-economic description, resource allocation and project evaluation. The chief characteristics of the conceptual framework are presented although a practical programming approach based on the available technical-economic description of the sector has not yet been devised in detail.

The activity format has proven highly effective for the collection and organization of process-analysis data in other sectors;[20] it can be provisionally retained for metalworking even if the objective of actual optimization were eventually abandoned. This format, moreover, lends itself readily to the type of extension discussed above, that is, relaxation of the rigidity of technical coefficients. Particular activities describing a set of industrial processes at a given level of detail can be readily replaced by other activities that incorporate a more detailed description of the same processes. Thus, if a sequential decision-making process is reduced to a particular subarea of the sector, more information can be channelled into the description of that subarea. With analysis and information-retrieval alternating in this manner, the planning process can be conceptualized as a series of programming models that become more detailed in a continually narrowing zone.

Semiquantitative programming data fit readily into this conceptual framework; they represent the initial and most approximate way to describe the technology of the sector. While such data are not sufficiently quantified to permit optimization in the formal sense, the orientation process which they make possible nevertheless involves an appraisal of alternatives and a selection of a range of preferred choices. This procedure is entirely in the spirit of optimization and, in the next stage, through the channelling of additional quantitative information into the description of the preferred alternatives, it in fact leads directly to formal optimization.

Programming models furnish an immediate integration of two parts of the planning, namely resource allocation (the preparation of consistent

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[19] The terms "activity analysis" and "mathematical programming" are used interchangeably. A simple type of mathematical programming is linear programming. References [14], [49], [50] and [54] are the standard works.

[20] The activity format is useful for data presentation and analysis in a variety of other sectors. See reference [14] for petroleum refining, chemicals, food and agriculture, and iron and steel. In reference [55] the chemical industry is considered.

resource balances) and project evaluation (the determination of priorities among competing projects). In the simplest case, namely, linear programming, two mathematical solution algorisms (the "primal" and the "dual" simplex methods [54]) can be regarded as paradigms (either working toward a perfect priority ordering of activities while resources are always balanced or, conversely, working toward the elimination of resource bottle-necks), while a highly efficient priority ordering of activities is always maintained. The two methods intersect at the optimal solution that satisfies simultaneously the criteria of optimal resource balance and optimal priority ordering of activities. The last property of the optimal solution of linear programming models also extends to the general nonlinear case, even though the solution methods themselves do not. This property is one of the key attractions of programming as a conceptual framework for planning.

The priority ordering of activities in programming models is achieved by means of so-called shadow prices calculated for all resources; at these prices costs are attached to individual activities. The designation "shadow price" distinguishes these calculated priority indicators from actually prevailing institutional prices in the economy. In linear programming models, shadow prices ensure that all activities included in the optimal solution at positive levels will exactly break even; that is, the costs of these activities calculated at shadow prices will exactly offset their revenues, which are also calculated at shadow prices. Activities showing losses will be ceased, while profitable activities may never occur in an optimal solution. In fact, the very presence of profitable activity indicates that the optimal solution has not yet been attained, since the expansion of profitable activities can achieve further benefits. The elimination of all profits in the optimal solution of linear programming models is analogous to the elimination of profits in the theory of perfectly competitive markets.

The presence of indivisibilities and economies of scale in programming models introduces major mathematical impediments to an optimal solution, since the usual strategies based on the gradual improvement of trial programmes can no longer guarantee the eventual attainment of the optimum. The source of the difficulties is the possible occurrence of several local optima that are separated from each other by zones of programmes that are less attractive in a manner analogous to the separation of distinct peaks in a mountain range by valleys or saddles. It is relatively easy to find a programming method that will arrive at some local high point, but it is very difficult to find one that will identify the highest peak.

To the extent that programming models can be taken as a conceptual paradigm of the broader planning and decision-making process, indivisibilities and economies of scale negate the certainty that a sequential decision-making process will converge to an optimal plan. Such a process may instead point to a local optimum, with the result that it will not even be possible to check whether the plan is tolerably efficient; that is, if the local optimum is reasonably close to the over-all optimum or if, on the contrary, it is drastically inferior to the over-all optimum. The same shortcoming characterizes market systems and, potentially, also the type of decentralized planning systems that are now being introduced in some centrally planned economies. It was mentioned earlier in this study that present planning methods often leave major doubt as to whether the sector as a whole is moving in the right direction; the possibility of convergence of either the planning process or the market toward a drastically inferior outcome was implicitly postulated. The problem is thus not merely academic; in fact, it is crucial for the assurance of a proper over-all orientation with regard to central decision-making and decentralized processes in general. The need for such an over-all orientation is of such importance that even rough approximations in the technical-economic description of the sector are acceptable if they furnish a complete overview within a large but known margin of error. [52] Since the case of economies of scale can be reduced to the case of indivisibilities represented by the occurrence of fixed costs, the discussion will be conducted in terms of the latter and, for the sake of simplicity, in the context of otherwise linear models.

The key step is to classify the fixed costs[21] that occur in such problems (in the metalworking sector, those that originate in minimal production series and minimal shop scales) into small and large fixed cost. The definition of small and large costs depends on the tolerable margin of error in finding an optimal solution. Given the status of planning for this sector, it is preferable initially to allow a relatively large margin of error rather than renounce the possibility of an over-all orientation, even though the margin of error may be rather large in many ways. Therefore, many fixed costs or perhaps most of them can be classified as small. They can be dealt with by dividing the fixed costs between the number of units produced on the basis of the estimated degree of capacity use. If full-capacity utilization is taken as the basis of distributing fixed costs, a lower limit on actual total costs is obtained; in other words, if it is assumed that the indivisibilities represented by fixed costs are, for the purposes of programming, none the less divisible, then the optimal programme so defined will always appear more favourable than in reality it could ever be.

After being distributed in this manner, fixed costs behave like the proportional costs of ordinary activities, and if all fixed costs are thus distributed, a normal programming problem will be obtained that can be solved readily to give normal shadow prices. In a linear model, these prices are in principle identical to the prices established by a perfectly

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[21] "Fixed costs" are here used in the sense of fixed resource inputs, which are given preferably in physical units.

competitive market mechanism provided that the individual enterprises base their cost calculations on their average (full) costs and not on their marginal costs.

What procedure should be adopted for the large fixed costs ? If they were similarly distributed over output either by linear programming or by some market mechanism based on full-cost pricing, the consequence would be to exceed the tolerable limit of error. Consequently, central decisions about fixed costs become mandatory instead of decentralizing mechanisms. As the tolerable margin of error increases, the number of "large" indivisibilities that require centralized decision-making decreases. At the same time, the chance diminishes that some unusually favourable combination of such large indivisibilities will remain unknown to specialists who have thorough knowledge of the sector. Thus, by describing and comparing programmes based on selected *a priori* attractive combinations of indivisibilities, a reasonable approximation to the optimal solution can usually be obtained. Any error will be subject to quantitative appraisal in the following manner. Since the fixed-cost distribution method based on the assumption of full utilization of capacity always surpasses the actual optimum, and while the combinatorial method based on a partial sample of fixed-cost combinations generally falls short of the optimum, or at most equals it, the estimates obtained by the two methods delimit the optimum, and their difference establishes an upper limit to the error of optimization.

Even though this result can be rendered sharper and more elegant by advanced mathematical methods, such as integer programming, the essence of the problem is sufficient for the overview required for practical planning applications. Where fixed costs are encountered, they are distributed over output to the largest tolerable extent, while the remaining fixed costs are tested in diverse combinations that appear *a priori* to be favourable. With each of these combinations there is associated a normal programming problem. Its total costs are calculated as the sum of the following three items: fixed costs that are explicitly treated as fixed, fixed costs that are distributed over output and proportional (variable) costs. The selection of the best of these alternative combinations is a central decision with regard to the large fixed costs; all other decisions concerning fixed and variable costs can be decentralized to any desired degree by means of a market or other linear incentive system.

In planning for the metalworking sector, the indivisible decisions concern the questions whether a given commodity should be produced or whether investment should be made in the establishment or expansion of some productive capacity. The majority of these indivisible decisions can be handled by full-cost pricing and can therefore be decentralized within a tolerable margin of error. The programming framework, however, also allows the identification of large indivisibilities and rational decisions about them. A key virtue of this approach is that it bases the cost calculations required for decentralized decisions in enterprises or lower-level planning organs on a set of prices that can in principle be determined only after the central decisions pertaining to the large fixed costs have been undertaken, regardless of whether the determination of prices is based on formal programming or on the automatic outcome of some market mechanism. Thus, this approach creates a rational basis for the establishment of a price system even in the presence of major indivisibilities and separates the decisions that can be effectively decentralized from those decisions that cannot be effectively decentralized.

The establishment of a rational price structure has primary significance for the international division of labour since, in the absence of such a price structure, it is almost impossible to judge the direction and extent of the desirable international specialization of a country. A reliance on these prices permits the determination of the upper limit of production costs for worth-while exports from any branch of the sector and also the estimation of the somewhat higher cost limit beyond which imports are preferable to domestic production. Apart from transport and other costs incident to foreign trade, these two limits determine the real value of foreign exchange. If commercial relations should be undertaken with two or more separate trade areas, a separate exchange rate must be determined for each area in the above system of prices.

The costs associated with the large fixed costs that are subject to central decision-making are not to be included as part of the production costs of individual commodities as long as a significant part of the indivisible capacity remains unused. If, however, as a result of general economic growth or physical depreciation, such capacities become subject to periodic renewal, then no slack remains just before such renewal. An exact mathematical solution would demand that in such no-slack periods, the respective commodities be charged not only with current costs but also with accumulated costs of the capacity that have not been charged in the preceding slack periods. Of course, this would lead to unacceptable cost and price fluctuations that must necessarily be moderated with a view to practical long-term price stability. A certain measure of fluctuation is none the less entirely rational, since it is desirable that secondary uses of the respective capacity be encouraged during periods in which there is a slack. In periods when the capacity limit is approached, all uses that are to some extent flexible should be deterred from using the capacity. This situation is similar to the price fluctuations that occur between peak and off-peak hours in the electrical power industry with the simple difference that the fluctuations are typically in a multi-year cycle rather than in a daily cycle. World market prices are established by bridging over these indivisibilities, which are, of course, small as compared with total world production. Individual countries can take advantage of the potentialities offered by their own price cycles in the long-term plans for production, trade and investment.

### *Emphasis of the study*

The fundamental assumption underlying the suggested approach is that every economy has a technological core that is potentially invariant between countries with different social systems and different *per capita* incomes. This invariance is called potential rather than actual, since many technical activities will be found uneconomical under given local conditions, and the actual selection will be highly (and systematically) differentiated. The invariance is thus postulated for the totality of technical activities from which the selection is made. This postulate is supported empirically by the rapid diffusion of technical know-how and by the experience that, under the proper conditions, any group of individuals can be trained and educated in the use of modern technology and modern concepts of technical and economic organization.

If the invariance of the technological core is accepted, the analytical task of devising rational planning and programming procedures for economic development can be divided into two main parts. The first task is to define the basic range of economic alternatives that are compatible with this invariant technological core, given the particular population, resources and the consumption requirements or preferences of the majority of the population that can be verified empirically. After the range of choices has been defined, the second task is to select from it development targets that are compatible with the cultural and institutional conditions. Alternatively, the kind of cultural or institutional changes that would be required to attain stated targets within the basic range must be analysed.

The present study has been directed almost exclusively at the first task, and its emphasis has been determined accordingly. Of course no conceptual dichotomy of such heroic proportions can ever be completely clear cut. Although there is some lack of definition at the periphery, the conceptual dichotomy is considered to be the key to a successful approach in depth to the difficult planning and programming problems of the metalworking sector.

The following institutional aspects have been largely disregarded: supply of skills, labour training, entrepreneurship; credit and financing problems; cultural and institutional conditions that determine an orientation to growth as against an essentially static outlook on economic reality; organizational problems in planning; incentive problems; resistance and inefficiency in the implementation of planning; relations between enterprises and market organizations; defining policies and economic development targets. The abstraction from training and education is a distinct limitation of the analysis, since the social costs and time delays of these activities are sufficiently significant to affect the main conclusions.

The omission does not create any long-term consequences since, at a later stage, the analysis can be expanded to include this aspect without significantly altering the key features of the approach presented here.

One institutional aspect that enters the analysis, at least at the conceptual level, is the consideration of international trading possibilities either by trade agreements or on the open world market. The emphasis here, however, is on the careful definition of alternatives rather than on the exploration of institutional arrangements conducive to successful negotiations or successful entry into particular export markets.

In defining the basic range of possibilities, emphasis has been placed on those features of technical-economic reality that are most characteristic of the sector. Thus the use of multiple-purpose productive equipment is at the centre of analysis, even though it is recognized that there are some branches of the sector in which highly specialized, single-purpose equipment is predominant.

An important limitation of the analysis is the exclusive reliance on the deterministic (as against probabilistic) description of alternatives. This has been dictated by simple expediency, even though it is recognized that reserve stocks and their fluctuations, queuing phenomena connected with capacity use, and related questions, are entirely glossed over by this approach. Considering that nonconvexity is explicitly taken into account, the former simplification will probably be found excusable. It is of course an empirical question which of the two analytical difficulties, nonconvexity or the role of uncertainties, is the more crucial in practice. In attempting to formulate an answer (pending an alternative approach) it should be noted that some of the phenomena mentioned, such as queuing, occur at a level of aggregation below the one chosen for this study, while others, such as the determination of optimal reserves, will not be unduly sensitive to the structure chosen for the sector by the suggested approach.

## 4. FULLY QUANTIFIED PROGRAMMING DATA

The description of the technical and economic features of the metalworking and engineering products sector is the foundation of the present study on which all other aspects must be built. It is therefore of crucial importance to develop adequate methods for performing this task.

The entire conceptual framework of the study was initially built around the collection, organization and programming application of fully quantified programming data. While semiquantitative data were defined and introduced at a later stage, and even though they were very productive in terms of immediately applicable empirical results, the conceptual framework of the fully quantified programming data continues to be of fundamental importance to the study for at least two reasons: (*a*) the effectiveness of semiquantitative programming data in handling key difficulties in planning for the sector would be impossible to judge, except with reference to the conceptual framework provided by fully quantified programming data, and (*b*) the rapid over-all orientation provided by semiquantitative programming data is only a starting point for a more exact quantitative definition of planning problems in the sector. Therefore, reliance must be placed on fully quantified programming data.

The term "fully quantified" defines the contrast between these data and semiquantitative data. It does not mean that fully quantified data have ultimate precision and reliability; they could equally well be referred to as "rough quantitative" data. The following discussion indicates that they are based on a modular description of productive facilities by means of the key concept of resource elements, which was briefly introduced in chapter 3. They are thus no more than initial approximations, although fully quantified. Feasibility studies based on them will be subject to large cost errors. All conclusions based on fully quantified data must be re-worked for final decision-making by reference to data representing a third level of detail and precision, such as concrete project engineering data or their equivalent.

The question may be posed: Why is the conceptual framework of the study given in terms of the second level of detail (fully quantified programming data) rather than in terms of the third and practically most significant level? The answer is the significant intermediate position of fully quantified programming data between the two extremes of semiquantitative data and project engineering data. The first level yields an over-all orientation with no precise detail, while the third level yields precise detail without an over-all orientation. In a future study on a sufficiently comprehensive scale, they can cover the sector as a whole at a tolerable cost in resources expended. Nevertheless, fully quantified programming data maintain a sufficient degree of precision to provide a starting point for fully refined cost estimates and other project engineering work preparatory to final decision-making and plan execution.

## *The University of North Carolina study of the machine-building industries*

In the approach to the technical-economic description of the metalworking sector at the fully quantified level defined above, the present study has drawn on the ample experience and empirical materials of the study of the metalworking and machine-building industries of the USSR undertaken over a number of years by the University of North Carolina that produced several substantial reports [9] prior to its abrupt termination in 1960. The UNC study used a process-analysis approach that was based[22] entirely on source material published in the USSR particularly for engineering and industrial data. The approach was developed in part as an experiment in the use of technical-economic data instead of scarce statistical information for analysing economic capabilities. The method evolved progressively over the course of years and in its latest version incorporated the fruits of much experimentation that has saved the present study time and effort.

The chief reason for revising the UNC methodology was that it was oriented towards a different economic task than the aim of the present study. The object of the UNC study was the definition of the capabilities of existing productive facilities and an estimate of the resources needed for capacity expansion based on the existing structure. The present study poses the much more difficult question of identifying the most suitable structure to promote economic growth. In brief, the investigation of basic production processes (technologies) constitutes the core of the UNC analysis and implies a two-step or two-phase route to the derivation of final input coefficients.[23]

In the first phase the input requirements of machinery, labour, material, and the like, of fourteen basic production processes, among them forging, founding, machining, heat treatment and assembly, were determined. Each input requirement is studied in a number of variants called resource elements. A total of 53 resource elements has been included. The input requirements are expressed in physical units (tons, man-hours or number of specified machines) per unit of output. The output itself is either a semifabricate, such as a rough forging, or a processing service, such as the heat treatment of a component part. In either case the output is again measured in physical units (in metric tons, wherever possible). As customary in activity analysis, the output can be regarded as defining the level of utilization of each process.

In the second phase the outputs of the first phase assume the role of inputs. The objective of this second phase is to generate numerical estimates of these inputs into a sample of typical but highly specific individual end-products, namely, machines of different kinds.

Thus, in the two-phase approach, capital, labour, material and other coefficients of input into machines are derived indirectly rather than directly by means of the levels of basic processes that are used in their manufacture. The advantages and disadvantages of this indirect method of

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[22] Except for some engineering-type information borrowed very occasionally from sources in the United States when a critical data gap was impossible to fill otherwise. See reference [9], Study No. 7, p. III 5C.

[23] In addition to the original UNC study, the present description is based on references [15], [16], and [19].

estimation may be summarized: it achieves an aggregation of the innumerable individual items of capital found in the sector at a level that is both meaningful and computationally manageable and it is the key to a comprehensive yet fully quantified description of technology.

For the purposes of capability analysis, the next step in the UNC study is to choose a small number (about six) of end-product classes to represent each branch of the machine-building industry. The inputs of these aggregate "representative products" are then constructed by averaging the inputs of selected individual products that are derived in detail, primarily from engineering sources. The individual products are referred to as "typical products" in the present study. The averaging procedure is based on statistical estimates of the total tonnage of each kind of product that is similar to a given typical product. A total of 33 branches of the sector has been covered by the UNC study, among them machine tools, boilers, diesel engines, gasoline engines, tractors, cranes, excavators, automobiles, lorries and railway cars.

If the methodology were to be applied directly to the present study, it might be used to estimate the kinds of productive facilities that could be established and reasonably used in a developing country. Thus, if the total requirements were known for the capacity of a medium forge capable of producing parts for agricultural implements, hand tools, builders' hardware and simple machines, which had been previously imported or for which an export market could be found, it might be discovered that such a forge could be fully used. In this way, when starting with a list of imports and potential exports and totalling the implied input requirements for several kinds of foundries, forges, metalworking shops and the like, some resource elements would be required on a scale equal to several times their basic yearly output; others (typically the heavy and specialized resource elements) would be required on so small a scale that they are used only a few days of the year and therefore could not be included in a reasonable investment programme. Intermediate cases would have to be analysed in greater detail prior to investment decisions.

The situation of partial domestic production in which some components of a complete product are domestically produced while others are imported can be handled by reasonable institutional assumptions. It has been frequently encountered, for example, in connexion with motor vehicle production in developing countries, where a decision is required concerning the domestic manufacture or import of components for assembly.

The principal difficulty inherent in the approach is lot sizes. Lot size or seriality refers to the number of identical workpieces produced in a single production run. In the UNC study, variants of a basic process (resource element) are distinguished by major categories of seriality, namely, "unit", "small series", "medium series", "large series" and "mass production". When the annual production varies, a given product is handled by this method as though it were an entirely distinct product. This procedure is acceptable as long as seriality is not one of the key variables in the decision-making process for an industrial branch. If the branch can be adequately subdivided into two or three typical seriality classes, each of which is associated with one or two kinds of products, then a half-dozen representative products will indeed reflect the assortment produced within the branch with a reasonable degree of approximation. In developing countries with restricted markets, however, the key decision in each branch is the extent import substitution and new exports should be attempted, since there is a progressive reduction in lot size in the first case as a larger variety of products must be produced to achieve additional foreign-exchange savings, while there is an increase in lot size in the second case. Unless these phenomena can be quantified, there will be inherent uncertainty in regard to the effectiveness of resource utilization, e.g. in regard to the costs of additional production in diverse industries. A method based on describing a branch of the sector by a handful of aggregate representative products will be inadequate to handle seriality as explicitly as is required here.

## *Extensions*

Certain extensions of the UNC method were required for the present study. First, while the preliminary subdivision of processes into major seriality classes is accepted, secondary corrections are essential to describe more exactly the changes in capacity utilization that result from differing lot sizes. Thus, in estimating how much of the yearly capacity of a medium-sized, medium-seriality forge is used to produce a specific part for a given agricultural implement, allowance must be made for the fact that, in somewhat larger lot sizes, each ton of output requires a somewhat smaller number of shop-hours. While no serious technical difficulties are foreseen in estimating approximate corrections of this kind, the procedure has not yet been tested in practice during the pilot data-gathering effort.

Second, the description of a branch by a few typical products for which detailed inputs are estimated is complemented by a "long list" of "listed products", for each of which only a very limited amount of information is to be collected. The long list contains from 100 to 200 products per branch; for each of them only two kinds of information are essential: to which of the handful of typical products is the given product similar, and the yearly demand for it. (If desired, this information may be slightly expanded, as discussed below.) From the information on typical products and the secondary corrections for exact seriality, inputs for the entire long list can be estimated.

Third, the rest of the branch is to be represented in an aggregative fashion by extrapolating the trend of resource utilization implicit in the long list. As the scale of production within a branch (measured in tonnage or value terms) increases, the increasing diversity of products will generally raise resource input (or cost) coefficients, except when serialities can be raised through exports. The concept underlying this method is from the work of papers by Chenery and Kretschmer. [29] Some remaining conceptual problems are attributable to the fact that the order in which different products on the long list are considered for domestic production must be known before the cost trend can be plotted for extrapolation; no major difficulties are anticipated, however, in resolving them after the problems concerning indivisibilities (fixed costs) are adequately considered.

With the three extensions above, the resource inputs required for progressive import substitution and export development in each branch can be closely estimated. The additional burden imposed on the process of data collection by these extensions is considerably smaller than the original task of defining resource elements and estimating inputs for typical products; thus the extended method should be manageable with the same scale of research effort as that of the original UNC study. In addition to import substitution and export promotion the method will allow the effects of the lengthening of series through standardization and through modular design to be estimated.

## *The resource-element concept*

The resource-element concept was developed in the course of the UNC study after years of experimentation with the estimation of capital, labour and other inputs for individual end-products. The aggregation of the great variety of capital equipment into self-contained resource groupings was the essential conceptual tool that permitted an adequate representation of technology in the sector. The resulting resource elements are defined to include the primary and auxiliary machines needed for a basic process and the necessary floor area of the plant.

> "The complexes of capital so formed are intended to serve a threefold function within the general framework of input-output analysis:
>
> (*a*) to contribute toward the estimation of capital input coefficients for a wide range of machinery items;
>
> (*b*) to provide a basis for measuring the inputs incident to their own expansion (viz., capital expansion coefficients); and
>
> (*c*) to facilitate the estimation of flow inputs incurred in the production of selected 'representative' end-products.

"A unit of capital is understood here to embrace the 'bundle' of individual equipment items associated on the average with certain well-defined production activities or sets of operations. For practical purposes this aggregation of individual pieces of capital is accomplished at actual levels of operation corresponding for the most part to the production shop or in some cases to the plant specializing in a particular process output."[24]

The data required for the definition of resource elements were taken in the UNC study entirely from "published Soviet source material, particularly of the engineering and industrial type. In fact the studies were in large part in the nature of experiments in the use of scattered 'technico-economic' data appearing in comparative abundance in these sources, in lieu of scarce statistical information." [15] It will of course be a great deal easier to define resource elements when any published material can be complemented by on-the-spot investigation of productive facilities. In its last and still incomplete stage, the UNC study identified the 53 resource elements shown in table 1.[25]

TABLE 1. RESOURCE ELEMENTS IN THE UNC STUDY

| *Production process* | *Number of resource elements* |
|---|---|
| Free forging | |
| Die forging | 8 |
| Mixed free and die forging | 2 |
| Cast-iron casting | 1 |
| Malleable-iron casting | 6 |
| Steel casting | 1 |
| Non-ferrous casting | 3 |
| Precision casting | 3 |
| Stamping | 1 |
| Upsetting | 5 |
| Machining | 3 |
| Tool-making | 6 |
| Assembly (including crating and painting) | 1 |
| Heat treatment | 7 |
| Steel fabrication (welding) | 4 |
| Total | 2 |
| | 53 |

[a] Production processes are described individually and their exact terminology is defined in reference [9]. Forging is the application of pressure to heated metal to form roughly finished parts. In die forging specially shaped moulds (dies) are used to apply pressure. Free forging is essentially a mechanized and greatly enlarged version of the hammering of hot metal in a smithy, except for the fact that not only hammers but also presses are used to apply pressure. Casting (in a foundry) is the pouring of metal into molten specially prepared moulds ("patterns") that are made of sand or metal. Stamping covers a variety of cold-working metal processes including all punch-press, squeezing and cutting processes. Upsetting is a variation of the forging process in which metal parts are formed into desired shapes in dies affixed to special upsetting presses and then finished on various types of equipment which are primarily automatic or semi-automatic in nature, fasteners (bolts, nuts, cotter-pins, washers, rivets and screws) being the main parts produced by this process

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[24] See reference [9], p. II 1.

[25] Ibid, p II 2. Tool-making is shown in table 1 but it is not included in the report.

Of the resource elements that were not included in the UNC study, spring making has been covered in a United Nations report.[26] The following processes are among those that have not been covered: electrical equipment (wiring, insulation and armature), auxiliary processes (storage, repair, internal transport, utilities and laboratory), minor production shops (electroplating and woodworking) and organizational functions (design, engineering, production planning, marketing, research and development and general administration).

Each resource element is generally defined by the following factors:[27]

The scale of operations, which is the average annual capacity of the resource element under normal working conditions (generally two shifts daily except for unusually heavy facilities operating a three-shift basis);[28]

The prevailing seriality of output (or repetitiveness of production lots);

The products and in some cases the kind of machine parts typically associated with particular resource elements;

The required floor area as a guide to the estimation of construction requirements;

A detailed equipment profile;

The part size, which is determined by the maximum weight of the part. However, the model range of weights is considerably less than the maximum weight. For foundries, the model range is systematically between 1 and 10 per cent of the maximum weight.[29] Variants of basic processes that are defined as separate resource elements in the UNC study are based on these factors. The number of variants is reduced because some of them can be correlated. [15]

During the course of the UNC study the number of variants was sharply reduced. In early versions, more than 75 foundry processes were distinguished in unit and small-series production alone.[30] They have been reduced to only two foundry resource elements in the seriality classes.[31] It is not implied that the estimation of these aggregate foundry shops or resource elements was easier than the detailed proliferation of casting processes which were undertaken for heavy machinery: actually the

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[26] Reference [56] also contains valuable previously unpublished appendices by the original authors of the UNC study to the definition of all major resource element groups and an analysis of the product classes in the shipbuilding industry.

[27] Most of the factors are from reference [9], pp. II 1 to II 33.

[28] Ibid, p. II 6. For example, for forging, presses larger than over 1,000 tons were assumed to work three shifts. Normally 2,330 hours per year per shift was considered the time available for forging.

[29] Ibid, pp. II 59.

[30] Ibid., p. I 5.

[31] Ibid., tables II 29 to II 42, pp. II 66 through II 94.

reverse is true, that is, the task of definition (averaging) proved to be more difficult in the global approach though probably in itself less accurate. Where the tremendous economies of research time occur are in the 'Phase II' aspect of the problem. With the shop formulation we can treat the weight of castings in a given commodity virtually as a unit and at most distinguish between a limited number of metal types, for example, cast iron, cast steel and non-ferrous. By contrast, the 'old' process definitions required the breakdown of product weights into as many as seventy-five different kinds of castings.

> "Corresponding simplifications have been achieved with respect to the forging and machining processes as well as in . . . stamping and upsetting. In all likelihood the altered framework for machining has yielded the greatest research efficiencies and without, it appears, significant changes in the accuracy of the results. What we have done in this area has been to abandon the 'chips-removed' technique for deriving machining inputs. Instead of estimating these requirements for a highly differentiated set of machine tool types and sizes we have placed reliance on direct (though adjusted) Soviet data relating to the total machine-hour needs of various commodities. These aggregate machine-time inputs, in turn, we have associated with complexes of machine tools of given capacities . . . These (resource) elements, as in the case of casting referred to above, are designed to handle a broad range of structurally similar commodities, homogeneous as to size class and seriality. Hence the whole machining requirement can be disposed of, so-to-speak, in one application."[32]

The resource-element concept is a compromise between two opposing requirements:

> "Ideally, the study aims at the formulation of internally homogeneous resource elements, but at the same time practically it requires that they be comparatively few in number . . . As a rough rule of thumb, we have sought to encompass the total of machine-building activities in something under seventy-five elements."[33]

The resource-element concept is subject to three limitations in the UNC study which will be relaxed in the present study:

(*a*) "By assumption no inter-element substitution is allowed."[34] This necessary limitation of input-output analysis can be relaxed when stronger programming techniques, for example linear or integer programming, are adopted. In practice the relaxation of this limitation means that alternative patterns of resource element inputs into an end-product become admissible. Thus, a crankshaft may be produced by either forging or precision casting, each followed by machining. The two methods require different inputs for crankshaft production.

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[32] Ibid., pp. I—6 to I—7.

[33] Ibid., p. II—3.

[34] Ibid., p. I—7.

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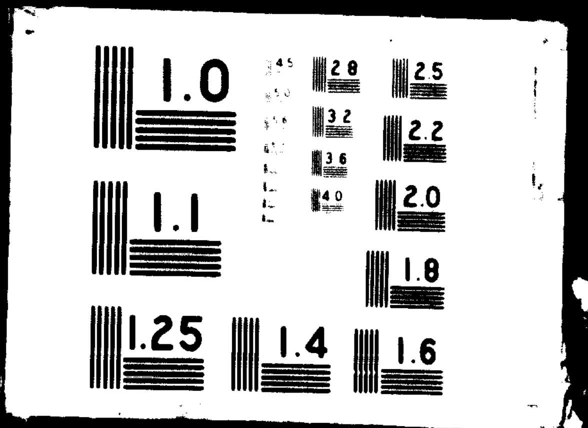

(*b*) The preceding quotation continues "... except as a commodity undergoes changes in the seriality of production (in which case, as we view it, it becomes a different commodity)." If substitution of resource elements is excluded by definition, then the unavoidable substitution of resource elements with different seriality in response to changes in demand must be redefined as a change in the nature of the product. The UNC method will be extended in regard to seriality by introducing secondary corrections.

(*c*) "Within each element... product substitution is considered to be complete. That is, a particular element is deemed to be capable of producing any of its 'own' products with equal efficiency (the meaning of 'homogeneity' as we use the term above)." This assumption yields a good first approximation. The individual estimating error margins up to 20 per cent that are generally assumed in the UNC study are entirely satisfactory for the present study. However, because the first approximation is good, secondary corrections can be introduced through simple multiplicative factors that take the entire structure of a resource element as unchanged; the estimated fraction of their capacity that is used to produce a particular output is merely adjusted. The seriality correction in the preceding paragraph is of this type; analogous corrections can be introduced for complexity in forging, for precision in machining and, in general, for the use of a resource element for a product mix that is slightly different from the one for which the resource element has been designed.

### *Advantages*

Some of the advantages of the resource-element concept have been implicit in the previous discussion. Eight major points are emphasized below.

(*a*) Through the resource-element concept the very large set of equipment combinations which produce the great variety of products of the sector can be represented by a limited number of "average" or "typical" combinations.[35]

(*b*) Since inputs and outputs are expressed in physical terms, technological information is separated from pricing information. It is then possible to transfer directly information on potential production processes from one country to another. Two qualifications to this second point are, however, necessary.

(i) Note the emphasis on "potential" production processes. A technology that is well adapted to one country may be

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[35] Reference [15], p. 2.

feasible in another from the engineering point of view but economically it is highly inefficient.

(ii) The averaging process implicit in the resource-element definition may incorporate characteristics peculiar to one country that are non-transferable. (Particular care must be taken to avoid this risk).

(*c*) Seriality is handled explicitly in the classification of resource elements although not in sufficient detail for the purposes of the present study. The description in this regard can, however, be improved.

(*d*) The convertibility of metalworking capital from one use to another is highlighted. It may be particularly useful for developing regions where the likelihood of low rates of output increases the importance of practical possibilities to combine the production of products usually produced in separate facilities in highly industrialized countries. For example, it may be feasible to integrate (on the basis of similarity in many of the constituent processes and, consequently, in capital equipment) the production of a variety of piston-type machines and mechanisms, such as internal combustion engines (diesel and petrol), pumps, compressors and steam engines, etc. An alternative approach such as, for example, the (definition of) capital requirements ideally designed to produce one end-product would not in itself suggest such possibilities for integration. The integration could make possible a project which the size of the market and capacity costs would otherwise preclude.

(*e*) Considerable institutional rigidity is avoided by the separation of major processes into separate resource elements. This separation permits considerable flexibility in recombining to suit various needs and alternative systems of industrial organization.[26] In particular, the concept leaves open the question of horizontal or vertical integration according to patterns observed in the industrialized countries or according to other patterns that might be more appropriate in developing countries.

(*f*) The resource-element concept simplifies the collection of information and the interpretation of incomplete data. Intermediate concepts may appear superfluous from a purely analytical point of view because they are eliminated from the analysis at a subsequent stage. In the present instance, for example, the resource elements disappear in the course of a matrix multiplication that carries their levels into capital and flow inputs. Nevertheless,

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[26] Ibid., p. 8.

they can be indispensable in practice, since they often correspond to the categories by which the original information is easiest to collect. In addition, resource elements permit the focusing of attention on a limited number of variables at a time, thus facilitating the recognition of basic connexions among the data. Finally, resource elements form broad classes of phenomena in which statistical regularities appear; whereas unaggregated information, such as coefficients of material or labour inputs directly into a particular product, are often so few that any potential relationships among them are masked by the accompanying random variations. Thus earlier attempts in the UNC study to evaluate directly the flow inputs into classes of individual end-products met serious difficulties, whereas the achievement of the same objective in an indirect manner through the intermediary of the resource-element concept has been successful and has permitted the compilation and organization of many empirical data.

(*g*) The resource-element concept is convenient to combine statistical and engineering information. In the UNC study, for example, the determination of resource-element inputs into typical individual products in an industrial branch is undertaken principally by engineering techniques, including the study of product blueprints, shop layouts, equipment lists and personnel classifications. The analysis is then complemented by estimation of a weighted average of individual products to represent the industrial branch as a whole; the weights are derived from statistical sources.

An alternative approach of Markowitz and Rowe [13] to derive material, labour and equipment input coefficients for the sector is based largely on census data; engineering estimates are suggested only for secondary corrections. Their method is useful and accurate in structurally stable and well-studied economies, such as that of the United States. Its applicability, however, becomes severely limited when either considerable structural change occurs in which statistical coefficients are rapidly obsolete, or the sources of statistical data are few and unreliable. In developing economies, there are both structural instability and a lack of reliable data. Therefore the combined engineering-statistical approach to requirement estimates used in connexion with resource elements appears to be considerably superior to an approach that transfers statistical information from one country to another country for which it is not available. In the planning and programming of the metalworking and engineering products sector in economies where structural changes are of central interest, the combined engineering-statistical approach made possible by the resource-element concept is decisively superior to an approach based largely on statistical data.

(*h*) The resource-element concept maintains a unique pattern of process inputs into end-products (as in the UNC study) yet it introduces a considerable degree of flexibility into the investigation of economic capabilities by allowing substitution of the kinds of output that can be obtained from a given resource element. Thus the yearly capacity of a foundry or forge expressed in tons of output is reasonably constant for pieces of generally equivalent complexity and unit weight that are produced under conditions of comparable average lot size. The overwhelming majority of trivial substitutions of standard metalworking machinery operations can be handled by the elementary method of creating an aggregated concept. When alternative input patterns are subsequently introduced (substitution of resource elements) attention can be centred on a relatively small number of critical substitutions without flooding the model with detail.

### *Problems and ambiguities*

Production shops in a country vary considerably, and the use of an average to represent a particular type of shop masks the factors that are responsible for the variation. Thus, even if the aggregate is reasonably representative of the conditions of the country from which the data were derived, the variability makes it necessary to proceed with caution in the transfer of data from one country to another. In the UNC study, in particular, the resource elements were defined to represent average conditions in the USSR for capability analysis. There can be no presumption that these data will directly fit the conditions of the developing countries, particularly in costing and programming.

Before proceeding to a detailed discussion of the analytical problems raised by the resource-element concept, it will be instructive to consider the work of Hare.[37] It is an illustration of the problems connected with any attempt to formulate a technical-economic description of the sector. The second and third levels of detail (fully quantified programming data as compared with detailed project engineering) have not been separated; this fact accounts in some measure for the apparently overwhelming complexity. It should be borne in mind that in the present study the description of the resource elements is suggested at the second (not the third) level of detail. Their modular character necessarily involves an approximation. It is anticipated that any cost estimates based on such a

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[37] Professor Hare suggested certain simplifications of the over-all technical-economic description problem that eventually lead to the development of the semiquantitative programming data approach of chapter 5.

modular description will be too high because of a lack of proper adaptation of technology to the particular individual production conditions. The conclusions from such a description are merely indicative and must be reworked in the course of a sequential decision-making process through the introduction of many technological refinements corresponding to the third level of detail.

The limitations of the resource-element concept in the UNC study are now considered. The flexibility of resource elements in representing a whole class of production activities by implied internal substitution is obtained at the expense of product-mix problems. Many actual shops are significantly specialized as to the range of products they produce. In defining general-purpose resource elements there are tendencies both to overestimate the average amount of machinery that will be required and, conversely, to overstate seriously the degree of substitutability that exists in each resource element. For machining resource elements, for example, the degree of overstatement rises sharply as the seriality characteristic moves from unit to mass production. Shops of the latter type are characterized by a large proportion of specialized equipment which can be employed for a range of products far narrower than that attributed to the resource element. Even shops having exclusively general-purpose machine tools of the same size can differ widely in terms of the mix of tools by functional type. The machine-hour capacity of an element is therefore strictly applicable only to the end-product for which it was designed. The suggestion is made in the UNC study that this problem might be handled by the use of correction factors that take into account the reduction of substitutability. Numerical factors that vary from 40 to 90 per cent are offered as educated guesses concerning the actual range of reduction.[38]

One way of handling the product-mix problem is to increase the number of resource elements and to narrow the definition of each; this, however, leads back to the same difficulties that have been experienced at an earlier stage of the UNC study. A possible compromise might be to handle specialized, outsize and otherwise scarce machinery items and their auxiliaries as separate resource elements. Only the actual research can indicate at which point the optimal compromise should be drawn between product-mix problems and a large number of resource elements.[39] It might be advisable to increase the target figure for the total resource elements from 75 to 200.

A second source of error in the UNC study is the use of the same coefficients for average capital requirements versus expansion. This

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[38] Reference [9], p. II — 98.

[39] Since this error is inherent in any modular description of productive facilities in the sector, it can be handled properly only in a sequential decision-making process. See chapter 3.

problem is not expected to create serious difficulties in developing countries. A shortcoming of the UNC study in its terminal but unfinished state was the existence of gaps in the coverage of resource elements. This of course should not be charged against the concept of resource elements. Of special interest are the organizational functions which have been found to absorb as much as 15 to 25 per cent of total money costs in the UNC study.[40]

Features of the resource-element concept used in the UNC study that were appropriate there create problems of transfer of technology from one country to another. The sizes or output capacities of resource elements were set at approximately the average of USSR shops. This datum was not considered critical in the UNC study since proportionality could be assumed for a considerable range of capacities, and also because very small additions of new capital were unlikely in so large an economy.[41] In application to smaller economies and particularly to those of developing countries, however, scale effects become critical. The data of Gallik show that even in the USSR there is a considerable increase of efficiency (measured in terms of labour productivity) not only with lot size but also with the scale of the production shop or the entire machine-building plant.[42] In these relationships, shop or plant scale is a separate and independent variable in addition to lot size. In general, there is a systematic shift in the assortment and cost of capital equipment with the scale of the shop or the plant. For the present study it is of crucial importance to quantify this relationship or at least to determine an approximate minimum economic scale for various resource elements.

The process content of some of the resource elements is not as "pure" as might be desired because more than one distinct process was incorporated in the same resource element. Examples are die casting and permanent mould casting of non-ferrous metals, free and die forging, which are due to the desire to reflect Soviet practice, the availability of data and the need to restrict the number of resource elements.[43]

Certain institutional conditions are incorporated in the definition of the UNC resource elements. Soviet metalworking plants have historically tended to be highly integrated as compared, for example, to plants in the United States, and until very recently few components or services were purchased from specialized plants. This tendency brought about "captive" facilities for nearly all components, including fasteners and other standard parts, as well as for such services as machinery repair, tool, pattern and die making, and utilities. To the extent that this is explicitly visible

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[40] Reference [15], p. 13.

[41] Ibid., p. 9.

[42] Ibid., tables 1 and 2, pp. 6—7.

[43] Ibid., p. 19.

in the UNC study, no difficulty is encountered. However, in many cases this integration is implicit in the definition of the resource elements.[44] A comparable degree of integration may not be appropriate to developing countries to which process technologies are to be transferred: however, while only one set of coefficients is available, no critical approach to this matter is possible. Soviet metalworking facilities generally are large-scale operations; on the other hand, seriality is probably lower than in the United States, with a concomitantly lower degree of specialization.[45]

A problem in the relation of the resource-element concept to cost and efficiency studies concerns coverage. Under the capability objectives of the UNC study, steel and non-ferrous rolling processes were not covered since they were not considered to be in the sector. In cost and efficiency studies, however, there are significant trade-offs with these processes that require attention. For example, the amount of machining to be done on a piece of round bar stock depends upon the number of standard sizes of this stock that are available; if there are many choices, a size close to the final dimension can be selected. There is thus a trade-off between the number of different kinds of stock produced by rolling in the primary metal sector where variety increases cost and the amount of machining to be done in the metalworking sector.

Another problem concerns aggregation. The degree of aggregation employed in the UNC study is inadequate to handle problems of cost and efficiency unless the method is revised and extended. The aggregation problems appear at the following three levels: end-products, resource elements, and capital and flow inputs. The suggested extension of the UNC method involves complementing the small set of typical products covered in the UNC study by a long list and an extrapolated portion of the product assortment in each productive branch.

The following problems occur at the level of resource elements:

(*a*) Inadequate adaptation of highly aggregated resource elements to specialized product assortments;

(*b*) Inadequate adaptation of such resource elements to specific serialities, complexity levels and precision requirements of particular products;

(*c*) Loss of description of technical process detail since mixtures of different processes are represented by a single resource element;

(*d*) Loss of description of potential variability in capital and flow inputs of resource elements that differ in scale but are represented by a single aggregated element;

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[44] Ibid., p. 8.

[45] Reference [15], p. 11.

(*e*) Loss of representation of the possible adaptations in the productive facilities to local conditions by capital/labour substitution and other means due to the definition of a single resource element for a given combination of technological characteristics rather than the definition of alternatives that take into account such adaptations.

Points (*a*) and (*b*) can be handled by secondary corrections that adjust the exact claims of particular outputs upon the capacity of an aggregated resource element for which the internal structure is assumed to be constant. The reliability of the results will depend upon the accuracy of the initial (uncorrected) approximation. Only country studies and their applications to concrete development programming tasks will indicate whether the margin of error implicit in the suggested level of resource-element aggregation (maintaining the UNC objective of approximately 75 resource elements) is adequate for practical applications.

Point (*c*) has not been of great importance in the UNC study. Adjustments of the resource-element concept given there would be required primarily in the definition of separate resource elements for tool, pattern and die making and for internal repair services, since most of these auxiliary processes are included in the UNC resource-element definitions.

Point (*d*) requires an important extension in the definition of resource elements. Scale effects must either be accounted for explicitly (functionally relating resource inputs to the scale of the resource element by distinguishing fixed and variable parts of inputs) or at least be taken into account by specifying reasonable lower economic limits on scale.

The aggregation problems of point (*e*) are inherent in the classification adopted for different classes of machinery that make up the resource elements and for the different labour, material and other flow inputs that their operation entails. Lack of detail at this level prevents the proper costing of these inputs. In particular, the expansion of the resource elements themselves may, to some extent, involve the appraisal of domestic production possibilities for the necessary machinery; the flow inputs involve problems of resource allocation in the economy that must be related adequately to economy-wide programming approaches.

Capital-labour substitution in the sector takes place primarily through the degree of mechanization and automation of the productive facilities and the organization of the typical queuing process of production shops. They are reflected in the definition of resource elements: namely, their machine park and labour inputs.

The mutual substitution of machines with different degrees of automation or different working methods has been studied for the process of machining. Since the investment costs of individual metalcutting machine tools differ, the respective capital labour ratios can be derived on the assumption that one worker per shift will be assigned to each machine. Such a study has been performed by Kurz and Manne [41] using the original data of Markowitz and Rowe [13] obtained from engineering estimates. Kurz and Manne found that the capital-labour substitution process could be adequately represented by a Cobb-Douglas production function of the form

$$Q = a\, K^{0.5}\, L^{0.5},$$

where $Q$ is the output, $K$ the capital, $L$ the labour and $a$ a proportionality factor.[46] The unit elasticity of substitution characteristic of such a function means that a 10 per cent increase in the price of capital relative to labour will result in a 10 per cent decrease in the use of capital provided that the total output remains constant. The numerical values of the labour and capital exponents of the function indicate the share of these factors in the total product under ideal competitive conditions; they are estimated as exactly equal for the present case. Since these data were derived from the engineering characteristics of various types of machine tools suitable for making specific cuts (for example, an outside circular cut) the results are transferable from the United States to other countries provided that they fall within the range of the original data.[47]

In another study [57] of capital-labour substitution in machining, Boon's aim was to determine which machine tool was optimal (in terms of minimum capital and labour cost) for performing a number of machining tasks. He considered a wide range of relative prices that were adequate to characterize conditions in developing, semi-industrialized and highly industrialized countries and also took into account lot-size variations. His conclusion was the higher the precision requirements in production and the larger the sizes of the workpiece, the greater the restriction in the choice of technology.[48] Thus, if it can be assumed that developing countries will begin or expand metalworking production for the simpler smaller tasks

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[46] Reference [41], p. 676. The output is the number of pieces produced during a $Q$ daily 8-hour shift. The capital investment $K$ is in thousands of 1962 US dollars. The labour input $L$ is the number of men working an 8-hour shift.

The unit elasticity of substitution typical of the Cobb-Douglas function was confirmed by an independent estimate of the elasticity of substitution treating the latter as a variable parameter. The estimate of this parameter was 0.989 with an excellent correlation coefficient; estimates of the other parameters were also very close to the ones obtained on the basis of the simple Cobb-Douglas function. Therefore the original specification of the function was essentially a good one.

[47] On the basis of one shift, the range for all machining operations is from $200 per worker to $450,000 per worker. With multiple shifts there is a corresponding reduction in these figures. This over-all range is of course much too wide for individual machining tasks.

[48] Reference [57], p. 30.

rather than for the complicated or very large tasks, their choices for capital-labour substitution will be wider than the choices of the more industrialized countries.[49] This observation must be qualified by the fact that, for 25 per cent of all tasks, flexibility was found to exist only at small lot sizes, while for another 25 per cent it was found only at large lot sizes.[50]

Boon, as well as Kurz and Manne, assumes a one-shift operation, a 1:1 ratio between workers and machines, and full use of the machines. In the first assumption, his results overestimate the degree to which optimal capital intensity differs between developed and developing countries, in the second assumption, the results underestimate it. The effect of the third assumption may be either an underestimate or an overestimate. If we consider continuous rather than one-shift operation in developing countries in order to improve capital utilization, unit capital costs decrease to less than one third. This is an element of great additional flexibility in capital-labour substitution.

In the United States and other highly industrialized countries, available machine time is reduced because less than one worker is assigned to each machine: thus, in the queuing process that characterizes machine-shop operations, idle machines typically wait for workers (whose time is fully used) to operate them. Conversely, in developing countries, more than one worker can be assigned to each machine in order to ensure that machine capacity is more fully used. Thus, in actual operating practice, the amount of capital per worker is greater in the United States and less in the developing countries than estimated by Boon. Thereby the gap between the optimal technologies tends to widen.

Whether indivisibilities are more important in the United States or in developing countries to reduce full use of machines depends on how efficiently the sector can be planned in an integrated fashion in developing countries. In the United States the dispersal of capacity between separate enterprises tends to reduce average machine use, while in developing countries limited markets create an inherent limit in many lines; there may also exist a capacity-dispersal problem for the same reason as in the United States which has been observed in the metalworking sector in Brazil.

Capital-labour substitution can to a lesser degree also take place through the operation of the following three mechanisms:

Given alternative production methods (alternative resource-element inputs) to produce the same product, there is an opportunity to choose more or less labour- (or capital-) intensive technologies;

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[49] Ibid., p. 15.

[50] Ibid., table 4, pp. 12—13, Patterns II and III.

Given alternative possible product designs to realize given technical specifications, the design can be adjusted to use more or less labour- (capital-) intensive technologies in its production;

There is a possibility of product substitution in final or intermediate uses in response to price (or allocation) signals reflecting greater or lesser labour or capital intensive technologies.

By capital-labour substitution resource elements can be adapted to prevailing local conditions. Depending on the relative scarcities of these factors, which are generally reflected in their prices, the productive process is organized to economize on one factor to a degree that can be readily determined either by market (or market-like) processes or by programming studies.

In addition to capital-labour substitution, the productive process may be adapted to local conditions by the following factors in the definition of the resource elements or in their mutual relationships in larger structures: the scale, specialization-integration with regard to output (horizontal integration), overlap of resource elements, specialization-integration with regard to resource elements and the over-all organization of the productive process.

The scale of individual resource elements and of entire factories composed of them can vary in response to the size of the market served. While larger scale entails significant economies, in small markets it may be preferable to forgo some of these economies rather than not to have domestic production at all.

Specialization-integration with regard to output (horizontal integration) is also related to the size of the market. In large markets, individual resource elements and entire factories can be adjusted in their basic design to a relatively narrow range of product outputs; in small markets, on the contrary, resource elements and factories must be designed for a wider product assortment. The economies of specialization are sacrificed, but again this may be preferred instead of the complete lack of domestic production. Note that scale and specialization are inversely related. Specialization may be increased by building smaller plants that turn out more homogeneous products, while scale increases integrated facilities at the expense of a wider product assortment. There is every indication that, for the size of markets in developing countries, scale effects are strongly dominant over specialization.[51] The overwhelming scale effects on small scales gives rise to the approximate definition of "minimum economic scales".

The overlap of resource elements is an aspect of the problem of resource-element specialization. It is more likely that a given semi-fabricating operation can be carried out by different resource elements

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[51] See the argument of Melman [34], especially pp. 63—64.

that are not highly specialized. In the UNC study, there is a large overlap of size classes. For example, the larger forges can handle most of the output of the smaller ones, and the smaller ones likewise can handle a good part of the output of the larger ones, since the average weight of parts handled is much less than the maximum. This leads to substitution of resource elements in the production of the same nominal output, which is not the same substitution as between forging and casting in the production of crankshafts.

The problem of overlap becomes troublesome when the scale of each resource element in an overlapping class is too small to be considered economical for a small developing country. For example, total demand may not admit forges distinguished by several size and seriality characteristics. Due to the overlap of the production capabilities of these resource elements, however, it might be possible to establish one or two forges that could handle a far broader range of sizes and serialities than the typical range of the product assortment on which the resource element had originally been defined. If secondary corrections are systematically applied to many of the individual products that make up the product assortment of the integrated forge in the developing country, the resulting estimates can be reasonably accurate.

If the machine park of productive facilities is regarded as flexible, the problem is to select the optimal number and composition of the facilities. If too few are built there will be a loss of efficiency, since the facilities will not be well adapted to any particular range of sizes or serialities. If too many are chosen, their adaptability will be much better but they will suffer from the diseconomies of small scale. The optimal structure depends on the solution of a non-convex programming problem. There is thus a clear analogy between this aspect of the overlap problem and specialized versus broad product assortments characterizing a productive facility, except that, in the present case, the criterion of specialization is not the nature of the product but its size and seriality.

Some overlap of resource elements in regard to size, seriality and product-assortment classes is desirable at all times, since it results in an increased flexibility in the productive process. If there were no overlap at all, the probability of bottlenecks would be greatly increased as a consequence of unforeseen fluctuations in demand and production. This flexibility is, however, achieved at the expense of reduced specialization and adaptability of a resource element to a specific class of outputs.

Specialization integration with regard to resource elements refers to the degree of vertical integration of the productive process. Does a factory have shops for producing minor parts such as nuts and bolts on a relatively small scale or does it purchase them ? Does it perform its own repair and maintenance operations with special machine tools that are infrequently used ? Does it have shops with large minimal capacities that are only partly used? Does it make its own tools, dies and patterns? These questions concern the scale and use of individual resource elements. Self-sufficiency is inversely related to the scale of resource elements as well as to the typical lot sizes for intermediate products: as the self-sufficiency increases, the scale and lot sizes decrease.

In the industrialized countries, production in the sector is typically organized around specific product lines, such as automobiles, agricultural machinery and ships. Although there are many enterprises that specialize in the production of semi-fabricates by a given process (commercial foundries and upsetting shops) and there is an extensive network of sub-contracting, the core of the productive process is undertaken in vertical integration between product-oriented activities (design, assembly, marketing, and product research and development) and the major semifabricating processes (casting, forging and machining). In the automotive industry, the manufacture of motors or of large stampings is typically undertaken with captive capacity, while the manufacture of such items as headlights, batteries, sparking plugs, carburettors, mufflers or trim is subcontracted. In the developing countries, on the other hand, the scale of demand may not justify the maintenance of heavy captive capacity in any given industry defined by a specific class of products, but may suggest the organization of the sector around facilities such as foundries, forges or machine shops to manufacture a wide variety of end-products. The contrasting pull towards organization by end-products versus organization by major fabricating processes will be referred to as the bipolarity of the sector. While the logic of organization around fabricating processes under the conditions of the developing countries is very clear, the contrary pull is far from negligible and centres on organizational functions, such as design and engineering. Product design for increasingly economical and efficient service of customers is closely connected with marketing experience and thus tends to favour organization of the sector by products. At the same time, effective design must be based on intimate day-to-day familiarity with the production process and thus favours the integration of fabricating processes with design.

It is necessary to differentiate the concept of a resource element and a standardized function or task that can be physically embodied in a number of standard shops (resource elements). In the initial planning and programming approach for a country only one single resource element should be defined for each standard task. Thus, in the first instance, the problems of capital-labour substitution and local adaptation are to be decided by informal judgement based on the results of country studies. The problems raised by this approach are standardization of tasks, efficiency of model resource elements, adequate range of variability and unnecessary prejudgement of the results of a broader planning approach.

Tasks are combinations of technological functions and characteristics that underlie the individual resource elements; the approach depends on their standardization although it permits the local adaptation of resource elements. In particular, the technical characteristics to be standardized for the definition of a task include the principal technical characteristic (free- or die-forging, iron, steel or non-ferrous casting), size class and seriality class. Features that are subject to local adaptation and are thus excluded from the definition of a task include capital-labour substitution, scale, product assortment and overlap with related resource elements. In the country studies the effects of scale should be functionally described if possible. The flexibility achieved by the given degree of overlap of resource elements should be evaluated qualitatively.

It is of course evident that the standardization of the number and kind of tasks will somewhat reduce the sharpness with which the resource element concept reflects local conditions. It might be desirable that the exact combinations of technological characteristics defining a task be adjustable.

A country could define an alternative set of tasks in addition to the standardized ones. The standardized set would then serve for international comparisons, while the more sharply defined set might be useful for additional experiments in programming. Since it is an essential part of the present approach to insist that all technical descriptions be based on a data-system concept that permits frequent revision and redefinition owing to reasons inherent in their subsequent programming use (completely independent of international comparisons), there is no loss of effort in working with a double set of resource elements. On the contrary, it is a useful exercise in testing the flexibility of the technical information system.

Do model resource elements have serious inefficiencies? Without further tests can it be assumed that the existing productive facilities in any given country are locally adapted with a perfect degree of efficiency? Conceivably the practice in a country might suffer from varying rigidities that prevent the full exploitation of known technological alternatives. Model resource elements based on such rigid practices would be burdened with the inefficiencies of their sources.

There is no doubt that this factor will lead to some errors that can be reduced in some cases where the source of inefficiencies is obvious and the description of a resource element is based on an engineering estimate of improved practice rather than on the prevailing unsatisfactory practice. It would, however, be dangerous to go too far in this direction, since it is often difficult to judge beforehand the feasibility of the suggested improvement.

Inherently more difficult are the cases of inefficiency that are not even recognized because there is no standard with which to compare existing practice adequately. One of the major dividends of the present approach is that its systematic long range application will result in alternatives based on standardized international comparisons with which existing practice in individual countries can be compared even with the admitted shortcomings of standardized description.

The range of local adaptations is too narrow to indicate a set of resource elements that are representative of conditions in any developing country. A dilemma appears to exist in this regard; either to apply resource element variants chosen from a limited but more reliable range that are not completely appropriate, or increase the range and thus include serious irrationalities in the model resource elements. The present approach uses the first alternative. After a complete programming technique has been established on the basis of the technological description, it will be possible to study the sensitivity of the results to any reasonable changes in resource-element coefficients that might be expected as a result of the (unrepresented) local adaptations to the conditions of the developing countries, and the error inherent in the approach will thus be readily measurable. Use of the second alternative would result in an uncertain and undefinable degree of misrepresentation.

The unnecessary prejudgement of the results of a broader planning approach could be avoided by including multiple variants of a given resource element in the programming model. However, the additional complexity created by the procedure does not appear to be worthwhile in the present study.

### *Resource element classification*

Follow UNC classification for forging. Where this is inadequate, it has been suggested[52] that additional resource elements be provided to

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[52] In the report [15], pp. 13–15 written for the United Nations concerning the applicability of the UNC material to development programming it has been recommended that the number of resource elements be increased to improve the estimation of investment requirements. In particular it was suggested that the seriality variable be taken into account more fully reducing the range of applicability to end-products and ascribing more homogeneous technological processes to each. The third suggestion, requiring only minor modifications does not increase the number of resource elements significantly. In regard to seriality a different suggestion is made for the present study, namely, the device of handling exact serialities by secondary corrections; still, a small increase in the major seriality categories would not be harmful.

The suggestion concerning product-assortment narrowing is rejected, since in developing countries it is often necessary to integrate the fabrication of intermediates for many diverse end-products, thus cutting across the horizontal integrations usual in the industrialized countries. Instead, specialization to product assortment is to be treated as one of the local adaptations; in reporting locally adapted resource elements, however, the additional freedom is provided that more than one typical product assortment may be given; two variants of the same resource element based on different product assortments may be reported, instead of just one standard variant.

give more flexibility to die-forging as well as to separate free- and die-forging in some of the UNC resource elements. "As developed, the resource elements reflect the high reliance on free forging, and the relatively low use of presses with open and impression dies in the Soviet Union."[53]

Follow UNC classification for casting. Gallik suggests adding a resource element for "simple, virtually unmachined castings such as manhole covers and sewage pipe fixtures" as well as the separation of die casting and permanent mould casting.

Follow UNC classification for machining. However, should a precision dimension be added for subclassification? To do so would change the machine park considerably. The exact precision requirement for a product can be handled by a correction factor based on comparison with average precision of the typical product mix; however, more than one precision class would permit assigning a product first to such a class in a rough way as is done in the case of seriality. Since the termination of the UNC study, a major technical innovation has taken place in machining: namely, the rapid spread of numerical control. It does not affect the classification of standard tasks but may make it desirable to introduce alternative resource elements for this particular process.[54]

Follow UNC classification for stamping, upsetting and heat treatment. The coefficients for resource elements iv, v and vi in the UNC study are known to be of very poor quality.[55]

Follow UNC classification for steel fabrication (welding) and assembly. The following processes are not included in UNC classification but their inputs may at times be included in UNC coefficients: pattern-making, tool- and die-making, repair services, storage, intraplant transport, plant laboratory services and quality-control services. Resource elements for certain industries not covered by UNC study are electrical industries (wiring, insulation, armatures) and shipbuilding (ways). The question of how to identify missing resource elements remains open.

There are organizational resource elements (for overhead-type activities) such as design, engineering, costing, estimation, production planning, marketing, research and development, and general administration. Certain major processes in the primary metals sector that are interrelated with sectoral processes by way of mutual trade-offs are ingot castings (steel, non ferrous copper and copper alloys and non-ferrous aluminium and aluminium alloys) and rolling (non-ferrous aluminium and aluminium alloys).

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[53] Ibid.

[54] The potential of numerical control in the metalworking industries of developing countries has been explored by Vietorisz. [58]

[55] Reference [15], pp. 13, 15.

An open question is whether an attempt should be made to cover each of these processes with resource elements in detail comparable to that of intrasectoral processes? The classification is arbitrary, and problems of standardization encountered with ingots and rolled shapes are exactly analogous to standardization problems with semi-fabricates in the sector as conventionally defined for the present study.[56] Source material on the above casting and rolling processes is more abundant than for metalworking processes in general. The methodology of a process-analysis study of the former could be readily adapted to the present study.

### *Description of products*

Given a set of resource elements, the next task of programming for the sector is the decomposition of a group of typical products for each branch into subassembly, component and resource-element inputs. The level of use of each resource element must be given in physical terms per unit of a specific individual end-product. For example, in a detailed breakdown of inputs into a specific gasolene engine, the number of tons of castings, forgings, stampings, welded fabrication and upsettings (fasteners) as well as the total tonnage of parts requiring heat treatment must be specified; the tonnage estimates must be complemented by figures for total machine-shop hours (machining) and square-metre-years (assembly floor space). The levels of resource-element use can be compactly summarized by a column of coefficients that are similar in many ways to a conventional activity vector except that, for purposes of cost and efficiency studies, it cannot be assumed that the levels of inputs vary linearly with the scale of production, since economies of scale must be taken into account both in regard to lot size and to the scale of the resource elements used.[57]

The product to which the decomposition into subassembly, components and resource-element inputs is applied is not an average but a single highly specific individual product that can be identified by year and design, or technical specification. In the UNC study, such an end-product is the ZIL-120 gasolene engine whose process level (resource element) inputs are shown in table 2. The inputs have been normalized to 1,000 metric tons of engine output. Given these process level (resource element) inputs, the primary capital and flow inputs can be derived using

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[56] Classes 35—39, International Standard Industrial Classification of All Economic Activities; see chapter 1.

[57] For a concise discussion of the need to distinguish between lot size and resource-element-scale economies, see reference [15], pp. 5—7 and tables 1 and 2.

the input coefficients of the set of resource elements previously defined. The primary inputs[58] are listed in table 3.

A specific individual product such as the ZIL-120 gasolene engine is referred to as a typical product. In the UNC study the typical products are used to construct "representative products" for each branch by a process of weighted averaging of their resource-element input levels. A representative product is thus a statistical aggregate and is used to characterize statistically defined classes of products in each productive

TABLE 2. PROCESS LEVELS PER THOUSAND TONS OF ZIL-120 GASOLENE ENGINE OUTPUT

| *Process* | *Resource element code* | *Unit of measurement* | *Process code* | *Process level* |
|---|---|---|---|---|
| Die forging | F9 | [a] | $A_9$ | 0.1603 |
| Stamping | S5 | | $A_{25}$ | 0.0361 |
| Upsetting | U3 | | $A_{33}$ | 0.0176 |
| Foundry: (cast iron) | C3 | | $A_{36}$ | 0.8345 |
| Foundry: (aluminium, manganese, zinc and alloys) | C13 | | $A_{46}$ | 0.0575 |
| Machining | M5 | [b] | $A_{60}$ | 0.4375 |
| Heat treatment | H1 | [a] | $A_{71}$ | 0.5051 |
| Heat treatment | H2 | | $A_{72}$ | 0.3104 |
| Heat treatment | H3 | | $A_{73}$ | 0.0388 |
| Rolled steel[c] | RS$^{3}$ | | $A_{126}$ | 0.3500 |
| Assembly | A5 | [d] | $A_{90}$ | 0.106 |

SOURCE: Reference [9], pp. III—92—95, IV—3—5, 13. Assembly is not listed in the source table on p. IV—13; the input level is derived from IV—24.

[a] $10^3$ metric tons.

[b] $10^5$ effective machine hours. It has been normalized by multiplication by a factor of 100. In this way coefficients of equal order of magnitude will reflect the same order of magnitude in costs

[c] Duplicates flow inputs into forging, stamping and upsetting plus 30 per cent. (The latter is possibly an error.)

[d] $10^3$ m$^2$/year.

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[58] For all resource elements except machining and assembly, the flow inputs into the end-product are obtained by multiplying the coefficient of the resource-element input into the end-product (from table 2) by the coefficient of the flow input into the resource elements (tables given in reference [9], chapter II). The percentages of capacity use are derived by dividing the coefficient of resource-element input into the end-product by the normal monthly capacity of the resource element. For machining, the UNC tabulation of flow data is inconsistent, since flow inputs are not on the basis of the same unit (effective machine hours) in which input requirements are expressed, but on the basis of use of the full capacity. Therefore, the foregoing flow-input computation procedure must be modified by dividing by the yearly effective machine hours of the resource element. The percentage of capacity is computed normally. For assembly, flow inputs are not directly proportional to the level of use expressed in square-metre-years. A special computation is required to derive them (see reference [9], pp. II—147—159). The percentage of capacity is again computed normally.

## TABLE 3. FLOW AND CAPITAL INPUT PER THOUSAND TONS OF ZIL-120 GASOLENE ENGINE OUTPUT

| *Type of flow or capital input* | *Process from which input originates* | *Code* | *Unit of measurement* | *Input* |
|---|---|---|---|---|
| *Labour* | | | | |
| Forging production | F | $b_1$ | a | 1,539 |
| Stamping production | S | $b_2$ | | 2,419 |
| Upsetting production | U | $b_3$ | | 1,072 |
| Casting production | C | $b_4$ | | 31,816 |
| Heat-treatment production | H | $b_5$ | | 44,780 |
| Machining production | M | $b_6$ | | 38,474 |
| Assembly production | A | $b_7$ | | 11,542 |
| Auxiliary | all processes | $b_{29}$ | | 78,159 |
| Engineering and technical personnel | all processes | $b_{30}$ | | 26,040 |
| Clerical and office personnel | all processes | $b_{31}$ | | 12,270 |
| Junior service personnel | all processes | $b_{32}$ | | 6,426 |
| Total labour | all processes | $b_{33}$ | | 254,587 |
| *Power and fuel* | | | | |
| Electricity | all processes | $b_{39}$ | b | 1,315,012 |
| Conventional fuel | FSUCHMW | $b_{40}$ | c | 769,502 |
| Steam | FSU HMW | $b_{41}$ | c | 628,478 |
| Compressed air | FSU HM | $b_{42}$ | d | 2,296,319 |
| *Metal* | | | | |
| Rolled forging steel | F | $b_{54}$ | e | 208 |
| Rolled steel (bars and shapes) | SUW | $b_{55}$ | | 62 |
| Pig-iron | C | $b_{56}$ | | 587 |
| Alloying ingots | C | $b_{58}$ | | 63 |
| Ferrous scrap | C | $b_{63}$ | | 318 |
| Non-ferrous scrap | C | $b_{64}$ | | 2 |
| Alloying additives | C | $b_{65}$ | | 23 |
| *Other materials* | | | | |
| Water | FSU HM | $b_{96}$ | d | 20,596 |
| Chemicals | FH | $b_{97}$ | | 113,865 |
| Lubricants | FSU | $b_{98}$ | c | 2,073 |
| Coolant (concentrate) | | $b_{99}$ | | 1,098 |
| Dies | FSU | $b_{100}$ | | 2,455 |
| Cutting tools | SUM | $b_{101}$ | | 3,031 |
| Measuring tools | M | $b_{102}$ | | 264 |
| Jigs and fixtures | M | $b_{103}$ | | 1,893 |
| Heat-treating fixtures | H | $b_{104}$ | | 7,378 |
| New sand and clay | C | $b_{105}$ | | 1,947,000 |
| Sand binders | C | $b_{106}$ | | 46,126 |
| Slag-forming | C | $b_{108}$ | | 108,854 |
| Refractories | CH | $b_{109}$ | | 96,189 |
| Electrodes | CW | $b_{110}$ | | 863 |
| Paint | A | $b_{115}$ | e | 10 |
| Paint solvent | A | $b_{116}$ | | 6 |
| Wood (crating) | A | $b_{117}$ | | 28 |

TABLE 3 *(continued)*

| *Type of flow or capital input* | *Process from which input originates* | *Code* | *Unit of measurement* | *Input* |
|---|---|---|---|---|
| *Capital: resource-element capacities* | | | | |
| Die forging | F9 | $c_9$ | $f$ | 6.99 |
| Stamping | S5 | $c_{25}$ | | 0.90 |
| Upsetting | U3 | $c_{32}$ | | 1.53 |
| Foundry (cast iron) | C3 | $c_{38}$ | | 10.01 |
| Foundry (alloys) | C13 | $c_{48}$ | | 34.50 |
| Machining | M5 | $c_{60}$ | | 83.33 |
| Heat treatment | H1 | $c_{71}$ | | 14.09 |
| Heat treatment | H2 | $c_{72}$ | | 44.87 |
| Heat treatment | H3 | $c_{73}$ | | 108.28 |
| Assembly, painting and crating | A5 | $c_{90}$ | | 29.17 |

SOURCE: Reference [9], IV—22—24; see also IV—6—11.

[a] man-hour.

[b] kWh.

[c] kg.

[d] m$^3$.

[e] metric ton.

[f] per cent of normal monthly capacity.

branch. In diesel-engine manufacture, the categories "light", "medium" and "heavy" were established on the basis of a statistical survey. The task then was to construct a representative product for each category. It was first ascertained that light diesels included automotive, aviation and tractor diesels. Data were available only for the latter type, but the coverage was deemed satisfactory, since automotive diesels were known from statistical sources to represent only about 10 per cent of the total. A tabulation of the year of production and technical specifications for thirteen different designs was then prepared. The data revealed a trend toward a reduction in the weight-to-horsepower (kg/hp) ratio. Detailed data were available only for the D-36 engine, which has a relative weight of 20 kg/hp. The weights of the most important parts and/or subassemblies were also available for the SMD-55 engine, which has a relative weight of approximately 10 kg/hp. The resource-element inputs were then derived for these two typical products, and coefficients for a representative light diesel engine were constructed on the basis of the assumption that the process levels per ton of D-36 engines was representative of process levels per ton of tractor diesels with a relative weight of 18—22 kg/hp (those produced in 1958), and that process levels per ton of the SMD-55 engine were similarly representative of the tractor diesels with relative weight around 10 kg/hp (which was the estimated production of 1959—1960).

The statistical weights used in the aggregation (85—15) were estimates of the share of each category in the total tonnage of the branch.[59]

Representative products are useful for capability analysis but are unsuitable for efficiency, cost and programming studies such as those of the present study. For this reason the present analysis uses the UNC method only until the decomposition of typical products into subassembly, component and resource-element inputs (determination of process levels). The typical sample product is used not to define statistically aggregated representative products but to construct on the basis of demand a sequence of products approximately in the order of increasing production costs per unit of output value by using a long list of products in each branch.

*Research technique of the UNC study*

In the UNC study the decomposition of typical sample products

> "...entailed first, the determination of the net distribution of processed metals. The latter were expressed, necessarily, in terms consistent with the outputs of resource elements (process activities)...
> "The second step in this typical pattern was to convert the net processed metal inputs to a gross (pre-machining) basis by means of given or estimated coefficients of metal utilization. The pertinent coefficients of utilization for our study are summarized. Having determined the requisite gross processed metal inputs, the calculation of implied flow and capital requirements followed in the usual case by applying the previously estimated inputs per unit of process activity [that is the resource element capital and flow inputs] and summing for all processes. This left the residual non-processed items, purchased from other sectors, to be determined according to the individual commodity analysis, i.e., in greater or lesser aggregation according to data availability."[60]

The three variants of the research method to establish process levels were part-by-part analysis, direct derivation of process levels on the basis of literature sources and analogy.

> "In a few instances the basic process distributions were developed piecemeal through a part-by-part analysis. This procedure itself has several variants all of which proved fairly laborious but in the main, economical of the time of skilled personnel. What was involved, essentially, was the detailed stripping and weighing of the elements of a given machine according to process origin."[61]

At times the required data were found in product catalogues containing weights of parts and metal or process designations; usually,

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[59] Ibid., pp. III—18 to III—23.
[60] Ibid., p. III—5.
[61] Ibid., p. III—5B.

however, because of incomplete data, considerable part-weight information from engineering drawings was grouped by engineering assessment in relevant process categories. Process distributions were sometimes given directly in the literature either for subassemblies or for complete products or product groups. Otherwise such coefficients were applied from more global sources on classes of products.

Analogy was used in part or whole for "data-scarce" commodities by borrowing and adjusting data referring to comparable Soviet machines and as a last resort from United States models. The scarce data that related primary inputs directly to specific end-products were used to check the two-phase derivation by resource elements and were occasionally used to supersede the latter.[62]

The machining, assembly, and heat-treatment process resource-element levels required special estimating techniques. Machining inputs had originally been related to chips removed, which is the difference between gross and net weights of the part.[63] Though this technique of estimation was abandoned for machining, the gross-net estimates are still essential for the transition from part weights as assembled to gross part weights prior to machining that determine casting, forging and other resource-element input levels. The final technique for estimating machining input levels based on "several dozen sources" by different end-product classes included technical norms, special technical studies and related references; it involved a direct estimate of effective machine-hours based on the literature sources.[64] Process levels for assembly "were derived in relation to machining inputs as were corresponding magnitudes (flow and capital) from the pertinent machining resource element... they represent a mixed reliance on norming and empirical evidence.[65]

Heat treatment inputs were estimated partly on the basis of aggregative data supplied in Soviet sources but mainly by means of specific engineering analyses. The latter involved establishing the percentage of each kind of processed metal in an end-product undergoing heat treatment (allowing for repeated applications) and subsequently a breakdown by major classes of heat-treating techniques (normalization and hardening, gaseous cementation and surface hardening).[66] The estimates are known to have considerable error.[67]

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[62] Ibid., pp. III—53 to III—5D.

[63] Reference [9], Studies Nos. 5, 5A, 6, and 6A.

[64] Reference [9], Study No. 7, p. III—5E.

[65] Ibid., p. III—5F; see also tables II—68, II—69, II—70, pp. II—157 to 159.

[66] Ibid., pp. 5F—5G and table III—2.

[67] Reference [15], pp. 13, 15.

### *Modifications and alternatives*

The principal modification of the UNC research technique is based on the additional degree of freedom afforded by studies in the country whose data underlie the work and original observations to complement or supersede published sources.

Given the specifications of a machine, the first task is to identify each part as to kind of metal and process of origin. In view of the very large number of parts in a complex machine, this is no mean task. For example, in a detailed analysis of sixteen Soviet metalcutting machine tools, the average part count was over 800. A working procedure that economizes the time of highly trained personnel is to have them indicate the individual parts on the specifications with a coded set of coloured pencils; thereafter the weight of each part can be calculated by research assistants of considerably lesser training. Initially, the colour coding must be performed by experienced mechanical engineers; eventually, much of this work could be carried out by specially trained graduate engineering students whose performance would still be supervised by senior engineers. Another task requiring a high degree of technical competence is the estimation of the gross-to-net weight ratio for different parts as well as effective machine hours for machining requirements and heat-treatment specifications. Purchased parts, such as motors, can be identified by reference to standard lists.

A suggested short-cut of the part-by-part approach is the grouping of parts by different functional shapes, such as axles, housings, gears and fasteners; then exact estimates of process origin, machining time, weight and the like can be restricted to the most important members in each class and two or three other members of smaller sizes and/or complexities. This procedure permits an approximate estimation of the other members of the group without the time-consuming individual inspection and measurement inherent in the fully detailed procedure. The method can also be used to estimate secondary corrections for resource-element inputs in regard to seriality, complexity and precision. The origin of this suggestion is a verbal account of an estimating procedure that is used in the USSR to define the production costs of new machine designs with an accuracy of 20 per cent. Such estimates are prepared for supporting appropriation requests for subsequently more detailed and accurate production analyses; their preparation is taught at engineering schools at the equivalent of the master of engineering level of instruction.

Among the other approaches used in the UNC study, the use of direct listings of process level inputs wherever available from previous technical studies is of course recommended if the reliability is comparable to the part-by-part estimate. Estimates by analogy must be restricted in so far as possible, as was also done in the UNC study. Two potential costing short-cuts that were not included in the UNC study are short-cut cost estimates in industries where bidding is a common practice and in industries where they are related to subcontracting.

Bidding on jobs is a common practice in branches connected with construction, as with oil refineries, power plants and chemical plants on which bidding may at times be international. The same applies to major pieces of custom-made equipment, such as hydroelectric turbines and generators, or certain categories of railway rolling stock. In all of these cases the preparation of bids must be undertaken on the basis of major specifications without reliance on detailed part-by-part designs, and shortcuts are used as a matter of normal technical and management practice. A detailed study of the estimating procedures would yield valuable data. Their use is nevertheless limited because in many cases the coefficients refer to value rather than to physical inputs; in other words, they implicitly incorporate assumptions concerning one particular set of price ratios. Whether the aggregated information can be divided into price and quantity components depends on the particular case. As a minimum, such estimating procedures can be used as independent checks on the quality of the technological descriptions derived from the part-by-part approach.

In industries where subcontracting is common, the contracting enterprises generally know the production costs of their subcontractors. The estimating methods employed in these industries would be instructive if they could be obtained possibly through consulting engineers familiar with the industries.

A special case of importance to the developing countries is the large distribution enterprise that contracts the manufacture of its merchandise with many different producers. The large United States mail-order houses have such a policy and are reputed to be able to estimate the production costs of the merchandise offered in their catalogues with great precision. Since their operations cover not only the United States but a number of developing countries, particularly in Latin America, international comparison of their estimating procedures for the large number of items in the metalworking and engineering products sector would be most valuable. The relevant products include not only consumer durables and semidurables (kitchen equipment and hardware) but also hand tools, farm equipment and builders' hardware.[68]

The basic advantage of product decomposition is that it permits the piecing together of joint requirements for resource-element capacities

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[68] Incidentally, these firms would also be prime sources of information concerning the structure of demand in some branches of the sector in considerably more detail than in conventional statistics. The probability of obtaining this information is, however, not high.

that originate in many different individual products and their parts. It is the most important justification of the technique; all attendant problems and ambiguities must be weighed against this virtue. The productive techniques that can be used for manufacturing a product need not be unique. As mentioned before, an automotive crankshaft can either be forged or precision-cast prior to machining. Depending upon the alternative, the same product will have two different breakdowns into process levels, which does not create particular difficulties after the framework of analysis is generalized from input-output to a stronger programming approach.

Only the simplest unassembled products can be represented by a single list of process levels (resource-element inputs). If there are subassemblies of different hierarchical orders and parts in each, any level can be treated as an end-product and must often be so treated in order to reflect possibilities of partial domestic manufacture complemented by imports or standardization and modular design. Thus, for example, the same engine, clutch, brake assembly or battery can be used in different kinds of vehicles and lorries, tractors and industrial engines. The same standard individual fasteners (parts) will typically be used throughout the sector for a great many different products. It is thus not easy to decide what is an individual product for decomposition purposes. A practical (though analytically not completely satisfying) procedure is to define not only a list of typical sample end-products to represent production possibilities in a sector but also a list of subassemblies and parts that are to be treated independently.[69]

To represent a set of subparts of a composite end-product treated as a unit by a single set of process levels is possible only if each part in the unit can be uniquely represented; otherwise there is a combinatorial proliferation of alternative proeess-level input patterns. If there are only a few significant combinations, these can be enumerated as such, but if the number of alternative combinations is large it is preferable to treat the subparts having several input-pattern variants as individual products.

The determination of coefficients of metal use cannot be regarded as a straight technical problem subject solely to engineering judgement. The amount of metal removed by machining from bar or other stock depends on the variety of bar sizes and other shapes produced in the

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[69] It would seem to be more aesthetically satisfying not to prejudge this issue by the very definition of a list but to allow the model itself to decide which items should be treated individually and which should be merged into the description of a composite product. Throughout the programming approach there is a recurring need for such simplifying prejudgements without which the complexities of programming the sector would be utterly dumbfounding.

primary metals sector; the amount of machining to be done on forgings and castings depends on the closeness of tolerance achieved in the preparatory processing. In each of these cases there is a trade-off between the metal losses and resource inputs attributable to machining and the added resource inputs required to produce a wider assortment of primary shapes or closer tolerances in preparatory processing. In practice, the trade-off will necessarily have to be handled implicitly, at least in the first definition of the problem; later, it can be added as a complementary sensitivity study built around the initially derived results. To take explicit account of the required resource-element and product-input variants appears to be intolerably burdensome, at least at this stage.

Inputs into end-products necessarily must be pre-classified in accordance with the set of pre-defined resource elements. Pre-classification categories in the UNC study include type of product (typical products characterizing a resource element), size class and seriality class. Further pre-classification categories that might be included in future resource-element lists are precision and complexity of part produced. In the UNC study the pre-classification operates in the following way: To analyse the production of a 2.9-ton turret lathe that has 896 separate individual parts, the resource elements representing the forging, casting and machining inputs of the turret lathe must first cover parts for machine tools among their listed output assortments. Since in the UNC study there is no distinction between most resource elements of the same size and seriality class by type of product assortment, it is necessary to ensure that the variant is actually appropriate.

The maximum weight of a part is the criterion in selecting the size class. Thus it is necessary to estimate the exact weight of the heaviest forging, casting or machined part. In the case of machine tools, this estimation is undertaken not on a part-by-part basis but by using the following additional statistically derived information: "Assume maximum weight of cast part of a machine tool to be between 20 and 40 per cent of the total weight (the heavier the machine tool the smaller the percentage share of its heaviest part), and $^1/_3$ of maximum weight of cast parts to be the maximum weight of forged parts. The given turret lathe has approximately a median weight among the sixteen machine tools listed, therefore an estimating factor of 30 per cent is appropriate for the maximum weight of casting that gives 870 kg; accordingly the maximum weight of forging is 290 kg. Assuming a seriality, it is possible to select Forging Resource Element No. 4 (heaviest forging, 320 kg). Foundry Resource Element No. 5 is the best among poor choices, since it is medium rather than small series. Its part-size is too large (5,000 kg, although 1,000 kg maximum part size would be more appropriate but is available only in "mass" seriality). For copper castings, the choice is again poor. Only two resource elements are defined for this alloy group; one is too high in seriality and the other in part size. For machining, the fit is considerably better: Machining Resource Element No. 3 is the preferred choice with a small and medium series and a maximum rough weight of part of 2 tons."

It should be noted that the underlying assumption is that all similarly processed parts for a given end product are handled in the same resource element: thus, forged parts are not subdivided by size class and distributed between larger and smaller forges; the same is true for operations such as casting or machining. The assumption is a consequence of the institutional set up, namely, that production is organized around end products rather than around the required processes for different end-products. As a result, each resource element tends to have a broad range of capabilities, and the degree of capacity use depends on the product assortment. To the extent that production (as in a developing country) can be organized more closely around the processes rather than around the end-products, the typical resource element can be defined with a considerably narrower range of capabilities, and the estimation of process-level inputs can be more independent of the exact size, seriality, precision or complexity distributions characterizing a given product assortment. In other words, the UNC material contains resource-element definitions that make the accuracy of the description of technology highly dependent on the use of approximately the same product assortments for which these definitions were originally derived. In revising the method for application to developing countries, it is therefore convenient to standardize a larger number of resource elements that have been more narrowly defined primarily by size class than the UNC study and to make capacity and flow input corrections.

### *Secondary corrections*

From the point of view of cost, efficiency and programming studies, the principal drawback of the unmodified UNC approach is the fact that once an end-product is associated with an input originating in one of the pre-classified variants (a resource element) of a fabricating process, the numerical magnitude of the process level whenever expressed in tonnage terms is proportionally connected to the gross weight of the fabricated parts. Thus, once the castings of an end-product (as in the case of the illustrative turret lathe above) are associated with Foundry Resource Element No. 5, all capital and flow inputs from that point in the casting process are proportional to the tonnage of castings produced, regardless of the number, complexity, tolerances and size distribution of the cast parts in that particular end-product. Moreover, given the seriality class of the resource element that determines its exact machine park and flow inputs, variations in the seriality class are likewise suppressed.

The exact fraction of output capacity that is used and the exact flow inputs can become independent of the ties of rigid proportionality to tonnage output by introducing simple correction factors. The basic assumption is that inputs are first pre-classified in a seriality class for which the corresponding resource element has a given fixed machine park adjusted to the range of serialities occurring in the given class. Corrections do not affect the assumed machine park but only the capacity requirement per ton of output. From the point of view of developing countries and their limited markets, the key correction is in seriality. In a given seriality class, the capacity of each resource element must be standardized by reference to production at a stated known "base" seriality.

The simplest way to obtain the necessary data for this correction is to calculate the total available yearly "effective hours" of each resource element in a way similar to that of the UNC study for the case of machining resource elements.[70] The yearly effective hours that are summed for different machines are in part determined technologically for they cannot exceed the maximum defined by continuous operation while allowing for reasonable down-time for maintenance and inspection purposes. Limits are clearly introduced by institutional conditions, such as the number of shifts and holidays, and the work-relief time of the workers. After the technologically feasible maximum effective hours are known, adjustments can be readily made to take into account the country-to-country variations in institutional conditions. Inherently more difficult is the estimation of a third, intermediate category of deductions from the yearly effective hours, owing to various delays that are more or less closely tied to the structure of production. They include worker-fatigue allowance, tool breakage, shortages of materials, time lost because of broken or defective parts, waiting time for cranes, absence of tools, unplanned repairs, labour absenteeism and failure to observe proper procedures.[71] A final category of deductions is planned underloading which is the incomplete use of productive facilities that is foreseen as a result of indivisibilities in the productive process. The category must be divided into two main parts.

One part is an allowance for the inherent lack of perfect balance between the capacities of the various machines of a productive facility in producing all parts of the product assortment, and the consequent impossibility of always operating all machines, apart from the factors

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[70] Ibid., p. II—9, pp. 147—150; reference [13], pp. 338—344.

[71] Percentage of time losses are typically of the order of 0.5—2 per cent for each category and add up to 12 per cent in the illustration cited. This excludes planned underloading which was almost 20 per cent in the same case. For worker fatigue refer to reference [13], p. 34.

mentioned earlier. The second part is that planned underloading arises from indivisibility in a productive facility (resource element) as a whole (it has a minimum economic scale measurable in terms of total output). Unless this minimum economic scale is small in relation to total demand for the capacity of a resource element, the unevenness of investment will reflect itself in a fluctuating, but at times marked, incomplete use of the capacity that can be clearly foreseen in the process of planning. In allowing for a deduction from the yearly time fund it is essential to exclude the latter kind of planned underloading and make a deduction only for the former one, since otherwise a key step in the programming process, namely, the appraisal of the used capacity, becomes a part of the definition of resource-element capacity rather than being handled explicitly.

The exact number of effective hours of used capacity per ton of resource-element output must now be related to the exact seriality (lot size). The relationship can be kept quite simple. It may take the form of an approximate fixed set-up time (in effective hours), regardless of seriality, plus a variable handling-plus-processing time proportional to seriality; or the sum of these two effective-hour requirements then characterizes a whole series of a single output. The relationship can be referred back to a per-ton basis by dividing by the total tonnage of the series.

The most precise way to use this method would involve estimating a separate set-up time (including tear-down time) and marginal (per unit) handling-and-processing time for each individual product. The estimates would, however, impose an excessive initial burden on the research procedure; therefore they are not recommended. Rather, the assumption of approximately valid uniform set-up and marginal effective-hour requirements is suggested as the basis for deriving secondary corrections. The latter can always be adjusted upward or downward informally on the basis of judgement, when additional qualitative information is available in regard to a particular series. For example, information that a given product requires an unusually high or low set-up or marginal time, or that two or more products produced one after the other have similar physical set-ups, result in a significant shortening of the complete set-up time when changing from one product to the other.

In order to translate the principle of this approach into a correction factor, the seriality of a given resource element must be standardized at a fixed numerical level. If the standard seriality is 50 units, the (uniform) set-up time plus 50 times the (uniform) marginal time give the total effective hours for the standard series. Division by tonnage yields per-ton effective-hour requirements for the standard series. The correction factor is the ratio of per-ton effective-hour requirements for a non-standard series divided by the same ratio for the standard series.[72] The correction factors can be tabulated or graphed for easy reference.

The correction is based on fixed and marginal requirements that are assumed to be independent of other production requirements and uniform between different outputs. The first assumption is weakened by the known variation of set-up and tear-down times according to whether the set-ups in a sequence are physically similar; the second is an approximation that suppresses the known variations between products. The seriality correction tacitly assumes that capacity and input requirements per ton are independent of the weight of the part produced. Since this is patently not correct, the accuracy of the seriality correction suffers unless a weight (size) correction of a similar nature is simultaneously applied.

Corrections for weight (size) can be exactly analogous to the seriality correction. Capacity requirements are standardized for a part of given weight (size), and the correction factor is calculated as the ratio between effective hours per ton of actual workpiece and effective hours per ton of standardized workpiece. The numerical estimate of the correction factor must be based on an empirical correlation between the size of the piece and the total effective hours. Corrections for the complexity of the part produced, for tolerance (or closeness to the final dimension) and for hardness (workability) of metal can be handled in an analogous manner.

A correction for product assortment cannot be made as exactly (or in as simple a manner) as the previous corrections. Assume that the machine park of a resource element is approximately balanced for a given product assortment, the production of pieces that have machine-input requirements widely divergent from that characterizing the average assortment can destroy the balance of different over-all input needs and increase the unavoidable incomplete use of capacity. As

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[72] Total and average effective hours are calculated for a series as follows:

$$TT = a + bS\,,$$
$$AT = (a + bS)/tS\,,$$

where $a$ is the set-up time in effective hours,
$b$ the marginal time (handling-and-production time in effective hours),
$S$ the length of series (lot size),
$t$ the weight of a unit of end-product in tons,
$Y$ the number of effective hours per year available from the given resource element,
$TT$ the total time for series in effective hours, and
$AT$ the average time for series in effective hours per ton.

Denoting concepts referring to the standard series by barred symbols,

$$\overline{AT} = (a + b\bar{S})/t\bar{S}\,.$$

Correspondingly, capacity uses are

$$C = AT/Y\,;\ \bar{C} = \overline{AT}/Y\,.$$

From the last two equations, $C = \bar{C}\,AT/\overline{AT}$, where $AT/\overline{AT}$ is the required correction factor which is applied to the used capacity per ton characteristic of the standard series.

mentioned earlier, corrections for this factor have been suggested in the UNC study for machining resource elements with the strongest corrections (greatest unbalance and therefore greatest increase in claim on nominal capacity) occurring in resource elements designed for high seriality.[73]

### *Empirical testing of the methodology*

The methodology for fully quantified programming data are now tested on a pilot basis by the problem of technical-economic description for transformers. All data are from United States sources.

The characteristic input requirements, the machine park and the labour and material flows needed for production are determined. The methodology requires the definition of a table of capital and flow-input coefficients based on the use of resource elements. It has not yet been possible to produce the desired table, since a well-defined, pre-existing set of resource elements must be available before coefficients of this type can be estimated. It is still a problem to define resource elements, and particularly those characteristic of branches not included in the UNC study.

Given a set of resource elements, what determines which typical end-products shall be decomposed into resource-element inputs ? Specific individual products must be chosen as typical of class of products in the branch; they will be representative of a very broad range of the different products in the branch. A product list is constructed for this purpose.

The product list is meant to represent the entire range of products in a particular sub-branch. The closest approximation is the listing provided by the 1963 Census of Manufacturers of the United States Department of Commerce (USDC). The Statistical Department of the National Electrical Manufacturers Association (NEMA), which is the industry trade association in the United States, also provided some data. The USDC data are better because they provide more coverage and greater refinement, since more manufacturers report to the census than belong to the Association, and also because the census receives more detailed data.

The product list for transformers given in table 4 groups about 200 products according to the USDC classification categories. They comprise at least 80 to 90 per cent of the volume of the United States transformer market. Identification of significant individual items was accomplished by reference to the product catalogues of several United States electrical

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[73] Reference [9], p. II –98.

### TABLE 4. TRANSFORMER PRODUCT LIST[a]

| | Voltage | |
|---|---|---|
| *(kVA)* | *Primary* | *Secondary* |
| A. *Control, signalling, doorbell and toy transformers, control transformers* | | |
| | Single-phase enclosed | |
| 0.25 | 120/240 | 12, 32, 120 |
| 0.50 | 120/240 | 32 |
| 0.75 | 120/240 | 32 |
| 1.00 | 240/480 | 120/240 |
| 1.50 | | |
| 2.00 | 600 | 120/240 |
| 3.00 | | |
| 0.50 | 240 | 120 automobile transformers |
| 0.75 | 240 | 120 automobile transformers |
| 1.00 | 240 | 120 automobile transformers |
| 1.50 | 240 | 120 automobile transformers |
| 2.00 | 240 | 120 automobile transformers |
| 0.50 | 600 | 120/240 no taps |
| 0.075 | 600 | 120/240 no taps |
| 0.100 | 600 | 120/240 no taps |
| 0.150 | 600 | 120/240 no taps |
| | Single-phase, non-enclosed | |
| 0.025 | 115 | 24 |
| 0.050 | 230 | 115 |
| 0.075 | 460 | 115/230 |
| 0.100 | 460 | 115/230 |
| 0.150 | 460 | 115/290 |
| 0.200 | 460 | 115/230 |
| B. *General-purpose transformers, dry type* | | |
| | Single-phase | |
| 3.0 | 240/480 | 120/240 |
| 5.0 | 240/480 | 120/240 |
| 7.5 | 240/480 | 120/240 |
| 10.0 | 240/480 | 120/240 |
| 15.0 | 240/480 | 120/240 |
| 25.0 | 240/480 | 120/240 |
| 37.5 | 240/480 | 120/240 |
| 50.0 | 240/480 | 120/240 |
| 75.0 | 240/480 | 120/240 |
| 100.0 | 240/480 | 120/240 |
| 167.0 | | |
| | Three-phase | |
| 3 | 480 Y | 208 Y/120 |
| 6 | 480 Y | 208 Y/120 |
| 9 | 480 Y | 208 Y/120 |
| 15 | 480 Y | 208 Y/120 |
| 30 | 480 Y | 208 Y/120 |
| 45 | 480 Y | 208 Y/120 |
| 75 | 480 Y | 208 Y/120 |
| 112.5 | 480 Y | 208 Y/120 |
| 150 | 480 Y | 208 Y/120 |

TABLE 4 (*continued*)

| | *Voltage* | |
|---|---|---|
| *(kVA)* | *Primary* | *Secondary* |
| 225 | 480 Y | 208 Y/120 |
| 300 | 480 Y | 208 Y/120 |
| 500 | 480 Y | 208 Y/120 |
| C. *Lighting transformers* | | |
| *(kW)* | Street distribution | |
| 10 | 2.400 | 2,160 6.6 A |
| 15 | 2,400 | 2,160 20 A |
| 20 | 7.200 | 6,480 6.6 A |
| 25 | 7.200 | 6,480 6.6 A |
| 30 | 7,200 | 6,480 6.6 A |
| *(W)* | Mercury-vapour ballasts | |
| 400 | Single-lamp | High reactance and regulated output |
| 250 | Single-lamp | High reactance |
| 175 | Single-lamp | High reactance |
| 425 | Single-lamp | Reactor type |
| 700 | Single-lamp | Reactor type |
| 700 | Single-lamp | High reactance |
| 1,000 | Single-lamp | Reactor type |
| 1,000 | Single-lamp | High reactance |
| 1,000 | Single-lamp | Regulated output |
| 400 | Two-lamp | |
| 425 | Two-lamp | |
| D. *Power and distribution transformers* | | |
| 3 | 2,400/4,160 | 120/240 Single-phase, dry type |
| 5 | 2,400/4,160 | 120/240 Single-phase, dry type |
| 10 | 2,400/4,160 | 120/240 Single-phase, dry type |
| 15 | 2,400/4,160 | 120/240 Single-phase, dry type |
| 9 | 2,400/4,160 | 120/240 Three-phase, dry type |
| 15 | 2,400/4,160 | 120/240 Three-phase, dry type |
| 25 | 2,400/4,160 | 120/240 Single-phase, dry type |
| 37.5 | 2,400/4,160 | 120/240 Single-phase, dry type |
| 50 | 2,400/4,160 | 120/240 Single-phase, dry type |
| 30 | 2,400/4,160 | 120/240 Three-phase, dry type |
| 45 | 2,400/4,160 | 120/240 Three-phase, dry type |
| 75 | 2,400/4,160 | 120/240 Single-phase, dry type |
| 100 | 2,400/4,160 | 120/240 Single-phase, dry type |
| 167 | 2,400/4,160 | 120/240 Single-phase, dry type |
| 75 | 2,400/4,160 | 120/240 Three-phase, dry type |
| 112.5 | 2,400/4,160 | 120/240 Three-phase, dry type |
| 150 | 2,400/4,160 | 120/240 Three-phase, dry type |
| | Single-phase, dry type | |
| 250 | 2,400/4,160 Y | 120/240 |
| 250 | 2,400/4,160 Y | 240/480 |
| 250 | 7,200/12,470 Y | 120/240 |
| 250 | 7,200/12,470 Y | 240/480 |
| 250 | 7,200/12,470 Y | 2,400/4,800 |

TABLE 4 *(continued)*

| | Voltage | |
|---|---|---|
| (KVA) | *Primary* | *Secondary* |
| 333 | 4,800/8,320 Y | 120/240 |
| 333 | 4,800/8,320 Y | 240/480 |
| 333 | 7,260/13,200 Y | 120/240 |
| 333 | 7,260/13,200 Y | 240/480 |
| 333 | 7,200/12,470 Y | 2,400/4,800 |
| 333 | 7,200/12,470 Y | 2,520/5,040 |
| 333 | 13,200 | 120/240 |
| 333 | 13,200 | 240/480 |
| 333 | 13,200 | 2,400/4,800 |
| 333 | 13,200 | 2,520/5,240 |
| 333 | 22,900 | 240/480 |
| 333 | 22,900 | 2,400/4,800 |
| 333 | 22,900 | 6,900/7,200 |
| 333 | 34,400 | 240/480 |
| 333 | 34,400 | 2,400/4,800 |
| 333 | 34,400 | 6,900/7,200 |
| 333 | 43,800 | 2,400/4,800 |
| 333 | 43,800 | 6,900/7,200 |
| | Single-phase, dry type | |
| 333 | 67,000 | 2,400, 4,800, 2,520, 5,040 |
| 333 | 67,000 | 240/480 |
| 333 | 67,000 | 6,900/7,200 |
| 500 | 2,400/4,800 | 120/240 |
| 500 | 2,400/4,800 | 240/480 |
| 500 | 7,260/13,200 Y | 120/240 |
| 500 | 7,260/13,200 Y | 240/480 |
| 500 | 7,200/12,470 Y | 2,400/4,800 |
| 500 | 7,200/12,470 Y | 2,520/5,040 |
| 500 | 13,200 | 120/240 |
| 500 | 13,200 | 240/480 |
| 500 | 13,200 | 2,400/4,800 |
| 500 | 13,200 | 2,520/5,240 |
| 500 | 22,900 | 240/480 |
| 500 | 22,900 | 2,400/4,800 |
| 500 | 22,900 | 6,900/7,200 |
| 500 | 34,400 | 240/480 |
| 500 | 34,400 | 2,400/4,800 |
| 500 | 34,400 | 6,900/7,200 |
| 500 | 43,800 | 240/480 |
| 500 | 43,800 | 2,400/4,800 |
| 500 | 43,800 | 7,200 |
| 500 | 67,000 | 240/480 |
| | Single-phase | |
| 500 | 67,000 | 2,400, 4,800 |
| 500 | 67,000 | 6,900, 7,200 |
| | Three-phase | |
| 225 | 2,400 Δ | 240/480 Δ |
| 225 | 4,160 Y/2,400 | 208 Y/120 Δ |

TABLE 4 *(continued)*

| | *Voltage* | |
|---|---|---|
| *(kVA)* | *Primary* | *Secondary* |
| 225 | 4,160 Y | 240/480 |
| 225 | 4,160 Δ | 208 Y/1,120 |
| 225 | 7,200 Δ | 240/480 Δ |
| 225 | 12,000 Δ | 240/480 Δ |
| 225 | 12,740 Y/7,200<br>13,200 Y/7,620 | 208 Y/120 |
| 225 | 12,470 Y or 13,200 Y | 240/480 Δ |
| 225 | 13,200, 13,800 | 240/480 |
| 300 | 2,400 Δ | 240/480 Δ |
| 300 | 4,160 Y/2,400 | 208 Y/120 Δ |
| 300 | 4,160 Y | 240/480 |
| 300 | 4,160 Δ | 208 Y/1,120 |
| 300 | 4,800 A | 240/480 Δ |
| 300 | 8,320 Y/4,800 | 208 Y/120 |
| 300 | 8,320 Y | 240/480 Δ |
| 300 | 7,200 Δ | 240/480 Δ |
| 300 | 12,000 Δ | 240/480 Δ |
| 300 | 12,000 Δ | 2,400/4,800 Δ |
| 300 | 12,740 Y/7200<br>13,200 Y/7620 | 208 Y/120 |
| 300 | 13,200<br>13,800 | 2,400 Δ/4,800 Δ |
| 300 | 13,800 or | 208 Y/120 or 240/480 |
| 500 | 208 Y/120 | 2,400 Δ |
| 500 | 208 Y/120 Δ | 4,160 Y/2,400 |
| 500 | 240/480 | 4,160 Y |
| 500 | 208 Y/120 | 4,160 Y |
| 500 | 240/480 Δ | 4,800 Δ |
| 500 | 208 Y/120 | 8,320 Y/4,800 |
| 500 | 240/480 Δ | 8,320 Δ |
| 500 | 240/480 Δ | 7,200 Δ |
| 500 | 2,400 Δ, 4,800 Δ | 12,000 Δ |
| 500 | 208 Y/120 | 12,000 Δ |
| 500 | 240/480 A | 13,200 Y/7,620 |
| 500 | 2,400 Δ, 4,800 Δ | 13,200 Δ |
| 500 | 240/480 | 13,200 |

[a] ***Key to symbols:*** A — ampere, V — volt, kVA — kilovolt ampere, Y — star connexion, Δ — delta connexion, / — alternative voltage.

manufacturers. Each transformer is distinguished by a kilovolt-ampere designation, which is a widely used reference unit in the industry,[74] and also by the primary and secondary voltages.

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[74] The kilovolt-ampere (kVA) is a measure of the power output of a transformer. Lighting transformers are also rated by kilowatts (kW). A kilovolt-ampere is exactly equal to a kilowatt if the phase angle between the current and the potential equals zero. Motors and transformers change the phase angle of a current; lighting fixtures do not.

From the mechanical point of view, a transformer is a relatively simple device, consisting basically of a laminated magnetic core and a current-carrying coil. While the coil usually surrounds the core (core type), the core may surround the coil (shell type). The basic core-and-coil assembly is usually mounted on a supporting form and enclosed by a housing or container. For higher-power-rated units, the container will be filled with oil to facilitate the insulation and cooling of the transformer parts. Oil insulation is advantageous for use in high-power units for two reasons: oil circulates in convection currents and facilitates heat transfer from the coils; its insulating effect is self-healing after breakdown of the coil insulation.

Only a few basic processes are used to produce transformers. These processes are basically the same in most of the branch. The sequence of the processes is as follows:

Transformer coils are wound by a winding machine. Fractional kilovolt-ampere-rated transformer coils can be wound several at a time on multiple winding machines with capacities as high as a dozen coils that are attended by a single operator in 15 to 30 minutes. Coils for transformers rated larger than 2 kVA must be wound singly. The winding process which can be used is determined by the transformer rating as follows:[75] less than 0.3 kVA, multiple winding machine; 0.1 to 2 kVA, either a single or a multiple winding machine; greater than 2 kVA, a single winding machine only.

As the coil is wound, insulation is inserted between successive layers of wire. A common type of insulation used for this purpose is a glass-composition sheet with an asbestos base. Asbestos or fibreglass spacers are also inserted between layers at intervals to dissipate heat.

After winding, the coil is dried in an electric oven to ensure that no moisture will be trapped in the coil by the next process (dipping).

The coil is then immersed in a vat of varnish until it has been thoroughly impregnated with it. The varnish coating has special heat-resistant and electrical characteristics.

The varnish is allowed to drip dry, and the coil is then re-baked until the varnish is cured.

The coil is given a preliminary (turns-ratio) test. This is necessary because the voltage transformation depends on the ratio of the number of turns of secondary to primary windings.

The core is formed by stacking silicon-steel laminations that have been stamped out by a press.

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[75] These data were originally reported in kilowatts.

The components are assembled and finished.

Final electrical tests are given before storage or shipping.

Data on the weights and material composition of transformer component parts were obtained from manufacturers and consultants.

The weights of copper (windings) and steel (core) for a sample of various transformer sizes are given in table 5. These figures confirm the

TABLE 5. WEIGHTS OF TRANSFORMER COMPONENTS
*(in pounds)*

| *Component* | *kVA rating* | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0.002 | 0.01 | 0.1 | 0.5 | 1.0 | 1.2 | 48 | 60 |
| Copper wire | 0.049 | 0.14 | 1.0 | 1.9 | 2.5 | 3.0 | 226 | 1080 |
| Core laminations | 0.146 | 0.7 | 3.2 | 3.5 | 12.0 | 14.0 | 679 | 2173 |
| Housing | | | | | 1.0 | 0.5 | | |
| Insulation | | | | | 0.5 | 0.5 | | |

SOURCE: Ajax Transformer Co., Bronx, New York and consultants.

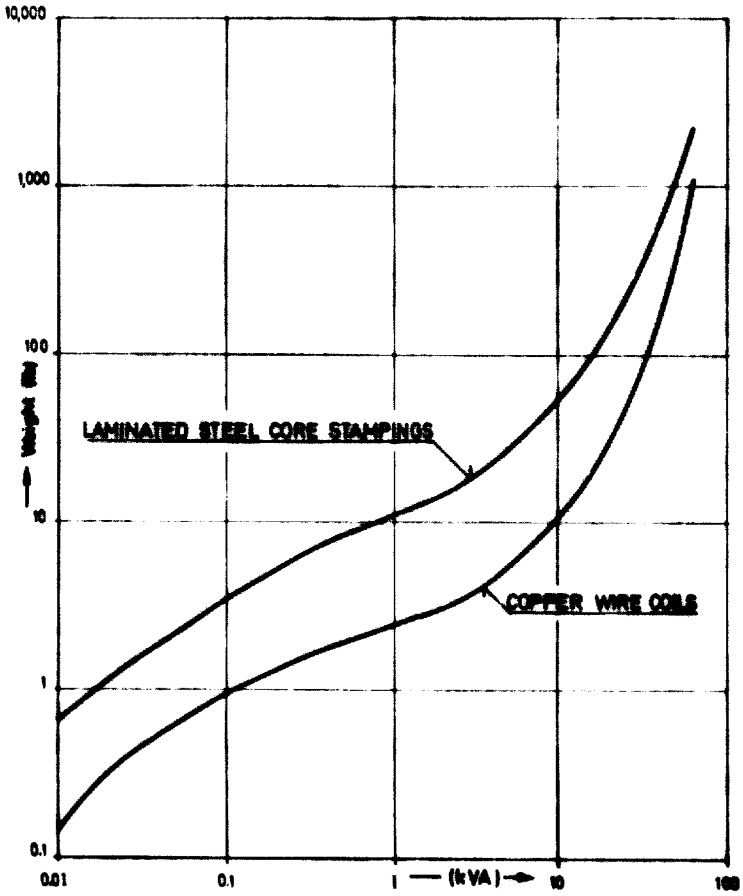

*Figure 1. Weights of transformer parts as a function of kVA for low-power, low-voltage, single-phase, dry-type transformers*

rule of thumb given by a transformer-design consultant; namely, that weights ratios between the copper and steel used in a transformer are (approximately) 4:1 for kVA ratings less than 3 kVA, 3:1 for kVA ratings between 3 and 60 kVA and 2:1 for kVA ratings larger than 60 kVA.

The decomposition data of table 5 plotted in figure 1 tend to confirm the rule of thumb given above. It will be necessary to collect data on transformer sizes larger than 60 kVA to test the rule that a 2:1 steel-copper ratio continues to hold true in the higher ranges.

As noted earlier, there has been a marked trend in transformer design and manufacture towards substitution of materials and reduction in unit weight. Moreover, this trend is continuing, so that decomposition data will have to be revised every few years. Decisive improvements have arisen from the use of better insulating materials that have been developed through the commercial research activities of the large chemical companies and as by-products of military and space research. Materials, such as paper and bakelite, that have been used for coil separation, have been displaced by composite materials such as fibre glass and asbestos; the latter may be displaced in turn by newer chemical composites. Turn-to-turn insulation that was traditionally of enamel or varnish is gradually being replaced by "solidable polyurethanes", which are plastic compounds saturated with solid particles that improve heat conduction and reduce temperature expansion coefficients. Some large sized transformers, which were traditionally oil insulated, are now being redesigned with dry insulation by epoxy or polyurethane plastics. From the point of view of costing, the significant aspect of such developments is that improvements in insulation allow large reductions in the weights of other materials. Insulation itself comprises only a small portion of unit weight (less than 10 per cent), but an improvement in insulation can lead to significant reductions in the weight of copper used.

In transformer design, there has been some substitution of aluminium for copper, mostly in the range of heavy power transformers. The use of aluminium conductors allows a considerable cost saving for equivalent electrical performance. This substitution, however, requires a complete redesign of the unit, and the design change will not usually be profitable for a firm that produces in small series. Other material substitutions have been made in lamination manufacture, such as the use of nickel or of alloys with high nickel content, but the high cost of such materials has thus far restricted them to military applications.

The question arises whether a separate "transformer resource element" should be defined.[76] The distinctive process in transformer manufacture is coil-winding. This process is peculiar to transformers in that it is not used to produce components for any other product. Consequently, the machine used to wind coils for electric motors cannot be

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[76] No "transformer resource element" is listed in any of the UNC studies.

TABLE 6. LABOUR REQUIREMENTS FOR TRANSFORMER MANUFACTURE

| *Direct labour* | *Approximate labour hours for a daily production of*<br>*100 transformers, fractional kVA* | <br>*25 transformers, 1 to 10 kVA* |
|---|---|---|
| Superintendent | 8 | 8 |
| Winders | 8 | 40 |
| Assemblers | 24 | 24 |
| Painter | 8 | 8 |
| Oven operator | 8 | 8 |
| Vat operator | 8 | 8 |
| Testers | 16 | 8 |
| Inspectors | 16 | 8 |
| Material handler | 8 | 8 |
| *Indirect labour* | | |
| Shipping and receiving clerk | 8 | 8 |
| Packing clerks | 16 | 8 |
| Truck-driver | 8 | 8 |
| Janitor | 8 | 8 |
| Plant engineer | 8 | 8 |
| Design engineer | 8 | 8 |
| *Office personnel* | | |
| Book-keeper | 8 | 8 |
| Secretary | 8 | 8 |
| Typist | 8 | 8 |
| File clerk | 8 | 8 |
| Office boy | 8 | 8 |

SOURCE: Reference [60], pp. 41—42.

used to wind transformer coils. Nevertheless, it may be desirable to construct a general coil-winding resource element, since all coils undergo the same subsidiary treatment after winding, namely, dipping (or insulating) and baking; moreover, a common set of parameters (weight and number of coils) characterizes all coil-winding operations.

In order to define a coil-winding resource element, it is necessary to have labour requirements per unit output (kVA), a list of the tools and machines needed to produce the products and a measure of machine capacity (hours/kVA). Available data cover only the first two of these. The published [60] labour and equipment requirements for a small transformer plant are reproduced in tables 6 and 7.

The labour requirements are given according to skill categories, including those needed to produce only windings. A winding resource element would require winders, an oven operator, a vat operator and an inspector. The labour-hours for these skills, shown under "direct labour" in table 6 can be adopted as labour requirements for a coil-winding resource element which produces coils for smaller sized transformers and motors.

The machine requirements in table 7 are illustrated by a transformer shop layout (figure 2) which is quite similar to the shop layout (figure 3) of a small local manufacturer of control and general-purpose transformers that was visited. The only significant difference is that the ICA plant (figure 2) does not have a stamping facility to produce laminations and therefore purchases them. The local manufacturer produces transformers rated at 1 kVA or higher (figure 3). He purchased laminations for transformers rated less than 10 kVA but produced his own for larger sizes. This practice is consistent with the ICA set-up. For purposes of resource-element definition, however, it is not possible to include the stampign process in a coil-winding resource element.

Some estimates of design cost have been obtained. Costs of design and quality control usually constitute about 5 per cent of the cost of a mass-produced transformer. It is feasible to carry out the redesign of an item if the estimated design cost is no more than 10 per cent of the estimated production cost of the item. This figure was given by a consultant; it agrees with that of a small manufacturer who estimated the

TABLE 7. TOOL AND EQUIPMENT REQUIREMENTS FOR TRANSFORMER MANUFACTURE

| *Item* | *Number required* |
|---|---|
| Multiple-winding machine | |
| 10–12 windings; fractional | 1 |
| Winding machines (for 1–10 kVA) | 5 |
| Bake ovens | 2[a] |
| Varnish vats | 3[a] |
| Overhead conveyance system | 1[a] |
| Conveyor section | 1 (300–500 ft)[a] |
| Spray booth | 1 |
| Spray gun | 1 |
| Hand tools | as required |
| Electric arc-welding machine | 1 |
| Vacuum pump | 1 |
| Hand trucks | 4 |
| Oil pump | 1 |
| Motor truck | 1 |
| Scales | 1 |
| Testing equipment | |
| Turns-ratio test equipment | 1 |
| High-potential test equipment | 1 |
| High-frequency test equipment | 1 |
| Polarity test equipment | 1 |

SOURCE: Reference [60], pp. 44–45.

[a] Custom made.

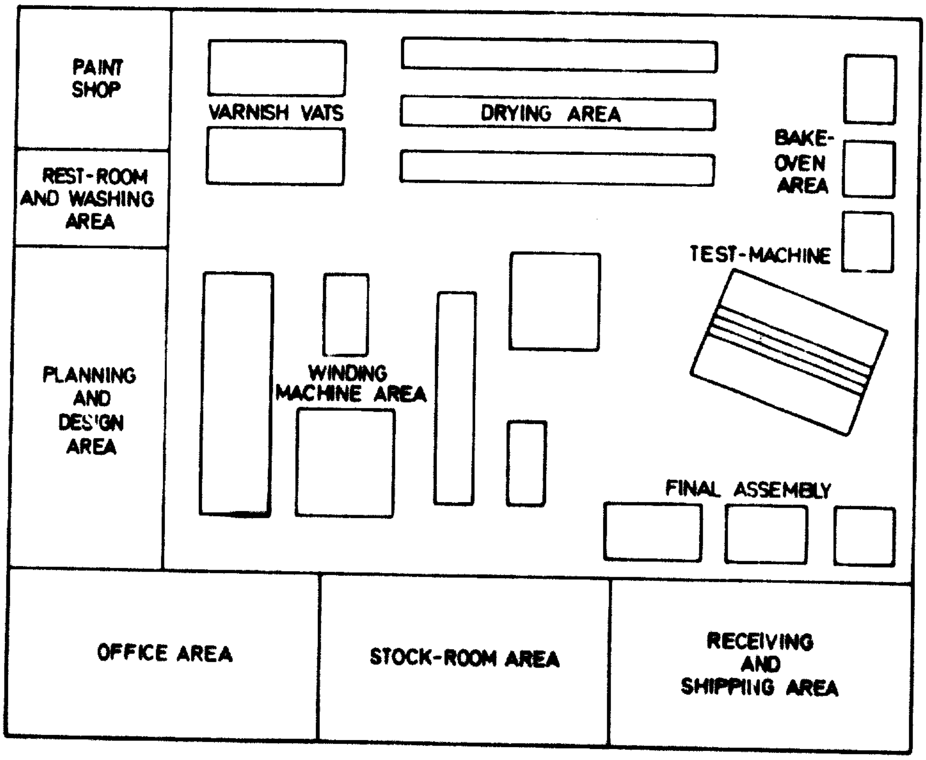

*Figure 2. Shop layout for transformer manufacture with an area of 10,000 ft² from reference [60], p. 52*

design of a custom transformer to be 8 to 10 per cent of its total cost. Generally, design and quality-control costs of custom-made items of seriality less than 50 units can become as high as 15 per cent of total cost.

Data for the transformer branch were gathered from manufacturers, a consultant and a plant visit. About a dozen manufacturers within a radius of 150 miles of New York City were canvassed, primarily by telephone. Only a small proportion of the telephone inquiries were in any way fruitful. Resources of the New York Public Library, the Engineering Societies Library and the Massachusetts Institute of Technology Library were used in a search for published data. In most cases, however, the results were sales promotional material (brochures and catalogues) or highly technical engineering design information.

The results of the data-collection methods are encouraging but not satisfactory because there are large gaps and open questions in the preliminary long list in the appendix. The large diversity of products in the branch prevents an adequate description of the branch by the present approach. Additional interviews would undoubtedly improve the results.

The efficacy of this research procedure, which depends on interviews by economic researchers, is seriously open to question. The material is presented primarily to indicate the need for reliance on technically qualified consultants. Another possibility is that a large corporation might possibly formulate a provisional product list more rapidly and with greater accuracy than a researcher who is alien to the subject; any product could be rapidly decomposed if desired. A third-party approach through trade associations might also be considered. All these possibilities are dependent upon a degree of voluntary co-operation that is seldom present. Therefore the research should be carried out by qualified industrial consultants, who must be sufficiently flexible to work within the conceptual framework imposed by the sectoral planning task.

## 5. SEMIQUANTITATIVE PROGRAMMING DATA

The semiquantitative level of technical-economic description provides general orientation. Concepts and classifications for the subsequent work are initially formed on this level.

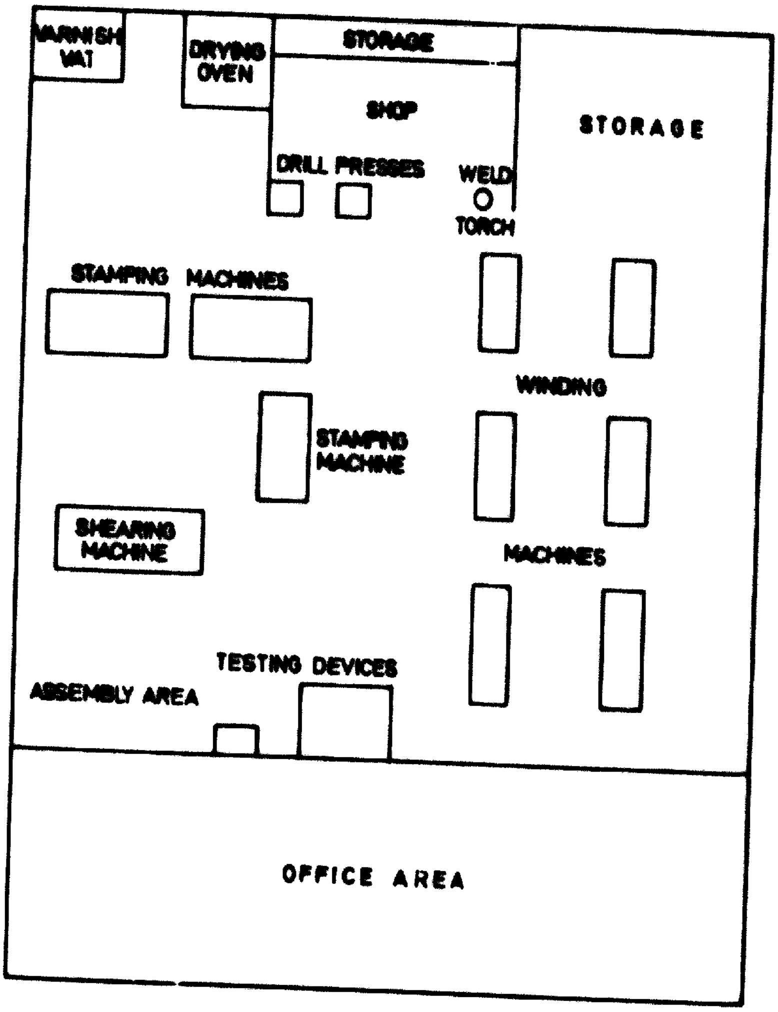

*Figure 3. Second shop layout for transformer manufacture*

## *Initiation of programming analysis*

Theoretical textbooks in mathematical programming and resource allocation describe the manipulations required to reach an optimum allocation of limited resources by adjusting the mix of activities or alternate uses of the resources, so that a specified formula (the objective function) is made as large (or small) as possible. A given but limited set of facts (the resources, activities and the objective function) is assumed initially; however, the basis for their selection is unknown. The fundamental difficulty in programming is not the solution of pre-set problems but the formulation and definition of the problems to be solved.

## *The basic classification and combinatorial problems*

The following three sets of symbols or fundamental classification groups are defined by the programming procedure: a set of possible resources, which may not now be available, but which represent potentially useful tools, materials and skills; a similar set of possible activities, which in reality represent technologically useful clusters of resource application (in specific ratios) that are most frequently described by an end-product or intermediate-product name; and a list of possible formulae to evaluate the results.

All three lists must be available to provide the starting point for the programming. If one is missing or incomplete, the problem is undefined or incompletely defined. In general, a change or reorganization of one list will alter the programming results. The details of classification and combination in the lists can be very complex. Indeed, the initial range of the available possibilities for classification and simplification is infinitely greater than the variety of computation required in the procedural phase of analysis for even the most extensive programming programme.

As an illustration of the potential variety of combinations consider an electric sign composed of 400 light bulbs arranged in a $20 \times 20$ grid. Each bulb is controlled by an individual electric switch, so that any bulb or group of bulbs may be switched on or off. The number of different patterns that may be displayed from the 400 bulbs is $2^{400}$ or approximately $10^{120}$. No draughtsman could ever plot all of the possibilities. Even the fastest computer could never complete the combinatorial possibilities since $10^{76}$ is a good estimate of the total number of atoms in the known universe; $10^{120}$ combinations or patterns is an astronomically large number.

The electric sign is a simple affair when compared to the patterns or combinations of 1,000 resource elements which might be considered in combinations as shops, productive units or work centres, for activities or productive levels for given end- and by-products. The potential for grouping components, subassemblies and even final products represents a similar combinatorial impasse.

Drastic measures are necessary to simplify the programming problem within the range of human and computer capabilities. The simplification process includes elimination, grouping, threshold discrimination and partitioning; it is used in the actual programming computation after the problem has been defined and in the initial phases of problem formulation. The largest simplification is required during the initial phases.

The most obvious form of simplification is to restrict the lists for resource elements, activities and possible objectives to a subclass. The range of the resource-element list for an entire economy can be simplified by considering one industry at a time. A similar constraint on the activities list and possibly on the list of objectives is implicit. This is the first simplification procedure used in the present study.[77]

A more difficult decision arises when the detail of the metalworking resource (and activity) list must be specified. From the myriad combinations, the list of resource elements must satisfy the six following requirements:[78]

The list should include all metalworking resources presently or potentially employed in the production.

The elements of the list should overlap as little as possible, so that modest adjustments in resource-element capacity can be evaluated in the computational phase of analysis.

The list must be readily understood by those who supply data and by others who interpret the results of the analysis. Detailed study of catalogues, dossiers or footnotes should not be necessary to interpret resource-element designations. Furthermore, the names chosen for the resource elements should be sufficiently general to be internationally understood.

The detailed resource categories should be amenable to later groupings or divisions as the need arises. The final needs cannot be known in the initial phases. There must be some flexibility for later modifications.

The detailed resource-element categories should also agree with available statistics, economic classifications and trade data to provide realism and practicality to the final result.

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[77] The dangers in even this first step are evident. With substitution of materials plastic, say, for steel—the constraint to all-metal end-products may give a distorted picture of the potential end-uses for an entire range of metal components. The fault can be overcome by carrying a miscellaneous category of "other resources" and "other products".

[78] Although the following discussion is restricted to the resource-element list, it is equally valid for the other two lists.

To provide a meaningful and generally useful result, the categories in the detailed list must be sufficiently standardized in description and content that the results may be transferred from the time and place of the analysis to applications elsewhere.

The above specifications for a resource-element list suggest that reliance on specific machine names or shop configurations in one country or at one time may not be transferable, clearly understood or valid as technology and practice change. Shops, moreover, vary from place to place and would be unknown to an information source without an extensive cross-referencing system. Although the discussion could be continued, little more argument is needed to suggest a hierarchy of resource-element descriptions that has the required characteristics.[79]

### *Description of the sector by semiquantitative programming data*

#### *A hierarchy of resource-element descriptions*

The most unchanging and general classifications for a list of productive facilities will be found in the functions performed by given tools, processes and methods — for example, metal-removal versus metal-forming. Consider "metalworking processes" as the genus. Metal-removal, metal-forming, metal-fastening and the like become species or subclassifications which can be exhaustive and reasonably exclusive. Moreover, such categories are highly standardized; they are internationally understood; and they are incorporated in most production tests. [62]

Specific metal-removal processes become species of the class "metal-removal" with turning, drilling, boring, reaming, broaching, and grinding as further subclassifications. The detail under "turning" may include hand lathes, semi-automatic lathes and fully automatic lathes. Specific equipment model numbers could be given in a further subclassification. The hierarchy of classification would appear as follows:

I. metalworking processes
    A. metal-removal
        (1) turning
            (*a*) hand lathes
                (*i*) Warney and Swasey Model XXXX

Any level of generality desired can be obtained with this arrangement; therefore the list of productive facilities may be constricted or expanded as desired. Moreover, data organized on this basis can be coded for later extraction, combination, sorting and programming by hand or by computer. An additional advantage is that data collected from informants whose knowledge varies can be organized consistently.

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[79] For an expansion of this form of reasoning, see reference [61].

In table 8, a two-level hierarchy of productive facilities is represented by the rows on the left. The classification is closely related to the concepts of standard task and resource element that were developed in chapter 4, but it does not coincide with either of them. The lower level corresponds most closely to standard tasks; at this stage of data organization the function (process) specified in the lower level does not depend on the specific machine-park that defines a resource element. There are two main differences between standard tasks and the rows of table 8.

TABLE 8 (A). RESOURCES REQUIRED FOR THE MANUFACTURE OF SOME TYPICAL METAL PRODUCTS

| *Resource* | *Commodity*[a] | | | | |
|---|---|---|---|---|---|
| | *Small motor (internal combustion): 3 hp, long run* | *Outboard motor: 3 hp* | *16-in chain saw* | *Portable sewing machine* | *Piston compressor: 2 cylinders, 100 lb/in², medium and short runs* |
| *Metal forming* | | | | | |
| Forge, die | 1 | 1 | 1 | | 1 |
| Casting, iron sand | | | | | 1 |
| Casting, non-ferrous die | 2[b] | 2[c] | 2[d] | 2 | 1[e] |
| Casting, precision | | | | 2 | |
| Press, draw (tubs) | 1 | 1 | | | |
| Press, bend (brakes) | 1 | 1 | | | |
| *Metal removal* | | | | | |
| Turn (lathe) | 1 | 1 | | 1 | 1 |
| Bore (drill) | 2 | 2 | 2 | 1 | 1 |
| Ream | 1 | 1 | 1 | | 1 |
| Grind | 1 | 1 | 1 | | |
| Mill | | 1[f] | | | 1 |
| Shape (plane) | 1 | 1 | 1 | | 1 |
| Tap (inside thread by die) | 1 | 1 | 1 | 1 | |
| *Metal-cutting* | | | | | |
| Press, shear | 1 | 1 | | 1 | |
| Press, punch | 1 | 1 | | 1 | |
| *Heat-treatment operations* | | | | | |
| Furnace | 1 | 1 | 1 | | |
| Quench | 1 | 1 | 1 | | |
| *Fastening operations* | | | | | |
| Nuts, bolts | 1 | 1 | | 1 | 1 |
| *Finishing operations* | | | | | |
| Dip (to clean, prime) | | | | | 1 |
| Spray, paint (short run) | | | | | 1 |
| Spray, paint (auto-line) | 1 | 1 | 1 | 1 | |
| Electroplate | 1[g] | | | | |
| *Final assembly and packing* | | | | | |
| Manual | | | 1 | 1[h] | |
| Standard performance test | 1 | 1 | 1 | | 1 |
| Semi-automatic packing | | | | 1 | |

TABLE 8 (A) *(continued)*

| *Resource* | *Commodity*[a] | | | | |
|---|---|---|---|---|---|
| | *Small motor (internal combustion): 3 hp, long run* | *Outboard motor: 3 hp* | *16-in chain saw* | *Portable sewing machine* | *Piston compressor: 2 cylinders, 100 lb/in$^2$, medium and short runs* |
| ***Materials handling*** | | | | | |
| **Conveyors (automatic)** | 1 | 1 | 1 | 1 | 1 |
| **Transfer machine** | 2 | 2 | 1 | | |
| ***Purchased items*** | | | | | |
| **Electric motors** | | | | 1 | 1 |
| **Electrical supplies** | 1 | 1 | 1 | 1 | 1[e] |
| ***Service functions*** | | | | | |
| **Subassembly co-ordination critical** | 1 | 1 | | 1 | |
| **Tool and die making** | 1 | 1 | | | 1 |

[a] In the commodity columns, 1 represents a used resource and 2 represents a critical process.

[b] Copper aluminium alloy.

[c] Die-cast aluminium total unit.

[d] Magnesium frame.

[e] Use 3-hp gas motor or 2-hp electric motor, no tank assembly.

[f] Hob gears for transmission.

[g] Chrome plate piston.

[h] Purchase plastic parts.

TABLE 8 (B). RESOURCES REQUIRED FOR THE MANUFACTURE OF SOME TYPICAL METAL PRODUCTS

| *Resource* | *Commodity*[a] | | | | |
|---|---|---|---|---|---|
| | *Electric clothes dryer* | *Electric clothes washer* | *30-in gas cooking stove* | *Jet water pump (centrifugal) short-run* | *Sinks and tubs for washing machines* |
| ***Metal forming*** | | | | | |
| **Forge, die** | | 1[b] | | | |
| **Casting, iron** | | | | | |
| **sand** | | | | 1 | |
| **mould** | | | 1 | | |
| **Casting, non-ferrous** | | | | | |
| **sand** | | | | 1 | |
| **die** | 1 | | | | |
| **Press, draw (tubs)** | 1 | 1 | 1 | | 2[c] |
| **Press, bend (brakes)** | 1 | 1 | 1 | | |
| ***Metal removal*** | | | | | |
| **Turn (lathe)** | | | 1 | 2 | |
| **Tap (inside thread by die)** | | | 1 | | |
| **Thread (outside thread by die)** | | | 1 | | |

TABLE 8 (B) *(continued)*

| *Resource* | *Commodity*[a]<br>*Electric clothes dryer* | *Electric clothes washer* | *30-in gas cooking stove* | *Jet water pump (centrifugal) short-run* | *Sirke and tubs for washing machines* |
|---|---|---|---|---|---|
| *Metal cutting* | | | | | |
| Press, shear | 1 | 1 | 1 | | |
| Press, punch | 1 | 1 | 1 | | |
| *Heat-treatment operations* | | | | | |
| Furnace | | | | | 1[d] |
| *Fastening operations* | | | | | |
| Self-tapping screws | 1 | 1 | 1 | | |
| Nuts/bolts | | | | 1 | |
| Weld, spot (long-run) | 1 | 1 | 1 | | |
| Designed (catch, interlock, plug) | 1 | 1 | | | |
| *Finishing operations* | | | | | |
| Dip (to clean, prime) | 1 | 1 | 1 | | 1 |
| Spray, paint (short-run) | 1 | 1 | | 1 | |
| Spray, paint (auto-line) | 2 | 2 | | | |
| Spray, vitreous enamel (short-run) | 2 | 2 | 2 | | |
| Spray, vitreous enamel (auto-line) | | | | | 2 |
| *Final assembly and packing* | | | | | |
| Hand (short-run, no pace, light) | | | | 1 | |
| Hand (long-run, paced) | 1 | 1 | 1 | | |
| Standard performance test | 1 | 1 | | | |
| Hand pack (short-run, no pace, light) | | | | 1 | |
| Semi-automatic packing | 1 | 1 | 1 | | |
| *Materials handling* | | | | | |
| Conveyors (manual) | | | | 1 | |
| Conveyors (automatic) | 1 | 1 | 1 | | 1 |
| *Purchased items* | | | | | |
| Electrical motors | 1[e] | 1 | 1[f] | 1 | |
| Electrical controls (simple) | 1 | | | | |
| Electrical controls (complex) | | 1[g] | | | |
| Electrical supplies (other) | | | 1[h] | | |
| *Service functions* | | | | | |
| Sub-assembly co-ordination (critical) | 1 | 1 | | | |
| Tool and die making | 1 | 1 | 1 | | 2 |

---

[a] In the commodity columns, 1 represents a used resource and 2 represents a critical process.

[b] Transmission parts; purchase belts.

[c] Very deep draw.

[d] Anneal (usually in steps).

[e] Purchase fan-blades.

[f] Purchase clock.

[g] Sequence timer and electrical valves.

[h] Light plug.

TABLE 8 (C). RESOURCES REQUIRED FOR THE MANUFACTURE OF SOME TYPICAL METAL PRODUCTS

| *Resource* | *Commodity*[a] | | | | |
|---|---|---|---|---|---|
| | *Refrigerator freezer 12 ft³, long-run* | *Refrigerator, 2 ft³* | *Metal wall cabinets (excluding sink)* | *30-drawer steel filing cabinet* | *De luxe 11,000-Btu air conditioner* |
| *Metalforming* | | | | | |
| Roll (tube, shapes) | | | | | 2 |
| Press, draw (tubs, etc.) | 2 | | | | |
| Press, bend (brakes) | 1 | 1 | 1 | 1 | 1 |
| *Metal removal* | | | | | |
| *Metal cutting* | | | | | |
| Press, shear | 1 | 1 | 1 | 1 | 1 |
| Press, punch | 1 | 1 | 1 | 1 | 1 |
| *Heat-treatment operations* | | | | | |
| *Fastening operations* | | | | | |
| Self-tapping screws | 1 | 1 | 1 | | |
| Weld, spot (long-run) | 1 | 1 | 2 | 1 | |
| Braze (silver solder) | 1 | | | | |
| Designed (catch, interlock, plug) | 1 | 1 | 1 | | |
| Glue | 1 | 1 | | | |
| *Finishing operations* | | | | | |
| Dip (to clean, prime) | 1 | 1 | 1 | 1 | |
| Spray, paint (auto-line) | 2 | 1 | 2 | 2 | |
| Spray, vitreous enamel (auto-line) | 1 | | | | 1 |
| *Final assembly and packing* | | | | | |
| Hand (long-run, paced) | 1 | 1 | 1 | 1 | |
| Standard performance test | 1 | 1 | | | |
| Critical adjustment needed | 2[b] | | 2[b] | | 2[c] |
| Critical asembly equipment needed | 1[d] | 1[d] | | | |
| Semi-automatic packing | | | 1 | 1 | |
| *Materials handling* | | | | | |
| Conveyors (automatic) | 1 | 1 | 1 | 1 | |
| *Purchased items* | | | | | |
| Electrical motors | 1[e] | | | | 1[f] |
| Electrical controls (simple) | 1 | | | | 1 |
| Electrical supplies (other) | 1 | 1[g] | | | 1 |
| *Service functions* | | | | | |
| Production sequence (critical) | 1 | | | | |
| Sub-assembly co-ordination (critical) | 1 | | | | 1 |
| Tool and die making | 1 | | 1 | | |
| Jigs and fixtures | | | 2[h] | | |

---

[a] In the commodity columns, 1 represents a used resource and 2 represents a critical process.

[b] Door.

[c] Critical fine assembly; hot and cold coils subassembly.

[d] Vacuum pump.

[e] Motor compressor.

[f] Purchase motor compressor unit.

[g] Motor compressor (this small unit may be made internally).

[h] Assembly jigs.

TABLE 8 (D). RESOURCES REQUIRED FOR THE MANUFACTURE OF SOME TYPICAL METAL PRODUCTS

| *Resource* | *Commodity*[a] | | | | |
|---|---|---|---|---|---|
| | *Pressure tank for air, water* | *10 in × 10 in light fixture* | *20-in portable fan* | *1,650 W portable electric heater* | *Complete warm-air heating system* |
| ***Metalforming*** | | | | | |
| Casting, non-ferrous die | | | | | 1 |
| Roll (tube, shapes) | 1 | | 1 | | 2 |
| Press, draw (tubs, etc.) | 1 | | | | |
| Press, bend (brakes) | 1 | 1 | 1 | 1 | |
| ***Metal removal*** | | | | | |
| ***Metal cutting*** | | | | | |
| Press, shear | 1 | 1 | 1 | 1 | 1 |
| Press, punch | 1 | 1 | 1 | 1 | 1 |
| ***Heat-treatment operations*** | | | | | |
| ***Fastening operations*** | | | | | |
| Self-tapping screws | | 1 | 1 | | 1 |
| Weld, spot (long-run) | | 1 | 1 | 1 | 1 |
| Weld, continuous | 1 | | | | 1 |
| Designed (catch, interlock, plug) | | | | | 1 |
| ***Finishing operations*** | | | | | |
| Dip (to clean, prime) | 1 | 1 | 1 | 1 | |
| Spray, paint (short-run) | 1 | | 1 | 1 | 1 |
| Spray, paint (auto-line) | | 1 | | | |
| ***Final assembly and packing*** | | | | | |
| Hand (short-run, no pace, light) | | | | | 1 |
| Hand (long-run, paced) | | | 1 | 1 | |
| Standard performance test | | | 1 | 1 | |
| Critical test needed | 1[b] | | | | |
| Semi-automatic packing | | | 1 | 1 | |
| ***Materials handling*** | | | | | |
| Conveyors (automatic) | | 1 | 1 | 1 | |
| Trucks (lift, pallets, bins, etc.) | 1 | | | | 1 |
| ***Purchased items*** | | | | | |
| Electrical motors | | | 1 | 1 | 1 |
| Electrical controls (simple) | | | 1[c] | 1[d] | 1 |
| Electrical supplies (other) | | 1[e] | 1 | 1[f] | 1[g] |
| ***Service functions*** | | | | | |

---

[a] In the commodity columns, 1 represents a used resource and 2 represents a critical process.

[b] For leakage.

[c] Thermostat.

[d] Thermostat and switch.

[e] Lamp socket and glass.

[f] Heating element.

[g] Gas valves and controls (probable purchase of rotary fan unit).

TABLE 8 (E). RESOURCES REQUIRED FOR THE MANUFACTURE OF SOME TYPICAL METAL PRODUCTS

| *Resource* | *Commodity*[a] | | | | |
|---|---|---|---|---|---|
| | *Aluminium boat, 13.5 ft* | *Aluminium truck camper* | *Aluminium skillet* | *Aluminium ladder, 16 ft* | *De luxe ironing board* |
| ***Metal forming*** | | | | | |
| Extrusion (tubes, shapes) | | | | 1[b] | |
| Roll (tube, shapes) | 2 | 2 | | | 2 |
| Draw (tube, wire) | | 1 | | | |
| Press, draw (tubs, etc.) | | | 1 | | |
| Press, bend (brakes) | | 1 | | | 1 |
| ***Metal removal*** | | | | | |
| ***Metal cutting*** | | | | | |
| Press, shear | 1 | 1 | 1 | | 1 |
| Press, punch | 1 | 1 | 1 | | 1 |
| Saw | | | | 1 | |
| ***Heat-treatment operations*** | | | | | |
| ***Fastening operations*** | | | | | |
| Rivets | 1 | 1 | 1 | 1 | 1 |
| Designed (catch, interlock, plug) | | 1[c] | | | |
| ***Finishing operations*** | | | | | |
| Brush and polish | | | | 1 | |
| Spray, paint (auto-line) | | | | | 1 |
| Spray, other finishes than above | | | 1[d] | | |
| ***Final assembly and packing*** | | | | | |
| Hand (short-run, no pace, light) | 1[e] | 1 | | 1 | |
| Hand (long-run, paced) | | | | | 1 |
| Critical test needed | 1[f] | | | | |
| Hand-pack (short-run, no pace, light) | | 1 | 1 | 1 | |
| Semi-automatic packing | | | | | 1 |
| ***Materials handling*** | | | | | |
| Manual (simple wheels and skids) | | | 1 | 1 | |
| Conveyors (manual) | 1 | | | | |
| Trucks (lift, pallets, bins, etc.) | | 1 | | | |
| ***Purchased items*** | | | | | |
| ***Service functions*** | | | | | |
| Jigs and fixtures | 1 | 1 | | | |

[a] In the commodity columns, 1 represents a used resource and 2 represents a critical process.

[b] Usually purchased.

[c] Purchase extruded shapes and cast corners.

[d] Teflon.

[e] Purchase foam floats, wooden transom.

[f] For leakage.

TABLE 8 (F). RESOURCES REQUIRED FOR THE MANUFACTURE OF SOME TYPICAL METAL PRODUCTS

| *Resource* | *Commodity*[a] | | | | |
|---|---|---|---|---|---|
| | *$^1/_4$-in electric drill* | *Contractor's wheel-barrow* | *Compost mill, 3 hp* | *Portable cement mixer* | *Canister vacuum cleaner, 1 hp* |
| ***Metal forming*** | | | | | |
| Forge, die (2) | | | 1 | | |
| Casting, non-ferrous (3) mould | 1 | | | | |
| Roll (tube, shapes) | | | | 2 | |
| Press, draw (tubs) | | 2 | | | 2[b] |
| Press, bend (brakes) | | 1 | 1 | 1 | |
| Wind (motors, transformers) | 2[c] | | | | |
| ***Metal removal*** | | | | | |
| Turn (lathe) | 1 | | | | |
| Thread (outside thread by die) | 1 | | | | |
| ***Metal cutting*** | | | | | |
| Press, shear | 1 | 1 | 1 | 1 | |
| Press, punch | 1 | | 1 | 1 | |
| ***Heat-treatment operations*** | | | | | |
| Furnace | | 1 | | | |
| ***Fastening operations*** | | | | | |
| Self-tapping screws | | | | | 1 |
| Nuts/bolts | 1 | 1 | | | 1 |
| Weld, continuous | | | | 1 | |
| Designed (catch, interlock, plug) | 1 | | | | |
| ***Finishing operations*** | | | | | |
| Brush and polish | 1 | | | | |
| Dip (to clean, prime) | | 1 | | | |
| Dip (to finish) | | 1 | | | |
| Spray, paint (short-run) | | | 1 | 1 | |
| Spray, paint (auto-line) | | | | | 1 |
| ***Final assembly and packing*** | | | | | |
| Hand (short-run, no pace, light) | | 1[d] | 1[e] | 1[f] | |
| Hand (long-run, paced) | 1 | | | | 1 |
| Hand-pack (unit and short-run, no pace, heavy) | | | 1 | | |
| Semi-automatic packing | 1 | | | | 1 |
| ***Materials handling*** | | | | | |
| Manual (simple wheels and skids) | | | 1 | | |
| Conveyors (manual) | 1 | | | | 1 |
| Conveyors (automatic) | | | | | 1 |
| Trucks (lift, pallets, bins) | | | | 1 | |
| ***Purchased items*** | | | | | |
| Electrical motors | | | | | 1 |
| Electrical supplies (other) | 1 | | | | 1 |
| ***Service functions*** | | | | | |
| Jigs and fixtures | | | | 1 | |

---

[a] In the commodity columns, 1 represents a used resource and 2 represents a critical process.

[b] Cited unit uses fibreglass, but others use drawn shapes.

[c] Integral motor.

[d] User assembly; uses purchased wheel.

[e] Purchase 3-hp gas motor and wheels.

[f] Purchase wheels and bearings.

TABLE 8 (G). RESOURCES REQUIRED FOR THE MANUFACTURE OF SOME TYPICAL METAL PRODUCTS

| *Resource* | *Commodity*[a]<br>*5-in bench vice* | <br>*Hand shovel* | <br>*18-in rotary lawnmower* | <br>*Commercial hand truck* | <br>*Open-end wrench set* |
|---|---|---|---|---|---|
| *Metal forming* | | | | | |
| Forge, die (2) | 2 | 2 | 2[b] | | 2 |
| Roll (tube, shapes) | | | | 2 | |
| Press, bend (brakes) | | | | 1 | |
| *Metal removal* | | | | | |
| Turn (lathe) | 1 | | | | |
| Bore (drill) | 1 | | | | |
| Grind | | | 1 | | |
| Mill | 1 | | | | |
| Broach | | | | | 2[c] |
| *Metal cutting* | | | | | |
| Press, shear | | 1 | 1 | 1 | |
| Press, punch | | 1 | 1 | 1 | |
| *Heat-treatment operations* | | | | | |
| Furnace | 1 | 1 | | | 1 |
| Quench | 1 | 1 | | | 1 |
| *Fastening operations* | | | | | |
| Nuts/bolts | | | 1 | | |
| Rivets | | 1 | 1 | | |
| Weld, continuous | | 1 | | 1 | |
| *Finishing operations* | | | | | |
| Dip (to clean, prime) | | | | 1 | |
| Dip (to finish) | | 1 | | 1 | |
| Spray, paint (short-run) | 1 | | | | |
| Spray, paint (auto-line) | | | 1 | | |
| *Final assembly and packing* | | | | | |
| Hand (short-run, no pace, light) | 1 | | | 1 | |
| Hand (long-run, paced) | | | 1[d] | | |
| Standard performance test | | | 1 | | |
| Hand pack (unit and short-run, no pace, heavy) | 1 | | | | |
| Semi-automatic packing | | 1[e] | | | 1 |
| *Materials handling* | | | | | |
| Manual (simple wheels and skides) | 1 | | | | |
| Conveyors (automatic) | | | 1 | | |
| Trucks (lift, pallets, bins, etc.) | | 1 | | 1 | 1 |
| *Purchased items* | | | | | |
| *Service functions* | | | | | |
| Jigs and fixtures | | | | 1 | |

[a] In the commodity columns, 1 represents a used resource and 2 represents a critical process.

[b] Magnesium frame.

[c] Breach hexagon box to nut size.

[d] Purchase 3-hp gasoline motor.

[e] Purchase handle.

The weight class of the output is not specified but is implicit. Since the net weights of the individual products has been collected, it should be readily possible at a later stage to divide each standard task into weight classes corresponding to approximate component weights. The present undifferentiated form is convenient, since it leaves open the issue of standard-task classification by weight until considerably more data about typical products are collected in many branches of the sector. In this way the semiquantitative data organization facilitates the definition of standard-task categories for subsequent fully quantified empirical work.

The seriality class of output from a process is not specified, but is again implicit by reference to the seriality characterizing a given product in an activity column. The remarks in the preceding paragraph apply to this case in an analogous manner.

In order to avoid confusion with standard tasks and resource elements, the rows of table 8 will be referred to simply as "resources". It is a convenient designation that corresponds to the usual interpretation of activity analysis models as describing resource inputs for specific activities. The resources corresponding to the columns of the table are then processes (or processing functions) that characterize production facilities at a rather high level of generality in the hierarchical classification.

The hierarchical approach to the organization of productive facilities is not new; classification and structure are common to systems such as the Dewey Decimal System used in libraries and standard industrial classifications used in government statistics. The specific extension to the organization of preliminary programming data has not been exploited fully. The advantages of the approach are not only those generally found in information-retrieval situations involving mass data but those inherent in research flexibility and data collection from diverse professional sources.

The hierarchical approach exhibits here as elsewhere well-recognized shortcomings. Foremost among them is the ambiguity of classification when there are several classificatory criteria that give rise to mutually inconsistent classifications. In the present case the shortcomings are not significant at the level of generality represented by table 8. At a more detailed level, however, a different kind of problem arises because there will not be a one-to-one correspondence between processing functions and productive facilities. It is thus true that (in the illustrative hierarchy above) a lathe of a given model may be required for the performance of a given turning operation. If, on the other hand, the workpiece is heavy, there will also be a requirement for hoists or other lifting equipment. The resource-element concept is an attempt to quantify such complementarities. In addition, however, it also creates a higher-level aggregate; for example, in machining many kinds of metal-removal processes (turning, drilling, planing, milling and the like) are found in a single shop that defines the resource element. The higher-level aggregate, however, does not coincide with a higher level in the above hierarchical classification.

### *Special problems in activity classification*

Activity lists present special problems because designers of products have exploited the principle of combinatorial variety by using many combinations of production processes and parts to produce a cornucopia of end-products from a small list of resources. Each could be considered as an activity. The two major problems are the possible definition of product groups to reduce the number of activities and consideration of the combinations of components, resources, and the seriality of the production (changes in tooling and design that follow the specification of longer or shorter production runs).[80]

One approach to these problems uses actual manufacturing practice, namely, the decomposition of assemblies into their components, subassemblies, material requirements and machine-labour requirements. The so-called parts-explosion or resource-explosion problem is a standard data-processing task in industrial factory planning but, because of the detail involved, only sophisticated firms, such as the automotive industry in the United States, have mastered it. Most firms pay for lack of such detailed organization by increases of in-process inventories, work halts and similar disturbances; indeed, the cost of such detailed planning is often justified only by extremely high seriality in a competitive economy.

The resources required for a detailed decomposition study of even a short list of typical products are extensive. The combinatorial dilemma appears again. Even with unlimited financial resources, the time factor would remain, and technology would change before a truly exhaustive decomposition study could be completed. Thus the unyielding basic theorem of planning and control is that, if the inputs and corrections of a process are not at least as rapid as the variations and changes to be controlled, it is doomed to failure.

There are, however, levels of control that can be exploited. Just as a hierarchy of resource classification permits flexibility (as well as the other advantages), a hierarchy of product types or activities also permits a multi-stage or sequential approach to programming. Using a combination of analytical approaches, it is possible to have general and comprehensive planning at one level and simultaneously to have detailed and specific planning at selected lower levels on a consistent basis.

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[80] From the activity standpoint, an end-product made by two different modes because of seriality, design, substitution of materials or custom must be described as a distinctly different pair of activity specifications; this will greatly expand the list than contract it.

*The semiquantitative resource/activity matrix and its virtues*

Many of the problems of resource lists are overcome by the hierarchy of description. Since the list at the higher levels of the hierarchy requires few categories and its details can always be consistently expanded by adding further lower levels, the initial work to construct a crude table of resources versus activities is not wasted but is a guide to further investigation. However, because there are many common components of finished products, it is difficult to isolate categories of products that produce sharply defined resources and activities. A partial separation of classes would be useful for the classification scheme.

The matrix of table 8 suggests a mechanical aid for the desired classification and partition of activities. If a large sample of products that shows the detailed check-list of resources needed to produce them can be obtained quickly and inexpensively, and if the sample is representative of the metalworking sector and its branches, then various mechanical sorting and grouping procedures can be used to construct product groups or prototypes that will be useful for planning. An extensive sample could be scanned for products of interest. End-products and components shown as columns in table 8 are considered as activities.

By restricting the variety of data collected about a given product and its resource elements to a check-list (indicated in table 8 by a "1" for a needed resource and a blank space for an unused resource), the possible products can be scanned. The collection of data is inexpensive; the resulting table has immediate quantitative possibilities and the potential for later refinement of selected resource activity blocks.

In table 8, the check-list aspect of display provides two semi-quantitative guides to activity importance as well as a check of need. A number "2" indicates processes which are considered in some sense critical to the production of a given product. In this notation, the definition of "critical" may be related to one or more of the following criteria: mass seriality, current technology, complexity of products or difficulty of assembly and test operations. Further pertinent information is indicated in footnotes to the resource activity.

It is of interest to describe parenthetically how such a table can be used to provide a mechanical self-grouping of products by their similarity (with respect to resources required in their manufacture). For this purpose, consider the much-simplified resource/activity matrix, often called an incidence matrix or binary matrix shown as figure 4. (For simplicity, the criticality designation and technical notes shown in table 8 are omitted.)

Using such an initial source document, it is now possible, by very simple means, to perform a number of quantitative manipulations which, although as yet highly unrefined, provide ranks of product and resource

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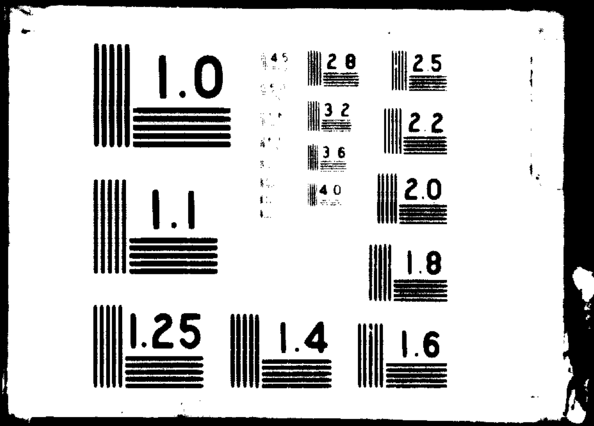

**Activities**

| | | A | B | C | D | E |
|---|---|---|---|---|---|---|
| | 1 | 1 | 1 | | 1 | 1 |
| **Resources** | 2 | 1 | | 1 | 1 | 1 |
| | 3 | | 1 | | | 1 |

*Figure 4. A resource/activity incidence matrix showing a list of resources as rows (1, 2, 3) and a list of products or activities as columns (*A, B, C, D, E*). This basic form is followed in subsequent examples*

similarity. For example, to compute an activity/activity or product/product similarity table, take each column of figure 4 and find the number of "matches" between its elements and those of the other columns of the figure where a match is defined as an equal cell incidence of ones. (Mathematically, this corresponds to matrix multiplication of figure 5 by its "transpose", that is, an equivalent table with rows and columns interchanged.) The result shown in figure 5 demonstrates how one product or activity is related to another by the number of common resources employed in production.

| | A | B | C | D | E | |
|---|---|---|---|---|---|---|
| A | 2 | 1 | 1 | 2 | 2 | |
| B | 1 | 2 | 0 | 1 | 2 | |
| C | 1 | 0 | 1 | 1 | 1 | |
| D | 2 | 1 | 1 | 2 | 2 | |
| E | 2 | 2 | 1 | 2 | 3 | |
| | 8 | 6 | 4 | 8 | 10 | **Column totals** |

*Figure 5. An activity/activity similarity matrix*

Figure 5 is read by first nothing the numbers on the diagonal, which give the number of self-matches, or the number of "ones" in a given product column. Reading to the right in any given row, there is the number of resources required for that given product's production that are also common to other products; for example, product A required two resources, which are also required by products D and E. Only one common resource (not necessarily the same) appears for products B and C. Thus, by a simple count of common resources, products D and E are more similar to product A than are products B and C. This measurement is one of many that could be used. It has at least one defect, namely, that it does not indicate which products could be made if others also could be. For example, consider the difference between products B and C, given resources 1 and 2. However, this deficiency can be overcome by other simple manipulations, and the product/product matrix does provide one way to group products by commonality of resources required.

Continuing by analogy, a resource/resource table may be produced, as shown for the example of figure 4 in figure 6 where the matches between one row and all other rows of figure 4 have been counted. (Mathematically, this corresponds to the multiplication of figure 4 by its transpose.) Again, the interpretation is the same. Process 2 is more similar to process 1 than to process 3, in the sense that more products in the list required the common resources 1 and 2 than 1 and 3 or 2 and 3. Thus, using the concept of similarity matrices or tables, in the initial listing mutually common resources and activities may be mechanically grouped by rearrangement of the rows and columns of table 8 to produce blocks of "1" entries.

|   | 1 | 2 | 3 | Row totals |
|---|---|---|---|---|
| 1 | 4 | 3 | 2 | 9 |
| 2 | 3 | 3 | 1 | 7 |
| 3 | 2 | 1 | 2 | 5 |

*Figure 6. A resource/resource similarity matrix*

One method of creating such blocks mechanically is to produce a table, such as figure 7, which reorders the rows and columns of figure 4 by the similarity sums of figures 6 and 7. Thus, if the numbers computed for the resource/resource matrix of figure 5 are added, striking a column total for each column, and if the row entries of figure 6 are added across for each row, striking a row total for each row, and if, in addition, a new table is constructed with rows and columns rearranged in order of their scores in this computation (with the highest-scored columns to the left, the highest-scored rows above), a new table will result in which resources and activities of highest commonality, as previously defined, will appear in the upper left corner. The result shown in figure 7 is a grouping of resources and activities as suggested. In such a table, the products having the greatest number of resource requirements will probably, though not necessarily, appear to the left; resources entering the greatest number of products will usually, though not necessarily, appear at the top. Although such a mechanical manipulation of the data does not guarantee a clean partitioning of the data into separated blocks (which may be considered independent for later analysis) it does point generally to the products that require the greatest number of resources (to the left) and the resources of the greatest common use (to the top). Such a display not only has immediate use in suggesting resources of great generality but also in suggesting "easy" versus "difficult" products. For a given row, indicating generality of resource-need by its rank, the easier products will usually appear to the right, the more difficult ones to the left. Other manipulations of this sort may be advanced, given the semiquantitative data of table 8 or figure 4.

|  | E | A | D | B | C | New order |
|---|---|---|---|---|---|---|
|  | A | B | C | D | E | Old order |
| 1 | 1 | 1 | 1 | 1 |  |  |
| 2 | 1 | 1 | 1 |  | 1 |  |
| 3 | 1 |  |  | 1 |  |  |

*Figure 7. The recorded incidence matrix of resources and activities. The rows and columns are ordered by the total-similarity scores shown in figures 5 and 6*

*Feasibility check*

The semiquantitative resource/activity matrix may be used for feasibility checks and to compute a comparative count of needed but unavailable resources. Although the index thus produced is simple, it is informative and permits quick comparison of needed versus available resources.

For example, using the simplified resource/activity matrix of figure 4, compute the column total for each column. This will be a simple count of all the resources required to make a given product. Then, make a list of the resources available presently, for illustration, say resources 1 and 2. Extract these rows from the full resource/activity matrix to produce a constrained matrix, and again total the column. The result of applying these steps to figure 4 is shown in figure 8.

| A | B | C | D | E |  |
|---|---|---|---|---|---|
| 2 | 2 | 1 | 2 | 3 | Full matrix |
| 2 | 1 | 1 | 2 | 2 | Reduced matrix |

*Figure 8. A comparison of resource counts for the complete resource activity matrix by activity versus the same count for a constrained resource list. An equal count indicates feasibility; the difference in the count gives the number of lacking resources*

If the full matrix and constrained matrix column totals are equal for a given product, then all the resources required for that product are available, and a scan of the product list will produce all of the feasible products with respect to the resource classification. Such a check is, of course, a preliminary feasibility check as an assurance that the right kind of resources are available but not the specific capacities. The crude approach does indicate, however, where potential capability may lie and is necessary for further refinement and quantification.

In the same way, a comparison of the scores computed for the full and constrained matrix columns gives an indication of the number of missing resources for products that are not at first feasible. The lesser count for these products specifically shows the number of resource categories lacking and not the specific category. Again, however, such a quick comparison, with its large possible scan indicates generally which products are likely candidates for addition to the list of feasible products. In other words, a product that requires only one resource that is not presently available is a more likely candidate than one for which none of the required resources are available; one possible ordering is according to the deficiency. Further possible applications that are not considered here include the introduction of criticality, weighting and normalization of scores.

### *Immediate practical uses*

After feasibility checks, attention is directed to a smaller number of possibilities for detailed investigation. The critical processes and other pertinent information in the footnotes to table 8 could indicate areas of special interest. Thus, the presentation in table 8 is a useful diagnostic tool.

As larger lists of activities are added to table 8, the problem of common components and subassemblies appears. In the subassembly problem, two forms of "treeing" processes (the decision tree and the "requirements-explosion" tree) are of interest.

The decision tree shown in figure 9 illustrates the hierarchy of choices in a selection process which leads eventually to a specific design or instance of that class of objects which would satisfy the general objective at the apex of the tree. Thus, if the general objective were to provide flexible ground transport under the constraints of certain terrain and environment, certain functions must be filled. For example, a prime mover is needed; there must be a method to control direction, speed and the like; there must be physical provisions for passengers. There is essentially no choice at this first step. Next, however, each function may have many modes of implementation, so alternative choice is possible. For example, the alternatives for a given function may be different subassemblies. When the subassemblies that perform each function are combined, they produce a product that meets the general stated requirements.

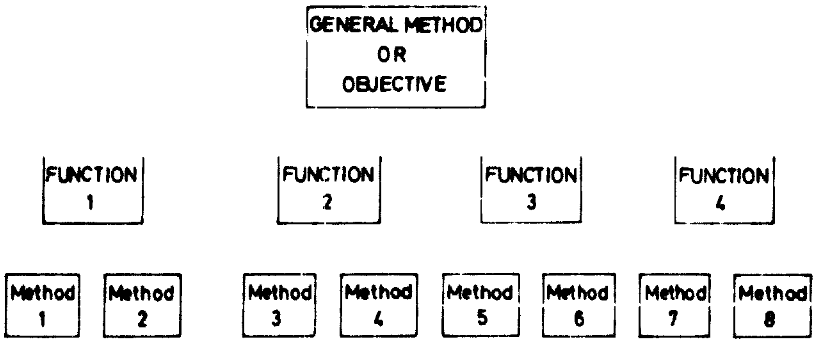

*Figure 9. A decision or option tree*

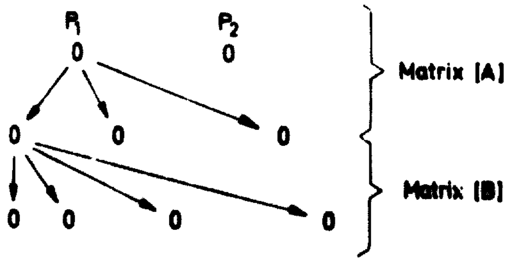

*Figure 10. A deterministic design tree*

The more detailed design or "explosion" tree of figure 10 is usually without a choice because it is the result of a sequence of decisions as in figure 9; it describes a specific group of products in the same way as they have been specified for production. The purpose of the tree is to evaluate in detail the volume of lower-level resources needed for product mix. Figure 11 shows the matrix equivalents of the explosion tree. When matrix [B] is multiplied by matrix [A] (in that order), the result is matrix [C], which is the parts list for the two end-products. The extension of this computation is shown in figure 12 in which the product mix for the final products, 500 and 200 respectively, is converted into a parts requirement by a further matrix multiplication. This type of computation is often a routine production-planning task for inventory control, machine loading and the like.

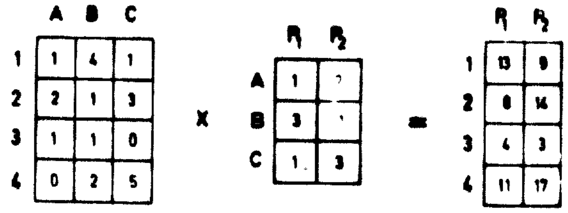

*Figure 11. A matrix display of figure 10*

In terms of table 8, the resource-activity matrix is more analogous to figure 10 than to figure 9, since it is assumed at the level of generality illustrated that design specifications have been fixed by the world market.

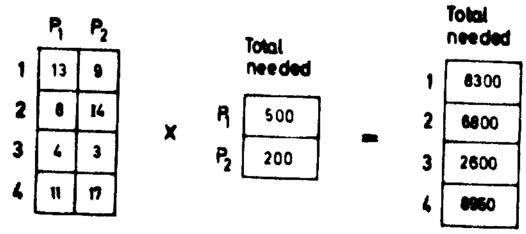

*Figure 12 Computation of "exploded" requirements by matrix multiplication*

In addition, no exact count has been made of the level of component or subassembly use in the list of finished products; components, subassemblies and finished products are listed in table 8 as activities without distinction.

Planning proceeds in two not necessarily independent stages as illustrated by the trees of figures 9 and 10. However, at the detailed planning level, the tendency is more toward evaluation of chosen plans than towards the comparison of alternatives: therefore the deterministic, choiceless tree becomes relatively more important.

The treeing processes are useful when the initial purpose is to detect the incidence of common resources and activities; the subassembly problem is treated as either a series of tables, in which components are considered as resource inputs in subassemblies and subassemblies as resource inputs in finished products or as a table of direct and indirect inputs that shows resource elements of a given column. In the latter case, all columns in the basic table would show an incidence entry (in both direct and indirect cases) for every pertinent resource.[81]

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[81] The similarity of this data organization to input-output tables of the conventional kind should be obvious. Although it is not developed in detail in the present study, the key for the systematic handling of subassemblies is to treat products, whether end-products, subassemblies or components, both as input resources and as production activities. Thus a resource activity table will have the following two major groups: Final and intermediate products including end-products, subassemblies and components, each of which can be produced endogenously by activities occurring in the table; and primary resources (standard tasks) that do not occur as output from any activity of the table. When handled in this fashion, inputs must be distinguished from outputs by algebraic sign. All inputs are taken to be direct inputs only. The table will have an "interindustry" part corresponding to the first major group above and a "value-added" part corresponding to the second group. In a purely hierarchical decomposition, such as that of figure 10, the interindustry part can be rearranged in triangular form. In order to get direct and indirect activity-level requirements corresponding to any pattern of demand, the interindustry part of the matrix must be invested endogenously; direct and indirect requirements for primary resources (processes) follow from the above inverse.

When alternate ways of performing a function exist (as in a design tree), the format must change from input-output to linear programming. In all of the manipulations, however, the 0—1 incidence indication is to be preserved, without further quantification.

The rationale of listing together subassemblies, finished products and even components in table 8 should now be apparent. The incidence check that is necessary for such a grouping has been complete. Although the contribution of subassemblies is lost for a given item (a shortening which can be remedied by construction of higher-level tables) the check is complete and gives a comprehensive scan in a single table. Thus, even though finished products and subassemblies are shown together, product families and inherent similarities of resource elements will not be lost.

After selection of general product families (and therefore resource elements), the multilevel analysis will be required to assess the breakdown in manufacturing stages, to avoid duplication in any decomposition studies and to serve as a design guide to alternative decisions of the type illustrated in figure 9. A rough illustration of the higher-stage incidence table is shown in table 9.

TABLE 9. COMPONENTS OF SELECTED FINAL PRODUCTS

| *Components* | *Final products* | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | *1* | *2* | *3* | *4* | *5* | *6* | *7* | *8* |
| Small stampings | | * | * | * | | | | |
| Metal cabinets | * | | | | * | * | * | * |
| Electric motors | | * | | * | * | * | | * |
| Compressors | | | | | * | * | | |
| Deep-draw items | | | | | | | * | * |
| Electrical controls | | | | | * | * | | * |
| Electrical parts | | * | * | | * | * | | * |
| Die castings | | | | * | | | | * |

*1* — Kitchen cabinets
*2* — Electric fans
*3* — Electric heaters
*4* — Household electric mixers
*5* — Refrigerators
*6* — Air conditioners
*7* — Kitchen sinks
*8* — Washing machines

### *Combining fully quantified and semiquantitative data by levels*

The incidence matrix (table 8) is useful in producing a wide scan, so that products or activities may be clustered according to their common resource requirements. The procedure will produce approximate product families. It can be readily determined that certain products differ from each other by small degrees that can often be accounted for by a variation in purchased parts, trim and so on. For example, a basic metal-product cluster may be centred around the metal-cabinet business. The addition of purchased electrical parts produces small home appliances, and the further addition of a deep-drawing process (to produce sinks and tubs) leads to the production of washing machines, driers, kitchen sinks.

Similarly, product clusters will be centred around piston pumps, compressors, small internal combustion engines, refrigeration equipment and hydraulic items: essentially the same processes are used in their construction. Small rotating machines, such as jet water-pumps, motors, generators and alternators, require the same initial processes with differentiation in the final stages of manufacture — for example, inserting laminations and windings in a motor or generator. When production groupings have been defined with much of the variation being taken up by purchased items, it is possible to consider seriality of the product group and devote attention to the specific tooling required for various production levels of the group.

Further refinement stresses the characteristics that are shared versus those that distinguish the isolated product groups. Inspection of the rearranged incidence matrices usually indicates that one or more resources is a "liaison" resource between product clusters; growth from the production of one cluster to another is usually through these common links. At the higher levels, inspection of subassembly tables will often reveal that certain subassemblies constitute liaison resources and are perhaps easier to detect.

The refinement now follows a divided approach: first, the development of more quantified programming data for a prototype of each product cluster, and second, the quantification of programming data for the liaison products or product clusters. Initially, this refinement must be restricted to fairly high-level groupings or to products in each group that may be considered typical, for example, to crude coefficients between the basic metal operations (forming, removal, fastening and so on) versus product families on a per-ton or a per-unit basis. A 10 × 10 or a 20 × 20 matrix is a reasonable start in this direction.

In other words, based on the manipulations, ranking, grouping and other semiquantitative investigations now under way, it is reasonable to expect that crude (one or two significant figures at most or perhaps order of magnitude only) coefficients could be estimated for a relatively small table. The programming analysis could proceed in stages to greater refinement from this basis.

### *Procedures for developing semiquantitative data*

The data for table 9 were collected by consultation with experts; by studying catalogues and documents; and by inspection of end-products and factory visits. Although the factory visit is the quickest source of detailed information about a given product and is recommended for data collection after product groups have been defined, it is also expensive and requires travel. Some difficulty in making visiting arrangements can also be expected. The alternative use here was visits to distributors or jobbers who stocked the end-products. The distributors are not usually familiar with component detail, but they do have catalogues and part lists and can answer a wide range of semitechnical questions on machine operation.

The catalogues and parts list usually show total product weight and price with a listing of parts. Part weights are usually not shown, and photographs of parts are not given. Customarily, one or more photographs of a product and its accessories are provided, although there are some catalogues of components that are illustrated.

The availability of photographs or assembly drawings for end-products and subassemblies should be stressed because a careful study of them furnishes valuable data as a basis for interviewing the experts. Total weight and price figures, in addition to photographs and a brief description of special features, also establishes the range of possible production processes that could have been employed in the manufacture of a given product, and thus are a check on the statements of the experts.

Tooling and production engineers find it difficult to generalize. It was therefore impossible to give an expert lists of resource elements and products and ask him to check the incidences. The expert usually thinks in terms of a narrow range of product types and a short list of machines with which he is very familiar. The expert can provide complete manufacturing details for a few products or processes or broad generalizations ("stampings are replacing forgings in this type of product"). Thus, to collect detailed information, the number of experts required approaches the number of activities considered. At the other extreme, the process and trend information obtained is not even semiquantitative, although it is both important and interesting.

Unfortunately, there is a vast difference in the time and cost required to collect semiquantitative data (which may range from $5—$10 per activity in volume) and the time and cost required to collect standard hours and material standards per unit for a given product-run size, and thereafter to investigate the tooling and other changes required for variations in run size or seriality. Because the latter data require consultation with a far greater number of experts, the cost of analysis for a thorough job can increase a hundredfold to the $500—$1,000 range per product or activity. (These are the consulting rates in the New York City area; it may therefore be worth while to seek sources for a volume of detailed product investigation beyond the semiquantitative data collection elsewhere than in the United States.) The cost is another argument for selecting carefully the prototype products or product clusters to be detailed semiquantitatively.

### *Empirical data*

There was limited testing of the concepts and procedures developed in the present study. Pilot data were collected for a limited range of products to construct the incidence matrix shown in table 8 and to determine the amount of time and effort needed for a coverage of given industrial branches.

The chief results of the empirical work are given in table 8. Table 10 lists the products according to the left-to-right column entry in table 8. Weights range from 0.5 lb to 618 lb. Retail prices are included for the selected products and a short description to indicate some tooling and material detail.

TABLE 10. ADDITIONAL DATA FOR THE SELECTED PRODUCTS IN TABLE 8

| *Description* | *Shipping weight* (lb) | *Retail price* ($) |
|---|---|---|
| 12.3 ft³ refrigerator-freezer; frostless, standard trim, sealed compressor | 312 | 199.95 |
| 66-in wall cabinet; white sheet metal, for above sink | 94 | 45.95 |
| 33-in × 22-in dual-bowl white stamped kitchen sink with faucets and fittings | 40 | 42.95 |
| Jet water-pump; centrifugal, for 30 to 50 lb/in²; uses 1-hp electric motor (included) | 84 | 105.00 |
| Small internal-combustion engine (Briggs & Stratton); 3 hp, heavy duty, 3,600 rev/min, copper-aluminium die-cast plated piston, 1 cylinder, 4-cycles | 35 | 63.50 |
| Contractor's piston air compressor; 100 lb/in², 2 cylinder, includes pressure tank, controls, 3-hp gasoline motor on wheels | 166 | 224.95 |
| Pressure tank for water; 82 gallons, uninsulated, glass-lined, tapped inlet/outlet | 120 | 50.00 |
| Complete forced warm-air heating system (75,000 Btu) for small home; includes furnace, ducts, returns, controls, registers, etc. | 618 | 299.00 |
| Electric clothes-drier; automatic, with timer and controls, motor blower | 164 | 134.95 |
| Electric clothes-washer; automatic, sequence timer, drive motor, heavy vitreous-coated deep-drawn wash-tub, sealed transmission, electric water valves | 247 | 189.50 |
| 30-in gas cooking stove; oven thermostat, clock, light electric outlet, die-cast burners, cast-iron supports | 164 | 149.95 |
| 20-in portable fan; $^1/_{12}$-hp motor, thermostat, 3-speed switch | 37 | 37.95 |
| 1650 W Portable electric heater; fan, thermostat, safety switch | 9.5 | 18.95 |
| 10-in × 10-in Recessed lighting fixture for ceiling; in terminal box, with glass | 10 | 7.95 |
| 2 ft³ Refrigerator for office or ice cubes; no deep drawers, plastic interior, compressor type (imported from Japan) | 85 | 97.95 |
| 10-in Aluminium skillet with Teflon coating | 1.25 | 1.78 |

TABLE 10 (*continued*)

| *Description* | *Shipping weight (lb)* | *Retail pri (\$)* |
|---|---|---|
| 6-ft Aluminium ladder; medium loads, 6 rivets each rung, xtruded I-beam rails and rungs, rope and pulley | 20 | 22.95 |
| 6.050-Gauge aluminium boat; 13 ft – 7 in, takes to 15-hp outboard motor | 150<br>135 actual | 210.00 |
| 3.5-hp Outboard motor; die-cast aluminium manual start, 1 cylinder magneto speed control to 7 m.p.h., remote tank | 39 | 107.00 |
| Aluminium truck camper, converts pickup truck to small house; safety-glass windows, 60 in wide | 185 | 299.00 |
| Commercial-grade $^1/_2$ in electric drill; full ball and needle bearings, geared chuck, reduction gears, aluminium-alloy housing, $^3/_8$ hp at 300 – 500 rev/min | 5.8 | 44.44 |
| Bench vice; 5-in jaw, forged from stock, Acme screw, plated handle, screw, nut | 42 | 18.20 |
| Round-bladed hand-shovel; forged and tempered blade 9 × 11$^1/_2$ in, wooden handle 47 in (U.S. Government Specification GGG-S-00326C) | 5 | 4.77 |
| Contractor's wheel-barrow; 5 ft$^3$, 500-lb capacity, ball-bearing wheel, one-piece seamless drawn tray, $^1/_8$-in steel legs | 64 | 28.22 |
| 18-in Rotary lawnmower; cast-magnesium frame, 3-hp gasolene motor | 49 | 63.50 |
| 16-in Direct-drive gasolene chain-saw; roller tip bar, die-cast magnesium frame, 4$^1/_2$-hp SAE-rated motor | 27<br>24 actual | 149.95 |
| 3-hp Compost mill; uses standard gasolene engine, direct drive to rotating versus fixed blades, on wheels | 87 | 97.50 |
| Portable cement mixer; can be towed, 24-in steel drum, 2 blades, 2 paddles, 2$^1/_2$ ft$^3$ mix in 60 sec., uses $^1/_2$-hp electric motor (included), roller-bearing wheel | 190 | 119.95 |
| De luxe ironing board; hexagonal tube legs, perforated steel table, wheels, foot adjustment | 16 | 12.99 |
| Commercial-grade hand truck; velded steel tube and strip, ball-bearing wheels, puncture-proof tires, to 600 lb | 39 | 19.44 |
| Portable sewing-machine, with zig-zag feature; in plastic case, electric motor with accessories (die-cast parts) (Imported from Japan) | 54 | 139.95 |
| Cannister vacuum cleaner; 1-hp, fibre glass body, vinyl trim, tubing and plastic attachments | 19 | 38.88 |
| De luxe 11,000-Btu air conditioner; thermostat, humidistat, zinc-dipped parts, plastic trim | 193 | 244.95 |
| 30-Drawer steel cabinet, for files | 85 | 39.95 |
| 6-Piece open-end wrench set; drop-forged, then broached, nickel-chrome-plated alloy-steel | 2.2 | 5.13 |

SOURCE: Sears Roebuck, Philadelphia, Mail-Order Catalogue Edition 232P.

The selected products are representative of a wide range of manufacturing processes in the metalworking industries. Electrical, plastic and similar component parts are assumed to have been purchased or made in a subsidiary facility, as are the necessary fasteners, springs, drive belts and similar stock components. In many manufacturing processes involved in the products described, a much wider range of parts and materials, such as extruded aluminium shapes, will also be purchased by many manufacturers; depending upon the available tooling, many component parts will be subcontracted. Large integrated manufacturers will produce all of the necessary component parts, including fasteners, but such a firm would be a giant in its industry.

The data-collection effort at the semiquantitative level readily yields assorted additional technical-economic information as a by-product that can often be obtained at negligible marginal cost. Such information may include crude quantitative data on gross product weights and weight distribution between components and subassemblies, special processing and tooling information, and design and marketing considerations.

## 6. GUIDELINES FOR COUNTRY STUDIES

Country studies based on the approach presented here will include a preliminary stage of semiquantitative orientation and a quantification stage. The aim of each stage is to give a self-contained over-all view of the sector as a whole, but an effort is made to add detail and to increase precision from one stage to the other.

The purpose of the orientation stage is to establish lists of products, subassemblies and components, and to revise and expand the list of resources.[82] On the basis of an input analysis by orders of magnitude and a similar analysis of the principal destinations of product and semimanufacture outputs, it is then possible to cross-tabulate products and inputs.[83] The cross-tabulation is intended to have sufficient accuracy to distinguish between the following three kinds of flows: those that are negligible, those that are significant and those that are regarded as dominant (coded as 0—1—2). The rudimentary analysis of the sector already has a range of practical applications; the availability of actual

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[82] The only available lists of precisely defined resource elements are in reference [9] and the resource/activity rows of table 8 above.

[83] In table 8, information concerning products is organized into corresponding production activities; resources (and possibly subassemblies and components) are inputs in these production activities. Since there is, however, a close correspondence between a list of activities to describe a branch of the sector and the long list defined in chapter 4, it is legitimate to extend the concept of the long list and of listed products to data gathered at the semiquantitative level.

and potential resources can be considered with the requirements of expanded production. There is thus a preliminary selection of interesting potential lines of development for the sector.

In each branch of production it is desired to distinguish some 200 "listed products" that do not represent statistically aggregated classes but unique individual designs. The listed products should jointly cover some 80 to 90 per cent of the total volume of demand in the branch. The "product" concept is intended to cover end products in the usual sense (such as refrigerators), subassemblies (such as motor compressor units or condensers) and components (such as nuts and bolts). In each branch, only those products should be listed that characterize the branch as a whole. Thus, while nuts and bolts are components of refrigerators, they should not be included among the listed products of this industrial branch. In some cases it may be questionable whether a given subassembly or component properly belongs to a given branch. Thus, in some factories, a wide range of components may be manufactured prior to assembly, while in others the same components might be purchased from a plant whose main activities are in another branch. In the case of nuts and bolts, there is little question that these would not be classed in the refrigeration branch, even if a factory did manufacture its own nuts and bolts; the opposite would be true with respect to compressors or condensers. In borderline instances it will be necessary to make reasonable *ad hoc* decisions. Such decisions will, of course, often result in multiple classifications of the same product which must later be reconciled to be mutually consistent.

The meaning of a "single" product can also be questioned. For example, is an electric motor of 5-hp and 110-V the same product as a motor of 5-hp and 125-V or 220-V? Or are two 5-hp, 110-V motors the same product if they differ somewhat in design specifications in response to export requirements of particular markets? Although it is preferable to work exclusively with individual, unaggregated products rather than with product classes, reasonably small variations of a design in the continuity of the production process need not be individually distinguished, since this would lead to an intolerable proliferation of distinct product types. In the case of small design variations, a single design can be taken as typical of all variants provided that the design is acceptable in all uses; of course this is a matter of standardization. If different variants are actually required because of prescribed performance characteristics or institutional constraints, it is still questionable if the variants are sufficiently close to each other that they can be produced essentially as a single series. Thus, for example, if a product is produced in a seriality of 10,000 items (5,000 of variant A and 5,000 of variant B), and if the production process is automatic and requires no more than a five-minute readjustment of a machine between the two half-series, each of which runs for many hours or days, then it would certainly be justifiable to treat the two variants as members of a single series. A preliminary rule of thumb suggests that variants form a single series if intermediate readjustments do not raise the costs of the series by more than 5 to 10 per cent. Exact criteria can be furnished only after the analysis has been completed and the sensitivity of the results to the readjustment costs is known.

In preparing product lists for a particular country it is essential that the lists should include not only domestic production but also imports (since the items on the latter list are required for the study of import-substitution possibilities) and potential exports. The best way of checking whether a potential-export list is reasonably complete is to use the corresponding production and import lists of large industrialized countries, such as the United States, as a source of reference. Additional reference sources are the many published norms of centrally planned economies. Collections of industrial standards are also useful reference sources.

Product decomposition into subassemblies and components precedes the decomposition into resource-element input levels and should not be confused with it. The subassemblies and components that are characteristic of a branch are included in the listing of products of that branch. At this stage the decomposition is concentrated on the establishment of an input list and need not be carried beyond the order-of-magnitude level (a 0—1—2 flagging of items as negligible, significant and dominant). Incidental quantitative information can also be recorded.

Product decomposition into subproducts can, of course, lead to several hierarchical levels. There are two main input classes that are distinguished in the course of decompositions. The classes are subassemblies and components produced in the metalworking sector and other items purchased from other sectors. The domestic or imported origin of purchased items can easily be determined by a questionnaire.

Using the broad definition of "products" that covers subassemblies and components, the purpose of product-destination analysis is to list either the major products into which the product in question is an input, or the final destinations (exports or sales to final demand). Domestic sales to other sectors occupy an intermediate position between intrasectoral and sales to final demand. They do not necessarily require the same product-by-product distinction of destinations as intrasectoral sales, even though it is convenient to have a narrowly defined destination if the information is available. Generally, however, it is sufficient to specify the intersectoral destination by statistical class.

The product-destination analysis yields no new information about the captive production of inputs for assembly, but it does add significantly to the available data in regard to subcontracting and commercial transfers of products in the sector. Product-destination analysis complements and furnishes a cross-check on product decomposition into subproducts. This is particularly important because both the product-input and product-destination lists are open-ended: the categories of the analysis are established as information is gathered rather than placing the data into preconceived classifications.

Products must next be decomposed into required input levels of production processes. At the level of generality represented by table 8 these are referred to as resources. The preliminary list of resources given in the rows of table 8 is a suitable starting point, but this list should be regarded as flexible in that additional resources may be listed as inputs, or the existing classification may be relaxed to improve the description of input categories. The decomposition is again to be of the order of magnitude (flagging inputs by a 0—1—2 coding system) with provisions for recording more accurate quantitative information if available.

Decomposition into primary resource inputs raises the problem of when should a subassembly or a component be listed as an individual product, and when should it be treated as an implicit part of a whole product that is directly decomposed into resource inputs? A general criterion for separate listing is the sharing of a subassembly among several end-products to increase the seriality of the shared item. Minor mass-produced components, such as nuts and bolts, however, are not listed individually but are treated as outputs from a special class of resources (upsettings).

Resource-destination analysis is similar to product-destination analysis. Its purpose is, first, to list the major products to which the output of the resource element is transferred as a required input and, second, the possible final destinations of the same output. The list of destinations is again open-ended to permit organization of the information into classes that are significant from the point of view of the production activities themselves rather than forcing the data into preconceived classifications. Matching input lists (resource inputs into given individual products) against output lists derived from the present destination analysis (individual products that are destinations for the outputs of given resources) leads to the final cross-tabulation that is the objective of the present stage of the work.

Reconciliation of input and output listings must be undertaken both in regard to resources and in regard to products that are inputs to other products. The present task, however, differs in two regards from conventional input-output analysis. First, the classification is open-ended; thus the output categories may not match the product classes by which inputs are organized, and the input categories may not match the resource element and product classes by which the destinations are organized. If the two kinds of information (the input information that is conventionally organized into columns and the output information that is conventionally organized into rows) are condensed into a single table, inconsistencies and overlappings will frequently occur that must be resolved by reclassifying both rows and columns into classes that cover all activities and resources without overlap. Secondly, at this stage the information is largely of an 0–1–2 order-of-magnitude character that is useful in arriving at a classification, but it forms only the initial stage of quantitative programming.

Although the cross-tabulation of inputs and outputs by order of magnitude is a quite primitive tool, it nevertheless opens the possibility for practical applications. The limits of error are large and only preliminary guide-lines of the main directions of potential progress for the sector as a whole should be expected.

A further warning is in order. Future potentialities can never be predicted solely on the basis of current status or even of historical trends, because the essence of the growth process is structural change. This principle applies with particular force in the metalworking sector, where predictions must necessarily rely on a careful study of combinations of alternatives, many of which have not been practised in the past, or of current practices in the sector. Thus, no cross-tabulation derived from a country study is sufficient in itself for predictions; it can, however, be complemented by data organized in a similar fashion that are taken from up-to-date engineering practice or the experience of more developed countries. The expanded tabulation can then be used as a planning tool. Its use for the pre-selection of attractive lines of development requires the following tasks: expansion of the data base, compilation of a resource-element inventory and matching the expansion of production against resource-element additions.

Expansion of the data base cannot be based on the historical data of the country in which the study is to be undertaken. Nevertheless, to a limited extent, outside data can and should be collected in the country. In every enterprise there is some knowledge of the technology of potential activities that are under consideration for future expansion. Moreover, technical specialists, who work either in domestic production activities or who are available for limited periods as visiting experts, have a fund of additional knowledge that can be fruitfully applied to the planning task if only such knowledge is systematically recorded. Methods by which a country study can overcome the limitations of local historical data must always be kept in mind while the questionnaire survey is being organized.

In order to be meaningful for inventory purposes, resources must be subclassified by main seriality classes (unit and small-scale, medium-scale, large-scale, mass production) and by ranges of workpiece weights; that is, the inventory must be conducted in terms of standard tasks. The construction of an approximate resource inventory from a list of standard tasks requires a complex, detailed census of productive facilities. The inventory should have the following key features:

It should establish qualitatively whether or not a given resource is present in the country.

It should establish semiquantitatively whether a given resource is represented by one or a few instances or whether it is available in larger numbers. This is crucial to decide whether the combined capacity of the given resource can be expanded only in large discontinuous steps or whether the capacity can be regarded as a continuous variable, within tolerable limits of error.

It should establish in a 0—1—2 order-of-magnitude fashion the extent of available capacity reserves for each resource, both on a conventional shift-load basis and on the basis of continuous year-round 24-hour operation.

In compiling the inventory, both captive facilities and facilities producing for delivery outside the plant should be taken into account. The purpose of the resource inventory is to provide an overview of the available productive facilities in the country. There will be many ambiguities of detail, since existing production departments or shops will never coincide perfectly with the process definitions, seriality ranges and weight ranges adopted for typical, but necessarily hypothetical, standard tasks.

Thus, in spite of the fact that there is large flexibility in the conceptual transition from the standard task to the standard shop,[84] allowing for different degrees of mechanization and other variations in standard tasks at specific production facilities, there will be difficulties in assigning production facilities even to standard-task categories. If, for example, the range of weights handled in a standard forge is between 100 and 1,000 kg, and a given existing forge has a range of 20 to 400 kg, how should it be classified ? If it were necessary to take an exact census, problems such as this would be almost insoluble, but for the purposes of an approximate inventory, large simplifications are entirely acceptable. The forge cited as an example may, accordingly, be classed in the 100 to 1,000-kg resource-element class and, in addition, also in the next-lower weight class. Qualitative annotations may accompany the numerical data to call attention to similar adjustments; the adjustments can later be taken into account in the practical application of the information.

Among the various resources the organizational resources (design, research and development, marketing, production scheduling and administration)[85] require particular attention. Data concerning them must be sought in the questionnaire survey. The resources play an important role, even at the semiquantitative orientation stage of planning, since it appears that much of the information that pertains to them cannot be further quantified adequately. Therefore, much of their influence on

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[84] "Standard shop" is used here as an exact synonym of "resource element".

[85] "Organizational standard tasks" have been defined in chapter 4. Organizational resources are taken here to correspond to these in the same way as standard tasks in general correspond to the resources defined in chapter 5.

planning decisions will be exercised at the (semiquantitative) orientation stage. Should this influence be inadequately exerted at this stage, the further quantification of the inputs of other resource elements that describe physical processes cannot decisively improve the over-all quality of the resulting planning decisions.

Matching the expansion of production against resource additions constitutes the key practical application of the information compiled during the orientation stage. The expansion of existing production by adding new products or product lines generally requires new kinds of resources. This qualitative expansion of the resource-element inventory can be readily predicted on the basis of the available information at the orientation stage. A convenient way of organizing the search for attractive product additions is to match the column of resource-element inputs for a given product against the existing resource-element inventory that has been condensed into a single column. A row-by-row comparison of the two columns will immediately call attention to needed process inputs that are not available in the inventory. It is thus possible to determine the addition of new products by integrated groups in such a manner that each group should require one or a few new resource elements of the same kind. The approach will automatically increase the use of new capacity, since it brings together lines of production that draw upon the new capacity jointly. The lines of production must, of course, be assured of domestic or export markets; otherwise the entire exercise would be futile.

Expanded production not only requires qualitatively new resources but also increases the load upon the existing capacity. The problems created by this can be handled in a semiquantitative fashion by forming a column of 0—1—2 indicators of the reserve resource capacities on the basis of the inventory data. When matching the columns of resource inputs into the products whose outputs are to be expanded against the reserve-capacity column, a row-by-row comparison will indicate the reserve capacities (ample, some or none) that are available for additional resource inputs. Since the inventory of reserve capacities is to be compiled for both conventional and round-the-clock shifts, the implied expansion requirements can be semiquantitatively appraised for both conditions.

The attraction of this approach is that it indicates the availability of capacity reserves in the sector that may exist outside the plant of an enterprise that contemplates expansion. Possible subcontracting arrangements offer the double advantage of raising capacity use (which improves the capital/output ratio of the sector) and expanding domestic production without new investment. If resource bottlenecks remain after consideration of subcontracting possibilities, the needed additions can be appraised in relation to all products that might be able to draw on the expanded capacity. Attention thus need not be restricted to the products that are being considered for addition in the same enterprise.

The semiquantitative appraisal of expansion requirements also calls attention to the continuous or discontinuous nature of the resulting cost increases from the point of view of the sector as a whole. If expansion requirements occur in regard to resources that are already present in significant numbers of units, the addition can well be regarded as continuous in nature, and the costs of capacity expansion can be charged against the capacity-using products on the basis of a simple accounting of average costs. If, on the other hand, the expansion requirements occur in regard to a resource element that is either new or present in only one or a very few units, the investment represents a discontinuous jump in costs. In the latter case it is essential to group the capacity-using product lines so that there will be an approximate match between the new capacity and the total demand for it. In estimating the match, it must be taken into account that demand typically shows a steady annual increase, whereas production facilities can be expanded only in jumps; thus such production facilities must be planned explicitly for a number of years. The planning will typically involve gradually shifting proportions between domestic and export markets. The disadvantages must counterbalance the alternative serious problems of under-use of the capacity in the years immediately following the large discontinuous expansion. At the orientation stage a semiquantitative evaluation of these aspects of a sectoral expansion plan is entirely adequate; even an awareness of the approximate problem areas from the data obtained during the orientation stage can be very beneficial for planning the main directions of future expansion in the sector.

The technical-economic description of the sector is improved in the quantification stage from an order-of-magnitude characterization to a numerical estimate of the principal input requirements and other programming data. However, the margin of error is likely to be wide. It is hoped that individual errors can be held to about 20 per cent, but this is by no means assured given the serious data problems, the problems introduced by the modular nature of resource elements and other problems in the metalworking sector. Therefore, the objective of the quantification stage is a first-approximation, numerical characterization of the sector.

Quantification presents the following three tasks: determination of the standard input structure, consideration of local adaptation and the development of trial programmes. While the rigorous application of programming techniques forms a part of a subsequent third main stage that is not discussed in the present study, the technical-economic description at the quantification stage can again be used for a second panoramic look at the sector as a whole.

"Standard input structure" refers to a specification of resource (metalworking process) inputs without the identification of seriality or exact weight of workpiece in the definition of resource classes.

The main tasks in the determination of standard input structure are the following: choice of typical products in each branch, decomposition of typical products into intermediate products and resource inputs, preparation of long lists and parametric transfer of inputs of typical products to listed products. The main aspects of local adaptation are determination of yearly demand for each listed product, adoption of sub-classifications for resources by seriality and weight class, specification of resource elements by labour intensity, scale and other locally adapted features, and revision of standard input structure for listed products on the basis of seriality and weight corrections. Local adaptation has been discussed in chapter 4.

The construction of trial programmes begins with preliminary production, import and export estimates. The main tasks in the construction of trial programmes are the estimation of appropriate social accounting prices[86] for stock (machinery, buildings) and flow (intermediate products, raw materials, primary factors) requirements and for products; the costing-out of selected listed products and the comparison of production costs with export and import prices. In addition, the estimation of the anticipated imports and exports of the selected products plays a key role in constructing trial programmes, since it determines serialities and thus the levels of several crucial inputs.

## *Techniques for country studies*

Prior to the collection of any information from primary sources it is convenient to survey the metalworking sector as a whole by compiling and reconciling the secondary statistical information available from governmental and private sources. Foremost among these data is a recent industrial census, sample surveys of domestic production, and import and export data.

Since the classification system used for domestic industries is likely to be different from the one used in international trade statistics, the first task is to reconcile these two classification systems and to obtain consistent production, import and export data. This is a considerable task unless a similar pre-existing effort can be used in the country study. For

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[86] References [63]--[65] are the standard references on the theory and estimation of social accounting prices. Reference [63] defines a "social marginal productivity" concept, illustrates its use in programming and gives a history of the development of the concept. The fallacy of using simpler criteria, such as capital/labour or labour/output ratios, is shown in reference [64]; The use of long-run equilibrium prices for labour and foreign exchange was suggested in reference [65]. A good summary of the case for using "accounting prices" is given in reference [65] pp. 23–25. The rationale of using social accounting prices in planning with an empirical approximation method is given in reference [28]. The same concepts have been further developed and translated into simple terms for practical programming purposes by ECAFE. [48]

the future planning of the sector it is a great convenience to develop, at the outset if possible, an information system for handling statistical data that is capable of furnishing not only standard statistical output but also the reconciled production-import-export series. Using elementary computerized data-processing techniques, such a task is easy to accomplish at near-zero marginal cost for the reconciled data.

The reconciliation of data is, however, only a starting point for the breakdown of statistical categories into finer detail as required for programming purposes. The programming task is undertaken through listed products which ideally represent individual engineering designs free of statistical aggregation. (In practice, several product variants may be treated as a single series under certain conditions.) Statistical categories very seldom coincide with individual listed products; compiling the list of the most important products is itself a considerable task. Once lists are available, statistical totals characterizing a branch must be allocated between the items on the list and a residual.

The following sources are available for the compilation of the product lists: domestic and foreign engineering and manufacturing standards, product lists from other countries and information obtained in a questionnaire survey. Thus, the statistical groundwork overlaps subsequent tasks. The stages of the work are, of course, not as sharply separated in practice as they are in the discussion.

The allocation of statistical totals between list items must be undertaken separately for domestic production, imports and exports. For domestic production the best sources are marketing organizations, large manufacturers who provide sizable fractions of the total supply and large buyers. For imports, not only importers but also large domestic users and, possibly, exporters in the main supplying countries, are potential sources of information. For exports, domestic manufacturers, export firms and, possibly, large importers in the foreign markets, may provide useful data. All sources should be complemented by the store of information that accumulates in various government organizations that are concerned with the regulation or supervision of these industries or that have commercial relations with them.

It should be noted that the kind of data sought here is not primary statistical information, although many data are collected from sources that are usually relied upon for primary data. A good estimate or even guess is needed about the quantitative distribution of a given market between individual listed products. Any businessman will usually have an excellent approximate idea of the market in which he participates. His estimate to this effect, then, is a secondary statistical source whose use is proper if the wide margin of error is recognized. It has a completely different status from statistical data collected directly from all sellers and from which market percentages can be established. In preparing a preliminary statistical groundwork for the questionnaire surveys and the other subsequent tasks of the country studies, the objective is merely to obtain good order-of-magnitude estimates of the phenomena that are to be studied in detail at a later stage. Therefore, reliance can be placed upon interviews with selected sources of information that would carry little weight in a more rigorous statistical inquiry.

*Questionnaires*

One key objective of the statistical groundwork is to help the cross-tabulation of information for the semiquantitative orientation of the country studies. It is generally recognized that the more specific a questionnaire is, and the more closely it conforms to categories to which the informants are accustomed in their daily work, the greater are its chances of success. Thus the statistical groundwork should culminate in the thorough revision of the preliminary questionnaires outlined here.

It is desirable to perform a pilot survey for a few selected branches of the sector before a comprehensive effort is initiated. Technical experts in given branches or in given production processes could be helpful. They should be included in the later phases of the statistical groundwork and should be consulted intensively in regard to the survey of technical standards the preparation of lists, the evaluation of potential sources of information for market breakdowns and the final revision of the questionnaires. The assistance of the experts can also be of great help in the practical execution of the pilot surveys.

The following five main types of questionnaires are suggested for the collection of primary information for programming purposes: questionnaire No. 1 (production inputs) addressed primarily to technical personnel by branch of production, questionnaire No. 2 (destination of products) addressed to business or sales managers by branch of production, questionnaire No. 3 (production resources) addressed to engineers and managers by type of production process, questionnaire No. 4 (imports) addressed to importers and major consumers and questionnaire No. 5 (exports) addressed to exporters and major suppliers. It has been found convenient to organize questionnaires by function, since the same establishment or enterprise may unite several functions, and it would thus be difficult to evolve standard questionnaires by type of establishment or enterprise. In administering the questionnaires, lists of establishments must be matched against the five functions to decide which questionnaire or questionnaires should be sent to each establishment. In the cover letter for the questionnaire, it must be pointed out that duplicate questions need be answered but once: alternatively, the repetitive parts may be united. Questions of style and presentation may best be left to local decision. In addition, provision must be made for offering extensive help to the enterprises in answering the questionnaires through personal visits by trained assistants, since completely satisfactory responses to a mail survey cannot be expected.

*Questionnaire No. 1 (production inputs).* The following key questions should be included in the questionnaire:

(*a*) List the products, subassemblies and components manufactured and the yearly production of each. Treat subassemblies and components separately in all cases where there is either a net surplus of a subassembly or component (outside sales) or a net deficit (wholly or partly purchased item). In the absence of such an imbalance, define a reasonable hierarchy of subassemblies and components for individual listings in keeping with industry practice.

(*b*) For each product, subassembly or component listed, give the following input structure:

- (i) Amounts or 0—1—2 orders of magnitude of lower-order subassemblies or components required as inputs. Specify if the input is a product of the metalworking sector. Also specify if the input is of imported, domestic or mixed origin. In the latter case, give percentage of imports.
- (ii) Amounts or 0—1—2 orders of magnitude of inputs of major resources. As a guide, the questionnaire should not only furnish a reference list of resources but also permit showing other resources as inputs (the process-input structure should be open-ended).
- (iii) Where the resource inputs do not imply them directly, give also the inputs of metals, if possible, both on a gross and a net basis. (Gross input is the amount of metal needed to begin the manufacturing process; net input is the amount actually incorporated in the product after losses.)
- (iv) List additional products, subassemblies and components that could be manufactured either with the existing production facilities or with specified additions to them.
- (v) For each item of the list under (iv), give input structure on the same basis as under (ii), to the extent that information is available.

*Questionnaire No. 2 (destination of products).* The following key questions are designed to gather data relating to markets:

(*a*) Same as for questionnaire No. 1.

(*b*) For each product, subassembly or component give the following market information:

- (i) Principal destinations of the output by other products into which it is a required input or by final destination. For each market, give percentage share or 0—1—2 order-of-magnitude indication.

(ii) Specify if each market is a domestic, export or mixed market. In the latter case, give percentages or 0—1—2 order of magnitude.

(iii) Characterize for each market the degree of stability or variability.

(iv) Indicate for each market the basis for estimating future short- and long range growth.

(c) List potential domestic and export markets.

(d) Indicate the extent of potential markets in absolute terms if possible or otherwise on a 0—1—2 order-of-magnitude basis. An open-ended reference list of markets by branch would be exceedingly helpful in answering the questionnaire.

*Questionnaire No. 3 (production processes).* The following key questions are addressed to managers and to engineering personnel associated with the operation of production processes (productive resources):

(a) Using a reference list of resources[87] as a guide, specify which resources are present in the establishment. Indicate whether the given resource classification is a convenient way of representing the actual productive structure of the establishment. If necessary, define resources in a different way from that given in the reference list and answer subsequent questions in terms of the latter definitions.

(b) For each resource included in the inventory give the following input information (at capacity and/or at other specified levels of operation) that refers to the concrete embodiment of the productive process in an actual resource element:

(i) machine-park and building floor-space;

(ii) metal inputs;

(iii) labour inputs classified by skill levels and auxiliary material flow inputs.

(c) For each resource element give the following capacity information:

(i) Total capacity on conventional shift basis. Specify number of shifts and total yearly working hours.

(ii) Average and peak-capacity use; capacity reserve either quantitatively or on an 0—1—2 basis both for the conventional number of shifts and for round-the-clock operation.

(iii) Capacity variation with average seriality of outputs and variation of capacity as deviations from this average seriality occur. What physical input changes determine the latter variations of capacity?

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[87] For inventory purposes, resources must be subclassified by seriality and by the weight of the workpiece handled.

(iv) Capacity variations in response to other typical production conditions such as average weight or average complexity of part produced.

(v) Capacity variations in response to deviation from typical output. Specify characteristics of current output and effects of deviations on physical inputs that determine capacity. What are the bottleneck capacities at present? How would this change if production assortment were changed?

(vi) What other potential output could be produced with currently available capacity?

(*d*) For each resource element give the following market information:

(i) Principal destinations of the output (products into which it is an input or by final destinations). For each destination, specify percentage share or 0—1—2 order of magnitude.

(ii) Specify for each destination if it is domestic, export or mixed. In the latter case give percentage shares or 0—1—2 orders of magnitude.

(iii) List potential future markets for the output of the resource element.

(*e*) Specify variation of input structure if the given resource element is smaller or larger than it actually is. The purpose of this query is to probe for economies of scale in response to the variation of the yearly capacity of resource elements.

(*f*) Discuss qualitatively the relationship of existing operations to current international practice. Discuss in relation to degree of automation, obsolescence of machine-park and other relevant factors.

(*g*) Discuss potential expansions or additions for each resource element. What is the role of current bottleneck capacity in defining the cost of such additions? How would over-all capacity respond? It would be very beneficial to have the assistance of technical experts in the final revision of the questionnaires and particularly in their adaptation to specific production processes.

*Questionnaire No. 4 (imports).* It is addressed to importers and large consumers and should contain the following key questions:

(*a*) List imported products, subassemblies, components and the quantities of each.

(*b*) List the principal destination of each import (by product into which it is an input or by final destination).

(*c*) Indicate the basis for estimating both the short- and long-term growth of each import.

(*d*) Indicate the potential future imports and estimated quantities or 0—1—2 orders of magnitude of each.

*Questionnaire No. 5 (exports).* It is addressed to exporters and large suppliers and should contain the following key questions:

(*a*) List exported products, subassemblies and components and the quantities of each.

(*b*) List the principal markets for each export by percentage or 0—1—2 order of magnitude.

(*c*) Indicate the basis for estimating the short- and long-term growth of each export.

(*d*) Indicate potential future exports and estimated quantities or 0—1—2 orders of magnitude of each.

There is a considerable uncertainty about how effective the proposed questionnaires will be in gathering information needed for planning decisions in the sector. In order to ensure the attainment of minimum objectives, the aim of the questionnaires is to obtain semiquantitative information whenever fully quantified data might not be obtained. The questions should, however, be directed at the collection of all quantitative information that might be forthcoming.

Mail surveys, as indicated above, are essentially valueless. Useful results cannot be expected from them without the investment of considerable effort in the testing of pilot questionnaires and the training of technical-information gatherers whose task it would be to assist the informants in answering the questionnaires in a meaningful and reasonably uniform way.

For maximum effectiveness the questionnaire survey should be carefully fitted with the technical work in connexion with the country studies, especially the decomposition of typical products. Most of the information for these decompositions will have to be derived from specific technical studies by associated engineers or experts.

# APPENDIX

## PROVISIONAL CLASSIFICATION OF THE ACTIVITIES OF THE METALWORKING SECTOR

The provisional classification provides a technical-economic description of the sector as discussed in chapter 4. On this basis, typical products and listed products are identified. It is a framework for the technical economic description at a semiquantitative level described in chapter 5.

The classification has been prepared by the Export Industries Section of UNIDO. The purpose of adding another scheme to the several major and innumerable minor classifications already in existence is to facilitate a reasonably uniform coverage by means of typical and listed products of the activities of the sector that are of major interest to developing countries. Existing classifications are patterned either on the classifications of industrial statistics in the industrialized countries [66] or on trade statistics. [67]

The provisional classification consists of 13 major groups and 93 branches. The sources used were the two major United Nations classifications [66], [67], national statistical classifications and classifications used for planning the sector by means of material balances in centrally planned economies. For illustrative purposes, a limited number of products are given as examples of products manufactured in each of the 93 branches. A noteworthy feature of the classification is the provision of major groups for farm machinery, construction and mining machinery, chemical processing machinery and equipment, food processing machinery and equipment, textile and shoe machinery, and household and service machines: each group represents a logical focus of attention from the point of view of developing countries. The provision classification will be revised and typical products as well as listed products identified as the technical-economic description of the sector progresses.

### *Provisional classification of the activities of the metalworking sector into 13 major groups, comprising 93 branches*

### *Majour Group 1: Manufacture of metal products (16 branches)*

A. Tin can and other tinware manufacture

   1. Metal cans
   2. Milk-shipping containers
   3. Other tinware

B. Hand-tool manufacture

   1. Wrenches
   2. Hammers
   3. Screwdrivers
   4. Pliers
   5. Shovels

C. Edged-tools manufacture
    1. Scythes
    2. Adzes
    3. Paper-cutting dies
    4. Planes
    5. Can openers

D. Handsaw and saw-blade manufacture
    1. Heavy hand-saws
    2. Hacksaws
    3. Carpenters' cross-cut saws
    4. Woodworking power-saw blades
    5. Metalworking power-saw blades

E. Cutlery manufacture
    1. Knives
    2. Knife blades
    3. Razors and razor blades
    4. Scissors and scissor blades

F. Furniture and builders' hardware manufacture
    1. Furniture hardware
    2. Door locks
    3. Radiators
    4. Stoves
    5. Window hardware

G. Transportation equipment hardware manufacture
    1. Marine hardware
    2. Aircraft hardware
    3. Motor-vehicle lock units
    4. Railway coach

H. Structural and sheet-metal work
    1. Metal doors and frames
    2. Stairs and staircases
    3. Store fronts
    4. Cornices
    5. Ventilators

I. Boiler-shop manufacture
    1. Boilers
    2. Tanks
        (a) Light tanks
        (b) Heavy tanks
    3. Gas cylinders

J. Metal-stamping manufacture
    1. Spoons

2. Stamped and spun hospital utensils
3. Aviation equipment stampings
4. Agricultural equipment stampings
5. Radio and television stampings

K. Metal fastener manufacture
1. Bolts
2. Nuts
3. Rivets
4. Screws

L. Lighting fixture manufacture
1. Incandescent lighting fixtures
2. Incandescent portable lamps
3. Motor-vehicle headlights
4. Flashlights
5. Airway lighting fixtures
6. Kerosene and gasolene lamps

M. Steel, nail and spike manufacture
1. Steel wire nails
2. Steel wire spikes
3. Steel cut nails
4. Steel cut spikes

N. Wire manufacture
1. Non-insulated wire cables
2. Upholstery wire springs
3. Precision mechanical springs
4. Composite cables

O. Steel spring manufacture
1. Helical automobile springs
2. Helical locomotive and railway-car springs
3. Leaf automotive springs
4. Leaf tractor springs
5. Leaf locomotive and railway-car springs

P. Safe and vault manufacture
1. Fire-resistant safes
2. Burglary-resistant safes
3. Safe-deposit boxes
4. Bank security vaults

*Major Group II: Machine tool industry (12 branches)*

A. Boring and drilling machine industry
1. Horizontal boring machines
2. Vertical boring machines

3. Precision boring machines
4. Vertical drilling machines
5. Radial drilling machines
6. Multiple-spindle drilling machines

B. Gear-cutting and -finishing machine industry
   1. Gear-hobbing machines
   2. Gear-cutters
   3. Gear-lapping machines
   4. Gear-tooth grinding machines
   5. Gear-boring machines

C. Grinding and polishing machine industry
   1. External cylindrical grinding machines
   2. Internal cylindrical grinding machines
   3. Surface grinding machines
   4. Boring machines
   5. Lapping machines

D. Lathe industry (except woodworking lathes)
   1. Bench lathes
   2. Engine lathes (swing dimensions)
   3. Automatic between-centre lathes
   4. Automatic screw machines
   5. Turret lathes

E. Special machine-tool industry
   1. Bench and hand-milling machines
   2. Bed-type milling machines
   3. Centering machines
   4. Sharpers
   5. Sawing machines

F. Metalworking press and forging press industry
   1. Mechanical inclinable presses
   2. Mechanical end-wheel presses
   3. Mechanical vertical arch-frame presses
      (*a*) 500 tons and under
      (*b*) 501 tons and over
   4. High-speed automatic presses
   5. Hydraulic and pneumatic presses
      (*a*) 500 tons and under
      (*b*) 501 tons and over
   6. Manual presses

G. Forging machine industry
   1. Steam and air hammers
   2. Mechanical hammers
   3. Headers and upsetters

   4. Swaging machines
   5. Bulldozers

H. Shearing, bending and forming machine industry

   1. Manually driven shearing machines
   2. Power-driven shearing machines
   3. Manually driven bending and forming machines
   4. Power-driven shearing and forming machines
   5. Welding and cutting acetylene apparatus

I. Power-driven hand-tool industry

   1. Electric drills
   2. Electric hammers
   3. Electric saws
   4. Pneumatic drills
   5. Pneumatic hammers
   6. Pneumatic saws

J. Cutting tool, die and jig industry

   1. Broaches
   2. Drills
   3. Reamers
   4. Gear-cutters
   5. Special dies and jigs

K. Precision measuring tool industry

   1. Micrometers
   2. Gauges
   3. Calipers
   4. Dial indicators
   5. Comparators

L. Woodworking machinery industry

   1. Sawmill equipment
   2. Lathes
   3. Planing machines
   4. Surfacing machines
   5. Sawing machines

*Major Group III: Power engine and general industrial machinery (5 branches)*

A. Steam-engine and turbine industry

   1. Steam engines
   2. Steam turbines
   3. Hydraulic turbines
   4. Steam-turbine generator sets

B. Internal-combustion engine industry
   1. Gasolene engines
   2. Diesel engines
   3. Liquified petroleum (LP) gas engines

C. Nuclear reactor industry
   1. Power reactors
      (*a*) Thermal reactors
      (*b*) Intermediate reactors
      (*c*) Fast reactors
   2. Research reactors
   3. Cooling systems
   4. Control systems

D. Pump and compressor industry
   1. Pumps
   2. Air compressors
   3. Gas compressors
   4. Blowers and fans

E. Bearing industry
   1. Ball bearings
   2. Roller bearings
   3. Mounted bearings
      (*a*) Ball
      (*b*) Roller

*Major Group IV: **Transportation equipment industry (10 branches)***

A. Passenger automobile industry
   1. Passenger automobiles
   2. Engines
   3. Carburettors
   4. Pistons

B. Truck, lorries and bus industry
   1. Lorries
   2. Truck trailers
   3. Automobile trailers
   4. Buses

C. Aircraft industry
   1. Aircraft
      (*a*) Commercial type
      (*b*) Sport type
      (*c*) Military type
   2. Aircraft engines
   3. Aircraft propellers

D. Shipbuilding and ship repairing

1. Building non-propelled ships
2. Building self-propelled ships
   (*a*) Other than military
   (*b*) Military
3. Ship repair

E. Boat building and repair

1. Boat building
   (*a*) Non-military
   (*b*) Military
2. Boat repair
   (*a*) Non-military
   (*b*) Military

F. Locomotive industry

1. Steam locomotives
2. Diesel-electric locomotives
3. Industrial locomotives
   (*a*) Diesel-electric type
   (*b*) Electric type
4. Mining locomotives
5. Locomotive tenders

G. Railway-equipment industry

1. Passenger cars
   (*a*) Coach
   (*b*) Sleeping
   (*c*) Dining
2. Freight cars
   (*a*) Box
   (*b*) Flat
   (*c*) Tank
   (*d*) Refrigerator

H. City transport industry

1. Street-railway cars
2. Trolleybuses
3. Subway cars

I. Motorcycle and bicycle industry

1. Motorcycles
2. Motor scooters
3. Motorbikes
4. Bicycles

J. Lift and conveyor industry

1. Lifts

   2. Escalators
   3. Conveyors

*Major Group V: Farm machinery equipment industry (3 branches)*

- A. Tractors
   1. Wheeled tractors
   2. Garden tractors
   3. Track-laying tractors
- B. Soil-preparing and cultivating farm machinery
   1. Ploughs
   2. Barrows
   3. Rollers
   4. Corn planters
   5. Broadcast seeders
   6. Sprayers and dusters
- C. Harvesting and dairy machinery
   1. Combines
      (*a*) Pull type
      (*b*) Self-propelled
   2. Maize harvesters
   3. Dairy machines
      (*a*) Cream separators
      (*b*) Other dairy machines

*Major Group VI: Heavy machine building industry (4 branches)*

- A. Metallurgical machinery
   1. Converters
   2. Ladles
   3. Ingot moulds
   4. Casting machines
- B. Foundry machinery
   1. Core-making machines
   2. Moulding machines
   3. Blast-cleaning machines
   4. Foundry machines
- C. Industrial furnace and oven industry
   1. Electric industrial furnaces
      (*a*) Metal melting
      (*b*) Metal processing
   2. Fuel-fired industrial furnaces
      (*a*) Metal melting
      (*b*) Metal processing

3. Industrial ovens
   (*a*) Electric
   (*b*) Infra-red

D. Rolling-mill machinery
   1. Rolling mills
   2. Rolling-mill equipment

*Major Group VII: Construction and mining machinery (4 branches)*

A. Construction machinery industry
   1. Contractors' wheeled tractors
   2. Cranes
   3. Scrapers
   4. Graders
   5. Road-rollers

B. Mineral-crushing and -sorting machinery industry
   1. Crushers
   2. Grinding machines
   3. Mixers
   4. Dimension stone-cutting machines

C. Mining machinery industry
   1. Coal-cutting machines
   2. Continuous mining machines
   3. Creeper underground loaders

D. Oil-field machinery industry
   1. Surface drilling machines
   2. Subsurface drilling equipment

*Major Group VIII: Electrical machinery and equipment industry (12 branches)*

A. Motor and generator industry
   1. Fractional-horsepower motors
      (*a*) Under 0.05 hp
      (*b*) 0.05—1 hp
   2. Integral horsepower motors and generators
      (*a*) Single-phase
      (*b*) Polyphase induction
         1—50 hp
         50—500 hp
      (*c*) Synchronous
         1—50 hp
         50—500 hp
         over 500 hp

   3. Gasolene-engine-driven generator sets
   4. Diesel-engine-driven generator sets
   5. Wind-driven generator sets
- B. Transformer industry
   1. Power and distribution transformers
   2. Speciality transformers (under 600 V)
   3. Power regulators
   4. Boosters
   5. Reactors
- C. Electrical distribution and control apparatus industry
   1. Distribution switchboards
   2. Switches
   3. Circuit-breakers
   4. Power switchboards
   5. Relays
   6. Fuses and fuse equipment
- D. Welding machinery industry
   1. Arc-welding machines
   2. Arc-welding electrodes
   3. Metal resistance welders
   4. Special welding apparatus
- E. Electrical measuring instrument industry
   1. Integrating instruments
      - (*a*) Watt-hour meters
      - (*b*) Demand meters
   2. Test equipment
      - (*a*) Oscilloscopes
      - (*b*) Voltmeters, ohmmeters and milliameters
      - (*c*) Microwave test equipment
      - (*d*) Radio-frequency measuring equipment
- F. Electrical appliance industry
   1. Fans
   2. Water heaters
   3. Cooling appliances
   4. Heating appliances
   5. Electric irons
   6. Household ranges
- G. Engine electrical equipment industry
   1. Ignition-harness sets
   2. Battery-charging generators for internal-combustion engines
   3. Cranking motors for internal-combustion engines
      - (*a*) Passenger cars and light trucks
      - (*b*) Heavy trucks and tractors

(c) Aircraft engines
4. Condensers

H. Electric lamp industry
1. Large incandescent lamps
2. Miniature incandescent lamps
3. Electrical discharge lamps

I. Radio and television equipment industry
1. Home radio receivers
2. Portable radio receivers
3. Photographs
4. Television receivers
5. Radio and television transmitters

J. Electronic tube and transistor industry
1. Cathode-ray tubes, television picture tubes
2. Transistors
3. Diodes
4. Other electronic elements

K. Telephone and telegraph equipment industry
1. Telephone sets
2. Telephone switchboards
3. Telegraph apparatus and equipment
4. Radar equipment

L. X-ray and therapeutic apparatus industry
1. Medical X-ray units
2. Dental X-ray units
3. Industrial X-ray units
4. Ultra-violet health-lamp fixtures
5. Cardiographs

### *Major Group IX: Chemical processing machinery and equipment industry (10 branches)*

A. Petroleum refinery machinery and equipment industry
1. Petroleum pumps
2. Petroleum-refining apparatus
3. Benzene-producing apparatus
4. Benzol-producing apparatus
5. Gas-producing apparatus

B. Pulp- and paper-mill machinery industry
1. Pulp-mill digesters
2. Pulp-mill grinders
3. Pulp-mill deckers
4. Paper-mill machinery

C. Paper-machine industry
  1. Fourdriniers
  2. Cylinders
  3. Calenders
  4. Bag-making machines
  5. Box-making machines

D. Printing trade machinery industry
  1. Letterpress machinery
  2. Offset lithographic machinery
  3. Typesetting machines
  4. Electrotyping machines
  5. Bookbinding machines

E. Plastic-working machinery industry
  1. Compression-moulding machines
  2. Extrusion-moulding machines
  3. Injection-moulding machines

F. Rubber-working machinery industry
  1. Mill-mixing machines
  2. Calendering machines
  3. Extruding machines
  4. Vulcanizing presses
  5. Tire-building machines

G. Cement-making machinery industry
  1. Natural cement machines
  2. Hydraulic cement machines
  3. High-temperature cement machines
  4. Fibro-cement machines

H. Glass-making machinery industry
  1. Bottle machines
  2. Laboratory glassware machines
  3. Window-glass machines
  4. Industrial glass machines
  5. Electric bulb machines

I. Chemical-processing machinery industry
  1. Distillery apparatus
  2. Purifiers
  3. Condensers
  4. Centrifuges

J. Clay-working machinery industry
  1. Clay-tempering furnaces
  2. Clay-brick machines
  3. Clay-tile machines

4. Clay-pipe machines
5. Stove-lining machines

*Major Group X: Food-product machinery and equipment industry (4 branches)*

A. Dairy and milk-product plant machinery industry
   1. Bottling machinery
   2. Pasteurizers
   3. Cheese making machines
   4. Cheese presses
   5. Cream separators

B. Bakery machinery industry
   1. Flour-mill machinery
   2. Grain-mill machinery
   3. Dough mixers
   4. Bake ovens

C. Food-processing machinery industry
   1. Sugar-plant machinery
   2. Fruit and vegetable canning machines
   3. Bottling machinery
      (*a*) Filling-capping machines
      (*b*) Bottle washers

D. Cigarette and cigar machinery industry
   1. Cigarette-making machines
   2. Cigar-making machines

*Major Group XI: Textile and shoe-making machinery industry (3 branches)*

A. Textile fibre-to-fabric machinery industry
   1. Garnetting machines
   2. Picker machines
   3. Carding machines
   4. Combing machines
   5. Spinning and twisting machines
   6. Winding machines

B. Textile-fabric machinery industry
   1. Power looms
   2. Knitting machines
   3. Weaving machines
   4. Braiding machines

C. Shoemaking and repairing machinery industry
   1. Hide-, skin- and leather-preparing machines
   2. Shoemaking machines

3. Shoe-repairing machines

*Major Group XII: Office and store machine industry (4 branches)*

- A. Computing machine industry
    1. Adding machines
        - (*a*) Electric
        - (*b*) Manual
    2. Calculating machines
    3. Punch-card-system machines
    4. Cash registers
- B. Typewriter industry
    1. Electric typewriters
    2. Manual typewriters
    3. Special and automatic typewriters
- C. Electronic data-processing machine and computer industry
    1. Analogue computers
    2. Analogue computers with added memory
    3. Digital computers
    4. Electronic data-processers
- D. Scale and balance industry
    1. Railroad-truck and motor-truck scales
    2. Retail and commercial scales
    3. Household scales
    4. Personal weighing scales
    5. Laboratory precision scales

*Major Group XIII: Household and service machine industry (6 branches)*

- A. Household washing-machine industry
    1. Fully automatic washing machines
    2. Semi-automatic washing machines
    3. Non-automatic washing machines
    4. Driers
    5. Ironers
- B. Laundry and dry-cleaning machine industry
    1. Washers
    2. Extractors
    3. Drying tumblers
    4. Laundry presses
    5. Dry-cleaning presses
- C. Sewing-machine industry
    1. Household sewing machines
    2. Industrial sewing machines

D. Vacuum cleaners and other household equipment industry
  1. Household vacuum cleaners
  2. Industrial vacuum cleaners
  3. Other household cleaning equipment

E. Refrigeration machinery industry
  1. Household refrigerators
    (a) Gas
    (b) Electric
  2. Home and farm freezers
  3. Industrial and commercial refrigerators and freezers

F. Clock and watch industry
  1. Electric clocks
  2. Spring-wound clocks
  3. Men's wrist watches
  4. Women's wrist watches
  5. Pocket watches

# PROGRAMMING OF PRODUCTION AND EXPORTS FOR METALWORKING: MODELS AND PROCEDURES

*by Thomas Vietorisz*

## INTRODUCTION

Some of the key characteristics of the suggested method of approach are presented in three simple models. They are formulated in linear programming format, which has excellent synoptic qualities.

One of the key problems is non-convexity, which originates from economies of scale and indivisibilities. In the format of linear programming the non-convexities are treated by specifying certain cost elements as fixed; that is, the variables that characterize the corresponding expenditures can only have values of 0 and 1, or in the case of multiple facilities values of 0, 1, 2, ... etc. They are integer variables. Although integer programming is a much more difficult mathematical task than linear programming, it does not create additional complexity for the models, since problem formulation in the format to be used is not affected by integer variables. After a problem has been properly formulated, there are many mathematical methods to find a suitable solution of the problem. Although the models presented here do not resolve all the difficulties, they constitute a basis for many generalizations and modifications as soon as they are thoroughly developed.

Chapters 1 through 6 present the models for the metalworking sector in isolation; the connexions to the national economy as a whole are implicit. Exports are treated as exogenously given. This simplification is relaxed in chapters 7 and 8 in which the connexions of the sector to the national economy are explored in detail with particular attention to economies of scale and indivisibilities. Furthermore, there is explicit consideration of variable exports which change the seriality of individual production processes and the loading of productive capacities.

### 1. THE COMBINATORIAL PROBLEM

The data of a given problem can be presented in a simple table by a slight modification of Tucker's combinatorial format. [68] In such a table each row can be conceived of as a resource and each column as an

MODEL (a

| | ILIS1<br>1 | ILIS2<br>2 | ILIS3<br>3 | ILIS4<br>4 | ILIS5<br>5 | ILIS6<br>6 | ILIS7<br>7 | ILFX1<br>8 | ILFX2<br>9 | ILFX3<br>10 | ILFX4<br>11 | ILFX5<br>12 | ILFX6<br>13 | ILFX7<br>14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ILIS1 1 | $(1-a_1^1)$ | $-a_1^1$ | $-a_1^1$ | $-a_1^1$ | $-a_1^2$ | $-a_1^2$ | $-a_1^3$ | | | | | | | |
| ILIS2 2 | $-a_2^1$ | $(1-a_2^1)$ | $-a_2^1$ | $-a_2^1$ | $-a_2^2$ | $-a_2^2$ | $-a_2^3$ | | | | | | | |
| ILIS3 3 | $-a_3^1$ | $-a_3^1$ | $(1-a_3^1)$ | $-a_3^1$ | $-a_3^2$ | $-a_3^2$ | $-a_3^3$ | | | | | | | |
| ILIS4 4 | $-a_4^1$ | $-a_4^1$ | $-a_4^1$ | $(1-a_4^1)$ | $-a_4^2$ | $-a_4^2$ | $-a_4^3$ | | | | | | | |
| ILIS5 5 | $-a_5^1$ | $-a_5^1$ | $-a_5^1$ | $-a_5^1$ | $(1-a_5^2)$ | $-a_5^2$ | $-a_5^3$ | | | | | | | |
| ILIS6 6 | $-a_6^1$ | $-a_6^1$ | $-a_6^1$ | $-a_6^1$ | $-a_6^2$ | $(1-a_6^2)$ | $-a_6^3$ | | | | | | | |
| ILIS7 7 | $-a_7^1$ | $-a_7^1$ | $-a_7^1$ | $-a_7^1$ | $-a_7^2$ | $-a_7^2$ | $(1-a_7^3)$ | | | | | | | |
| EXTM 8 | | | | | | | | | | | | | | |
| FR 9 | | | | | | | | | | | | | | |
| S 10 | $-\bar{k}^1$ | $-\bar{k}^1$ | $-\bar{k}^1$ | $-\bar{k}^1$ | $-\bar{k}^2$ | $-\bar{k}^2$ | $-\bar{k}^3$ | $-\bar{k}^1$ | $-\bar{k}^1$ | $-\bar{k}^1$ | $-\bar{k}^1$ | $-\bar{k}^2$ | $-\bar{k}^2$ | $-\bar{k}^3$ |
| ISTP1 11 | | | | | | | | | | | | | | |
| ISTP2 12 | | | | | | | | | | | | | | |
| ISTP3 13 | | | | | | | | | | | | | | |
| ISTP4 14 | | | | | | | | | | | | | | |
| ILFX1 15 | $-\frac{1}{f_{11}}$ | | | | | | | 1 | | | | | | |
| ILFX2 16 | | $-\frac{1}{f_{12}}$ | | | | | | | 1 | | | | | |
| ILFX3 17 | | | $-\frac{1}{f_{13}}$ | | | | | | | 1 | | | | |
| ILFX4 18 | | | | $-\frac{1}{f_{14}}$ | | | | | | | 1 | | | |
| ILFX5 19 | | | | | $-\frac{1}{f_{15}}$ | | | | | | | 1 | | |
| ILFX6 20 | | | | | | $-\frac{1}{f_{16}}$ | | | | | | | 1 | |
| ILFX7 21 | | | | | | | $-\frac{1}{f_{17}}$ | | | | | | | 1 |

VARIABLE INPUTS

FIXED INPUTS (LISTED PRODUCTS)

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a) The symbols used are defined in the appendix to this study

| ILM1 15 | ILM2 16 | ILM3 17 | ILM4 18 | ILM5 19 | ILM6 20 | ILM7 21 | ISTP1 22 | ISTP2 23 | ISTP3 24 | ISTP4 25 | EXTM 26 | EXOG 27 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | | | | $-d_1$ | LISTED PRODUCTS |
| | 1 | | | | | | | | | | | $-d_2$ | |
| | | 1 | | | | | | | | | | $-d_3$ | |
| | | | 1 | | | | | | | | | $-d_4$ | |
| | | | | 1 | | | | | | | | $-d_5$ | |
| | | | | | 1 | | | | | | | $-d_6$ | |
| | | | | | | 1 | | | | | | $-d_7$ | |
| | | | | | | | 1 | 1 | 1 | 1 | 1 | $-e$ | EXTRAPOLATED PRODUCTS |
| $m_1$ | $-m_2$ | $-m_3$ | $-m_4$ | $-m_5$ | $-m_6$ | $-m_7$ | | | | | $-n$ | $+b$ | FOREIGN EXCHANGE |
| | | | | | | | $-\gamma_1$ | $-\gamma_2$ | $-\gamma_3$ | $-\gamma_4$ | | | MONEY COST |
| | | | | | | | -1 | | | | | $l_1$ | STEP FUNCTION FOR EXTRAPOLATED PRODUCTS |
| | | | | | | | | -1 | | | | $l_2$ | |
| | | | | | | | | | -1 | | | $l_3$ | |
| | | | | | | | | | | -1 | | $l_4$ | |
| | | | | | | | | | | | | | FIXED-COST CONSTRAINTS |
| | | | | | | | | | | | | | |
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IMPORTS EXTRAPOLATED PRODUCTS EXOG

activity. [69] For example, in model 1 the first seven rows correspond to "listed products";[88] each row is a balance of one specific listed product. Other rows may represent "resources" in a more generalized sense; any limit, restriction or constraint placed on the data creates an economic scarcity of one kind or another that will have a scarcity value, as with ordinary resources, such as products or services. Examples of such activities are production, imports and exports.

The data (parameters and technical coefficients) that appear in the models are placed inside the solid frame of each table. All data are constants; they represent either availabilities or requirements, according to whether they are positive or negative. Examples of availabilities (positive sign) are outputs and supplies; examples of requirements (negative sign) are inputs and demands. Both availabilities and requirements are standardized to a unit level of the activity in the column in which they appear. Thus, the constant $-m_1$, which appears at the intersection of row 9 and column 15 in model 1 represents a requirement of $m_1$ units of foreign exchange (the balance for this resource appears in row 9) for importing a unit amount of the first listed product (the activity of column 15). The number $m_1$ is measured in physical units of resource per physical unit of activity level, for example, in foreign (not domestic) currency units per ton of imported product, where the units of foreign currency play the role of physical units (not expressed in the domestic monetary units).

Table 11 shows schematically a linear economic system in the modified Tucker format used for models 1 to 3. The data (parameters and technical coefficients) occurring in these models are given the generic name $\alpha_{ij}$, where the index $i$ refers to the serial number of the row (shown at the left margin of models 1 to 3), and $j$ refers to the serial numbers of the column (shown at the top margin of models 1 to 3). If a parameter $\alpha_{ij}$ is multiplied by the scale of the activity in the column it appears, the total availability or requirement of the given resource connected with the activity in question is obtained. The scales of the activities are shown as $x$ variables at the bottom of the column (activity). Thus the total availabilities or requirements of any resource $i$ in connexion with activity $j$ can be obtained by forming the product $(\alpha_{ij})$ $(x_j)$. If such products are formed for all the $\alpha_{ij}$ parameters in table 11, then a row balance can be obtained for each row by algebraically adding the products in a given row. The algebraic sum represents the net availability, surplus (if positive), net requirement or deficit (if negative) of a resource in connexion with all activities. Since all $x_j$ are treated as variables, the sum denoted by $s_i$ is a variable. The $s_i$ variables are shown in the left margin of table 11; the equality sign following them refers to their definition as

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[88] Detailed explanations of the notations for the models are given in the appendix to this study.

row balances. The symbol * above the $x_j$ variables denotes the multiplication operation undertaken when forming row balances. The $s_i$ and $x_j$ variables are not shown in models 1 to 3, but these variables are implicitly present and row balances are formed exactly as indicated in table 11.

TABLE 11. A LINEAR ECONOMIC SYSTEM IN MODIFIED TUCKER FORMAT

$$\begin{array}{cc|ccccc|c}
 & & -l_1 & -l_2 & -l_3 & \dots & -l_n & \\
 & & = & = & = & & = & \\
\hline
s_1 & = & \alpha_{11} & \alpha_{12} & \alpha_{13} & \cdots & \alpha_{1n} & {}^*y_1 \\
s_2 & = & \alpha_{21} & \alpha_{22} & \alpha_{23} & \cdots & \alpha_{2n} & {}^*y_2 \\
s_3 & = & \alpha_{31} & \alpha_{32} & \alpha_{33} & \cdots & \alpha_{3n} & {}^*y_3 \\
\cdot & & \cdot & \cdot & \cdot & & \cdot & \cdot \\
\cdot & & \cdot & \cdot & \cdot & & \cdot & \cdot \\
\cdot & & \cdot & \cdot & \cdot & & \cdot & \cdot \\
s_m & = & \alpha_{m1} & \alpha_{m2} & \alpha_{m3} & \cdots & \alpha_{mn} & {}^*y_m \\
\hline
 & & * & * & * & & * & \\
 & & x_1 & x_2 & x_3 & \dots & x_n &
\end{array}$$

Notation:

| | |
|---|---|
| $x_j$ | Scale of activity vector corresponding to column $j$, where $j = 1, 2, 3 \dots, n$. |
| $s_i$ | Slack (surplus) of resource corresponding to row $i$, where $i = 1, 2, 3 \dots, m$. |
| $y_i$ | Shadow price of resource corresponding to row $i$, where $i = 1, 2, 3, \dots, m$. |
| $l_j$ | Loss (at shadow prices) of activity corresponding to column $j$, where $j = 1, 2, 3, \dots, n$.<br>Note that $-l_j$ is a profit for the same activity. |
| $\alpha_{ij}$ | See definition under parameters in the appendix. |
| * | Denotes multiplication, as explained in the text. |

See the appendix for a formal definition of the symbols.

In addition to row balances, it is possible to form column balances. If a parameter $\alpha_{ij}$ is multiplied by $y_i$, which is the price of the resource in the row it appears (table 11), the resulting economic value of the availability or requirement of the resource is standardized to a unit level of the activity $j$. The value represents a revenue (if positive) or a cost (if negative) at the unit activity level. If the products $(y_i)(\alpha_{ij})$ are formed for all parameters $\alpha_{ij}$ in table 11, then it is possible to obtain column balances by adding all products in a given column algebraically. The sums represent net revenues or profits (if positive) and net costs or losses (if negative). Since all $y_i$ are treated as variables, the above sums are variables; they are denoted by the symbols $-l_i$ at the top of table 11.

MODEL P

| | 1LIN1 1 | 1LIN2 2 | 1LIN3 3 | 1LIN4 4 | 1LIN5 5 | 1LIN6 6 | 1LIN7 7 | 1LPX1 8 | 1LPX2 9 | 1LPX3 10 | 1LPX4 11 | 1LPX5 12 | 1LPX6 13 | 1LPX7 14 | 1LM1 15 | 1LM2 16 | 1LM3 17 | 1LM4 18 | 1LM5 19 | 1LM6 20 | 1LM7 21 | INTP1 22 | INTP2 23 | INTP3 24 | INTP4 25 | EXTM 26 | RES1 27 | RES2 28 | PXLS 29 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1LIN1 1 | $(1-a_1^1)$ | $-a_1^1$ | $-a_1^1$ | $-a_1^1$ | $-a_1^2$ | $-a_1^2$ | $-a_1^3$ | | | | | | | | 1 | | | | | | | | | | | | | | $-d_1$ |
| 1LIN2 2 | $-a_2^1$ | $(1-a_2^1)$ | $-a_2^1$ | $-a_2^1$ | $-a_2^2$ | $-a_2^2$ | $-a_2^3$ | | | | | | | | | 1 | | | | | | | | | | | | | $-d_2$ |
| 1LIN3 3 | $-a_3^1$ | $-a_3^1$ | $(1-a_3^1)$ | $-a_3^1$ | $-a_3^2$ | $-a_3^2$ | $-a_3^3$ | | | | | | | | | | 1 | | | | | | | | | | | | $-d_3$ |
| 1LIN4 4 | $-a_4^1$ | $-a_4^1$ | $-a_4^1$ | $(1-a_4^1)$ | $-a_4^2$ | $-a_4^2$ | $-a_4^3$ | | | | | | | | | | | 1 | | | | | | | | | | | $-d_4$ |
| 1LIN5 5 | $-a_5^1$ | $-a_5^1$ | $-a_5^1$ | $-a_5^1$ | $(1-a_5^2)$ | $-a_5^2$ | $-a_5^3$ | | | | | | | | | | | | 1 | | | | | | | | | | $-d_5$ |
| 1LIN6 6 | $-a_6^1$ | $-a_6^1$ | $-a_6^1$ | $-a_6^1$ | $-a_6^2$ | $(1-a_6^2)$ | $-a_6^3$ | | | | | | | | | | | | | 1 | | | | | | | | | $-d_6$ |
| 1LIN7 7 | $-a_7^1$ | $-a_7^1$ | $-a_7^1$ | $-a_7^1$ | $-a_7^2$ | $-a_7^2$ | $(1-a_7^3)$ | | | | | | | | | | | | | | 1 | | | | | | | | $-d_7$ |
| EXTM 8 | | | | | | | | | | | | | | | | | | | | | | 1 | 1 | 1 | 1 | 1 | | | $-r$ |
| PE 9 | | | | | | | | | | | | | | | $-m_1$ | $-m_2$ | $-m_3$ | $-m_4$ | $-m_5$ | $-m_6$ | $-m_7$ | | | | | $n$ | | | $+b$ |
| RES1 10 | $-c_1^1$ | $-c_1^1$ | $-c_1^1$ | $-c_1^1$ | $-c_1^2$ | $-c_1^2$ | $-c_1^3$ | $-\bar{c}_1^1$ | $-\bar{c}_1^1$ | $-\bar{c}_1^1$ | $-\bar{c}_1^1$ | $-\bar{c}_1^2$ | $-\bar{c}_1^2$ | $-\bar{c}_1^3$ | | | | | | | | | | | | | 1 | | |
| RES2 11 | $-c_2^1$ | $-c_2^1$ | $-c_2^1$ | $-c_2^1$ | $-c_2^2$ | $-c_2^2$ | $-c_2^3$ | $-\bar{c}_2^1$ | $-\bar{c}_2^1$ | $-\bar{c}_2^1$ | $-\bar{c}_2^1$ | $-\bar{c}_2^2$ | $-\bar{c}_2^2$ | $-\bar{c}_2^3$ | | | | | | | | | | | | | | 1 | |

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DMAT 12 | $\mu^1$ | $\mu^1$ | $-\mu^1$ | $-\mu^1$ | $-\mu^2$ | $-\mu^2$ | $-\mu^3$ | | | | | | | | | | | | | | | | | | | | | | |
| LAB1 13 | | | | | | | | | | | | | | | | | | | | | | | | | | | $-\lambda_{11}$ | $-\lambda_{12}$ | |
| LAB2 14 | | | | | | | | | | | | | | | | | | | | | | | | | | | $-\lambda_{21}$ | $-\lambda_{22}$ | |
| IMAT 15 | | | | | | | | | | | | | | | | | | | | | | | | | | | $-\xi_1$ | $-\xi_2$ | |
| CAP 16 | | | | | | | | $-\bar{\varphi}^1$ | $-\bar{\varphi}^1$ | $-\bar{\varphi}^1$ | $-\bar{\varphi}^1$ | $-\bar{\varphi}^2$ | $-\bar{\varphi}^2$ | $-\bar{\varphi}^3$ | | | | | | | | | | | | | $\kappa_1$ | $\kappa_2$ | |
| S 17 | | | | | | | | | | | | | | | | | | | | | | $-\nu_1$ | $-\nu_2$ | $-\nu_3$ | $-\nu_4$ | | | | |
| ISTP1 18 | | | | | | | | | | | | | | | | | | | | | | $-1$ | | | | | | | $l_1$ |
| ISTP2 19 | | | | | | | | | | | | | | | | | | | | | | | $-1$ | | | | | | $l_2$ |
| ISTP3 20 | | | | | | | | | | | | | | | | | | | | | | | | $-1$ | | | | | $l_3$ |
| ISTP4 21 | | | | | | | | | | | | | | | | | | | | | | | | | $-1$ | | | | $l_4$ |
| ILFX 22 | $-\frac{1}{f_{11}}$ | | | | | | | 1 | | | | | | | | | | | | | | | | | | | | | |
| ILFX2 23 | | $-\frac{1}{f_{12}}$ | | | | | | | 1 | | | | | | | | | | | | | | | | | | | | |
| ILFX3 24 | | | $-\frac{1}{f_{13}}$ | | | | | | | 1 | | | | | | | | | | | | | | | | | | | |
| ILFX4 25 | | | | $-\frac{1}{f_{14}}$ | | | | | | | 1 | | | | | | | | | | | | | | | | | | |
| ILFX5 26 | | | | | $-\frac{1}{f_{15}}$ | | | | | | | 1 | | | | | | | | | | | | | | | | | |
| ILFX6 27 | | | | | | $\frac{1}{f_{16}}$ | | | | | | | 1 | | | | | | | | | | | | | | | | |
| ILFX7 28 | | | | | | | $-\frac{1}{f_{17}}$ | | | | | | | 1 | | | | | | | | | | | | | | | |

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*) The symbols used are defined in the appendix to this study.

The equality sign $=$ again refers to the definition of these variables by means of column balances.[89]

The above form of a linear system is called "homogeneous". In this form all activity scales and resource prices are variable. The present task is to find values of these variables (a "programme") which will in some sense be optimal.

Optimality can be defined in two complementary ways as follows:

Selecting a resource $m$ whose surplus $s_m$ will be maximized by varying the activity scales $x_j$ subject to the conditions that deficits (negative $s_i$) are avoided for all other resources and that no activity scale will be negative;

Selecting an activity $n$ from which the profit $-l_n$ will be minimized by varying the resource prices $y_i$ subject to the conditions that profits (negative $l_n$) are avoided for all other activities and that no resource price $y_i$ will be negative.

Note that the conditions imposed in both can be summarized by the rule that no variable may be negative. This is merely common sense in regard to activity scales, since activities generally cannot be run in reverse;[90] one cannot make pigs from sausages. Negative prices are meaningless. The avoidance of deficits on any resource is again economic common sense, since this study is directed towards feasible and practical resource allocation. Although the avoidance of profits at first seems paradoxical, it corresponds to the maxim of neoclassical economics that, under perfect competition, profits are eliminated (with well known favourable implications for the efficiency of resource allocation).

The maximization of a resource surplus may mean either the maximization of net output or the minimization of net input. The resource in question can be a composite resource if desired for it may consist of a weighted average of several resources. In addition, it is necessary to introduce scarcity for the maximization to become meaningful. As long as all activities are treated as variable and thus can be indefinitely expanded, there is generally no limits on the expansion of the quantity to be maximized;[91] some part of the system, however, must be fixed.

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[89] It may be questioned why the symbols chosen to represent column balances are negative rather than positive as in the case of row balances. This is done conventionally to obtain the simplest scheme of algebraic manipulations for the linear system. Each $l_j$ represents a loss on an activity; if $-l_j > 0$, the activity is profitable.

[90] In some cases such conditions may be relaxed. For example, exports may be treated as negative imports provided that the export and import prices of a commodity are equal within a tolerable margin of error. Then the statement of optimality requires a slight revision.

[91] At times it is impossible to find any programme with all $x_j$ and $s_i$ variables non-negative. In this situation the question of optimization does not arise.

An activity is therefore selected whose scale is set to unity. It is convenient in sectoral planning problems to treat the exogenously given supplies and demands of the economic resources as fixed-scale activities. The activity thus fixed becomes the activity whose profit is minimized under the definition of optimality. This offers a clue to the interpretation of profit minimization; prices should be chosen that will reduce the value of exogenous supplies and increase the value of exogenous demands (they reduce the scarcity of limited supplies and enhance the benefit of prescribed demands).

The following features of linear programming models are particularly valuable:

Linear programming models permit the representation of alternative activities. For example, the output of a given product may be obtained by domestic production or by imports, or there may be more or less labour-intensive production. Any alternative may appear with a zero scale in the optimal programme. The inclusion of inefficient alternatives in the model, therefore, is not harmful.

The models that permit the representation of joint products for a given activity may have more than one output (positive entries). This overcomes a limitation of Leontieff, input-output formulations.

Multiple restrictions may operate on the same activity or group of activities. In particular, the restrictions may be inequalities, such as an upper limit to the scale of an activity. If such a limit is written in the form $x_j \leqq L$, it can be converted into an exact equality by adding the surplus variable $s_i$ to its left side;

$$s_i + x_j = L \ ,$$

from which

$$s_i = (-x_j) + L \ ,$$

places the restriction into the conventional format applied to all resource balances with $L$ being an element of the exogenous vector. Any restriction may appear with a non-zero surplus in the optimal programme; such a restriction is ineffective and may thus be included in the formulation.

The models presented in this format, unless otherwise noted, are simple linear programming models which can be readily solved by a number of well-known methods. [49] When some variables (always activity scales) are required to assume only integer values, the presentation of the model remains identical, but the mathematical and computational procedures for obtaining an optimal solution are considerably more complex. In some cases, especially for small models, exact optimal solutions can be derived; in other cases, the results are only reasonable approximations.[92]

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[92] See reference [49], chapter 26.

## 2. THE SIMPLEST PROGRAMMING MODEL

Both models 1 and 2 refer to a single branch and are two variations of the simplest programming model for the metalworking sector. The $x$, $s$, $y$ and $-l$ variables are not indicated in the margins as in table 11 but in the rows and columns; they are numbered sequentially and have symbolic designations that are derived from the nature of the resource or activity represented. While not explicitly shown, the former variables play exactly the same role as in table 11, particularly in the formation of row and column balances.

The products represented in models 1 and 2 are listed products [69] numbered 1 through 7. The technical coefficients of a listed product are based on the technical coefficients of one or more typical products. The inputs per ton of product may be transferred without change from the typical product to the listed product. This is the simplest procedure and has been adopted here for illustrative purposes. Alternately, the coefficients may be modified to some extent on the basis of simple parametric correlations of size, capacity and so on. With each listed product there is an associated activity (1LIS1 . . . 1LIS7) that represents the domestic production of the product in question and a row (1LIS1 . . . 1LIS7) that represents the commodity balance. In the first seven rows and columns of models 1 and 2, there is a diagonal of +1 (unity) elements with a $-a$ element in every cell. The +1 elements represent stated amounts of intermediate input of other listed products used in the production of the given listed product — for example, the requirements for an electric motor in the production of a pump. Generally, most of the $a$ entries will be zero.

The formulation of such an input-ouput submatrix for listed products permits various stages of production to be taken into account. End-products, subassemblies and components can be designated as separate listed products, and the input requirements of each product can be given (including the requirements for lower-order intermediate commodities). Alternative methods of manufacturing a listed product could be included, although they are not shown in the models. Models 1 and 2 refer to a single branch of the sector; however, in more comprehensive models (as in model 3), input-output relationships connecting several branches of the sector will occur without posing any difficulty of formulation.

The superscripts are identical for the first four columns and for the next two columns. The superscripts refer to the serial number of the typical product from which the technical coefficients of the listed product have been derived. In the present illustrative case, it has been assumed that four listed products are derived from the first typical product, two from the second and one from the third. The listed products derived from the same typical product differ formally among themselves only in regard to their seriality.

Typical products do not occur in the models as such; they are required only to derive the technical information for the listed products. Typical products, however, may and generally will appear as members of the product list in a branch; thus they will enter the model as listed products without further distinction.

In model 1 all other inputs of the production activities for listed products are condensed into a production cost figure $-k$, which has the same superscript as the corresponding $a$ coefficients; in model 2 the production costs consist of the cost of using the resource-element capacities and that of direct material inputs. The only other coefficients of the production activities for listed products are the $-1$ $f$ coefficients of the fixed-cost constraints, that is, rows 1LFX1 . . . 1LFX7.

The fixed-cost constraints connect the first group of seven activities with the next group of seven activities in both models. Activities 8 through 14 in both models are designated as 1LFX1 . . . 1LFX7 and refer to the activity of incurring fixed costs connected with setting up a production series. This postulates that the costs of the required tooling, jigs and fixtures must be met before beginning the manufacture of a product. In addition, it is necessary to set up the machinery before each individual production run. The amount of fixed costs is given as a single dollar figure, $-k$ in model 1, but is divided into a lump sum capital requirement and fixed capacity requirements of two different resource elements in model 2. The fixed-cost activities are connected with the production activities in such a way that the entire fixed cost is incurred whenever a production activity is used. This procedure converts the problem into an integer programming problem as is shown in detail below.

From an empirical point of view the properties of models 1 and 2 make allowance for economies of scale arising out of the length of a production run in the manufacture of individual products without allowing for economies of scale in regard to the size of productive facilities. All productive resources are still assumed to be infinitely subdivisible; the only consideration in their employment is the resource or money cost associated with their use.

The third block of seven activities in models 1 and 2 relates to imports. Each activity has an entry of $+1$, corresponding to the product which it makes available, and an entry of $-m_i$, corresponding to the expenditure of foreign exchange per unit (ton) of product $i$, that is, to the world market price. Generally, it is assumed that imports are irreversible. It might be convenient to permit imports to behave as free variables, that is, variables that may take on negative values and indicate exports. This procedure introduces only a minor modification in the mathematical statement of the problem.[93]

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[93] Whenever a variable $x_j$ is to be treated as a free variable, the loss variable $l_j$ the top of table 11 must be zero; it is not permitted to be positive. Not only is usual no-profit condition valid for this variable but also a no-loss condition; activity is required to break even exactly.

The next block of five activities refers to the extrapolated products [69] of the branch under study. In effect, products not listed individually in a branch are handled by a single cost function which attributes increasing domestic production costs to output as the output approaches the total demand for the branch. The device of extrapolation is meant to be used only for a minor part of the total demand in any branch; because of an inherent asymmetry in the distribution of demand for individual products, it is assumed that the major portion (perhaps 85 to 90 per cent) of total demand in the branch can be handled by the individual description of about 200 listed products. The cost trend of the listed products is to be extrapolated for the remaining products, which can be several thousand in number. The rationale of this extrapolation is developed below; for the moment it suffices to indicate that in model 1 the increase in production costs is handled by a step function such as shown in figure 13; it can be seen that the total output of the extrapolated product is presented as the sum of the four step variables $x_{22} \dots x_{25}$ (they correspond to the columns with the same serial numbers in models 1 and 2). Each step has a given constant cost $\gamma$ associated with it and is limited to a maximum length $l_1, \dots, l_4$. In an optimizing model the lower-cost steps will always be used to the limit before changing to a higher-cost step; thus the steps will be used in the correct sequence as specified by the shape of the step function even without explicit sequencing instructions. The output of the extrapolated product may be measured either in tons or in foreign-exchange units corresponding to the world market price as discussed below. Activity 26 in models 1 and 2 is an import activity for the extrapolated product. Model 2 does not contain a detailed resource listing for the extrapolated product.

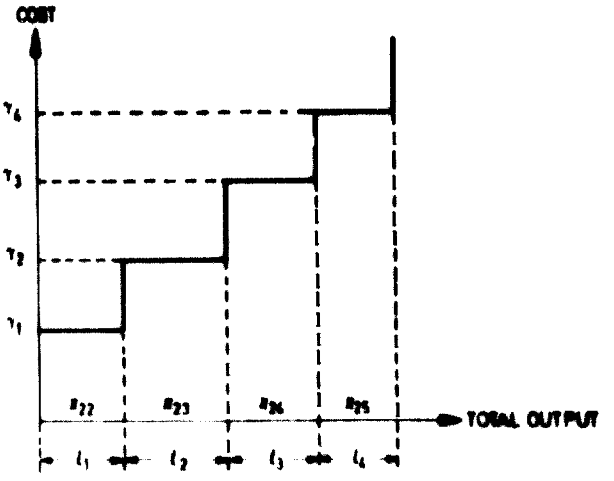

*Figure 13. Step function for extrapolated products*

In model 1 there is only one further column, namely, the column (no. 27) of exogenous supplies and demands. It includes the demand for the listed products, the demand for the extrapolated products, the exogenous supply (allocation) of foreign exchange and the limits associated with the step function of the extrapolated products. The exogenous column (no. 29) in model 2 has the same structure.

Two additional activities included in model 2 correspond to the input flows associated with maintaining given capacities of the two resource elements that appear in the model. It is assumed that indirect material inputs, capital input and two kinds of labour input are accounted for separately. The amount of detail can be increased without altering the structure of the model. The output of each activity is a + 1 entry associated with a unit of available capacity.

The objective function in model 1 consists of row 10 and involves the minimization of total money cost.[94] As a result of it and the usual conditions of non-negative variables the cost of meeting all sectoral demands is to be minimized, while the supply of foreign exchange is not to be exceeded; all constraints pertaining to the step function and the fixed costs are to be observed. In model 2 the objective function is defined as a weighted average of rows 12 to 17, where exogenously given prices of the resources in question (not shown in the model) are to be used as weights. By definition, the price of money is set at unity. The conditions of this optimization are the same as those in model 1, except that two additional row-constraints (10 and 11) must be satisfied and that the resource-element capacity requirements must be fully met.

Fixed costs are introduced into the models in the form of independent activities (such as 1LFX1 . . . 1LFX7) which are connected with the corresponding production activities for listed products (1LIS1 . . . 1LIS7 to be referred to as variable-cost activities) in such a way that the entire fixed cost is incurred whenever the variable-cost activity in question is used. The principles presented here are applicable to the connexion between any fixed-cost and variable-cost activity. Later fixed costs will be introduced in connexion with the size of productive facilities and with the technical specialists who must be hired to ensure production.

The scale of a fixed-cost activity is a mathematical variable that can be interpreted as the number of times fixed cost is incurred; the fixed cost itself is given either in monetary terms (in model 1, the $k^i$ coefficients) or in terms of more detailed individual fixed resource inputs (in model 2, the $c_j^i$ and $\varphi^i$ coefficients). For example, the meaning of the relation $x_8 = 0.2$ (where $x_8$ is the scale of activity 8 in model 1) is that the fraction 0.2 (20 per cent) of total fixed costs associated with the production of listed product 1 is being incurred.

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[94] Formally, the surplus of the row $s_{10}$ is being maximized.

However, it is an unreasonable economic representation to indicate that a fixed cost is 20 per cent, since it is indivisible by its very nature; one cannot build half of a factory or carry out only one fifth of a production programme. The scale of a fixed-cost activity should be represented by an integer variable which can only assume the values 0, 1, 2 .... Where the fixed costs are incurred more than once, values larger than 1 have the economic meaning of multiple production facilities, production runs and so on.

The device to compel fixed-cost incurrence in the models (referred to as the tie-in between the fixed-cost and variable-cost activities) consists of constraining the scale of the fixed-cost activity to be equal to or larger than some constant proportion of the scale of the variable-cost activity. (The tie-in is provided, for example, for listed product 1 by row 15 in model 1 or row 22 in model 2.) As long as the variable-cost activity is not used, for example, the production scale $x_1$ of listed product 1 is 0, the scale of the fixed-cost activity $x_8$ can also remain 0. In this case no fixed cost need be incurred. However, as soon as the scale of the variable-cost activity $x_1$ rises above 0 (no matter how small the increment is) the tie-in with the fixed-cost activity $x_8$ forces the scale of the latter to rise by at least a small amount above 0. Up to this point there has been nothing to prevent the scale of the fixed-cost activity $x_8$ from assuming a fractional value; in fact, if there were no further restrictions, the optimal solution would contain fractional values. However, the integrality requirement for the fixed-cost-activity scale $x_8$ forces this scale to move upward to the nearest integer in the direction in which the tie-in constraints permit an inequality.[95] Thus the full fixed cost is incurred at least once when the scale of the fixed-cost activity $x_8$ (determined as a constant proportion of the variable-scale activity $x_1$) is between 0 and 1 prior to the application of the integrality requirement. If $x_1$ is larger than 1, the fixed cost will be incurred more than once.

The connexion between the production and fixed-cost activities is shown in figure 14, which illustrates the tie-in between column 1 and column 8 in model 1. The scale of the production activity (column 1 in model 1) is $x_1$ and that of the fixed-cost activity (column 8) is $x_8$. The variable $x_8$ measures the number of times the fixed cost is incurred. The fixed cost $-k^1$ is measured along the vertical axis denoting cost; the minus sign is omitted since all costs are inherently negative. The horizontal axis measures $x_1$, which is the scale of the production activity.

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[95] Inequalities are converted into equalities for representation in the models by adding a positive surplus $s$ to the smaller side. The greater the difference between the two sides of the inequality, the larger the surplus $s$. Thus, as the fixed-cost activity scale $x_8$ moves to the next integer value, the corresponding surplus ($s_{15}$ in model 1 or $s_{22}$ in model 2) increases.

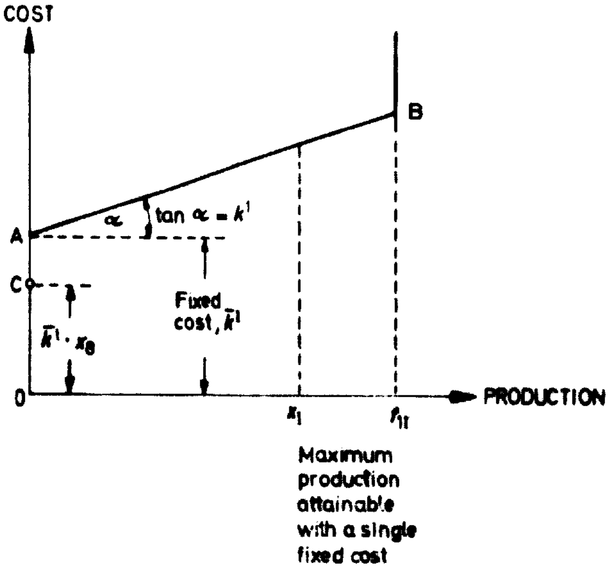

*Figure 14. Fixed costs*

The variable cost $-k^1$ is the slope of the total-cost line AB. To interpret the nature of the fixed-cost tie-in parameter $1/f_{11}k$, it is assumed that a maximum production scale $f_{11}$ is associated with the expenditure of a single fixed cost. If there is an upper limit on yearly production, it can be identified[96] with $f_{11}$. In other instances, when the variable costs are tied to investment in a fixed productive facility, the capacity of the facility can be identified with the corresponding tie-in parameter as shown below in model 3. The row balance in row 15 of model 1 can be written in full as follows:

$$s_{15} = (-1/f_{11})(x_1) + (1)(x_8) .$$

When this row balance holds without surplus, $s_{15} = 0$, and

$$0 = (-x_1/f_{11}) + x_8 ;$$

thus

$$x = x_1/f_{11} .$$

In figure 14, $x_1$ is about three-quarters of the way toward the maximum; therefore, $x_1/f_{11} = \frac{3}{4}$. Accordingly, the scale of the fixed-cost activity will be (at least) equal to it, that is $\frac{3}{4}$; the amount of fixed cost incurred will be $\frac{3}{4}$ of $k^1$ or point C, which is about $\frac{3}{4}$ of the elevation of 0A. The latter is equal to the full fixed cost $k^1$. The fixed-cost constraint

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[96] If there is no economically meaningful upper limit of this kind, $f_{11}$ is simply set to an upper bound on the practically occurring values of the variable-cost activity scale to ensure that fixed cost will be incurred no more than once.

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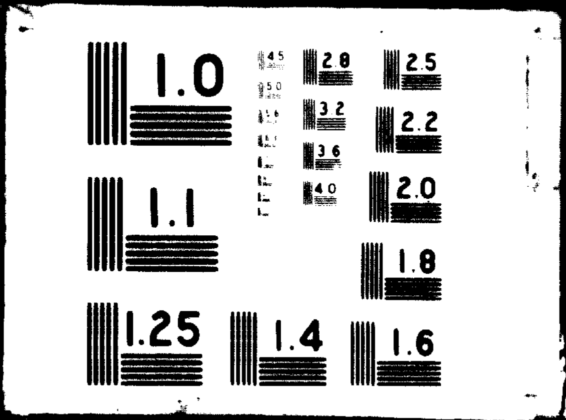
4 OF 5

0 4 5 3 3



thus prescribes that the fraction of fixed costs incurred must be at least equal to the fraction of the actual maximum production. At this point the integrality requirement for $x_8$ ensures that as soon as this fraction exceeds 0, it will increase to unity, and the fixed cost incurred will rise to 0A.

In figure 14, a value of $x_1$ was chosen that is smaller than $f_{11}$; accordingly $x_8$ was less than unity prior to the application of the integrality requirement. In figure 15, $x_1$ is assumed to be $1.5f_{11}$, that is, larger than the largest possible single production run. Figure 14 shows the relationship of fixed and variable costs on the assumption that multiple production runs are possible. In each of these runs fixed costs are incurred once; thereafter variable costs are constant (a constant slope) until the maximal production series. Incurring fixed costs twice will thus secure a maximal total output of $2f_{11}$. The tie-in parameter $f$ or $g$ generally denotes the upper limit on the scale of the variable-cost activity that corresponds to a single fixed cost. If the scale of the variable-cost activity exceeds this parameter, the number of fixed-cost incurrences will be equal to the next larger integer.

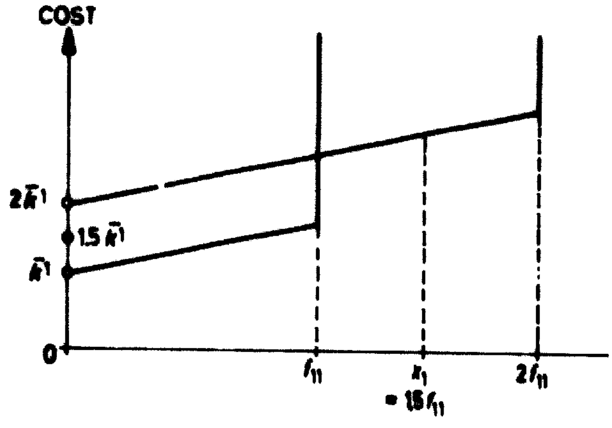


*Figure 15. Multiple fixed costs*

### 3. A MULTIBRANCH MODEL

Model 3 is a generalization of the simplest model. It avoids the unrealistic assumption that the sector can be programmed branch by branch and explicitly introduces the sharing of productive facilities (resource elements) between branches. In order to restrict the model to a manageable size, distinctions between listed products by typical-product origin are omitted, and only two listed products are shown for a pair of branches.

Model 3 is organized by branches; therefore all production, fixed-cost, import and extrapolated-product activities of a branch are grouped together. Beginning with the listed-product balances in the first four rows, intermediate-input requirements can be shown as interconnecting the branches (rows 1 and 2 intersecting columns 12 and 13 and rows 3 and 4 intersecting columns 1 and 2). All other features of the entries in all rows of the first 22 columns and of the exogenous column remain essentially unchanged between model 2 and model 3 except for a slight generalization of the notation to allow the labelling of parameters by branch and for intermediate-input coefficients $(-a)$ by branch both of origin and of destination. Apart from thus simultaneously showing more than one branch, the novelty of model 3 is concentrated in columns 23 to 26. They are resource-element capacity-maintenance activities labelled RES1 and RES2 that correspond to the identically labelled columns in model 2, except that they are now connected to the respective fixed-cost activities RFX1 and RFX2. The fixed costs must be incurred whenever the capacity of a resource element is to be maintained at a level exceeding zero. The mathematical tie-in between the fixed-cost activity RES1 and the variable-cost activity RFX1 that characterizes the first resource element is precisely the same as the previously discussed tie-in between a production activity such as 1LIS1 and a fixed-cost activity such as 1LFX1. The tie-in is provided by the constraint of rows 28 and 29.

The fixed and variable costs associated with maintaining given resource-element capacities are intended as an approximation to the economies of scale that are known to occur when the total yearly capacity of a given resource element increases. With a given fixed cost and constant variable costs, a larger capacity will imply lower resource inputs per unit capacity. The variable costs consist of specific resource inputs exactly as those in model 2, while the fixed costs are given as labour, material and capital requirements in lump sums. There is an upper limit on capacity that corresponds to the empirical observation that large processing facilities are not constructed indefinitely; if the size exceeds a certain limit, a duplication of facilities occurs. This limiting factor can be represented mathematically by setting the fixed-cost tie-in parameter equal to the reciprocal of the capacity limit. In accordance with the earlier discussion on fixed-cost constraints, this will increase the scale of fixed-cost incurrence (for example, the variable $x_{25}$, which corresponds to activity RFX1 in model 3) to at least $x_{23}/y_1$, which is the ratio of the scale of the variable-cost activity RES1 to the upper limit imposed on the capacity of resource-element 1. If this ratio is between 0 and 1, the integrality requirement imposed on the fixed-cost activity scale $x_{25}$ will push $x_{25}$ to unity; if the ratio is greater than 1, the integrality requirement will push $x_{25}$ to the next larger integer. In this way the requirement for multiple facilities and the multiple incurrences of fixed costs are properly represented.

MODEL 9

| | 1LIS1 1 | 1LIS2 2 | 1LFX1 3 | 1LFX2 4 | 1LB1 5 | 1LB2 6 | 1STP1 7 | 1STP2 8 | 1STP3 9 | 1STP4 10 | 1EXTM 11 | 2LIS1 12 | 2LIS2 13 | 2LFX1 14 | 2LFX2 15 | 2LB1 16 | 2LB2 17 | 2STP1 18 | 2STP2 19 | 2STP3 20 | 2STP4 21 | 2EXTM 22 | RES1 23 | RES2 24 | RFX1 25 | RFX2 26 | EXOG 27 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1LIS1 1 | $(1 - a_{11,11})$ | $-a_{11,12}$ | | | 1 | | | | | | | $-a_{11,21}$ | $-a_{11,22}$ | | | | | | | | | | | | | | $-d_{11}$ |
| 1LIS2 2 | $-a_{12,11}$ | $(1 - a_{12,12})$ | | | | 1 | | | | | | $-a_{12,21}$ | $-a_{12,22}$ | | | | | | | | | | | | | | $-d_{12}$ |
| 2LIS1 3 | $a_{21,11}$ | $a_{21,12}$ | | | | | | | | | | $(1\ a_{21,21})$ | $a_{21,22}$ | | | 1 | | | | | | | | | | | $-d_{21}$ |
| 2LIS2 4 | $a_{22,11}$ | $a_{22,11}$ | | | | | | | | | | $-a_{22,21}$ | $(1 - a_{22,22})$ | | | | 1 | | | | | | | | | | $d_{22}$ |
| 1EXT 5 | | | | | | | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | | | | | | | $-e_1$ |
| 2EXT 6 | | | | | | | | | | | | | | | | | | 1 | 1 | 1 | 1 | 1 | | | | | $-e_2$ |
| FE 7 | | | | | $-m_{11}$ | $-m_{12}$ | | | | | $-n_1$ | | | | | $-m_{21}$ | $-m_{22}$ | | | | | $n_2$ | | | | | $+b$ |
| RES1 8 | $-c_{1,11}$ | $-c_{1,12}$ | $\bar{c}_{1,11}$ | $-\bar{c}_{1,12}$ | | | $\delta_{1,11}$ | $-\delta_{1,12}$ | $-\delta_{1,13}$ | $-\delta_{1,14}$ | | $-c_{1,21}$ | $-c_{1,22}$ | $\bar{c}_{1,21}$ | $-\bar{c}_{1,22}$ | | | $-\delta_{1,21}$ | $\delta_{1,22}$ | $-\delta_{1,23}$ | $\delta_{1,24}$ | | 1 | | | | |
| RES2 9 | $-c_{2,11}$ | $-c_{2,12}$ | $-\bar{c}_{2,11}$ | $-\bar{c}_{2,12}$ | | | $-\delta_{2,11}$ | $-\delta_{2,12}$ | $-\delta_{2,13}$ | $-\delta_{2,14}$ | | $c_{2,21}$ | $c_{2,22}$ | $-\bar{c}_{2,21}$ | $-\bar{c}_{2,22}$ | | | $\delta_{2,21}$ | $\delta_{2,22}$ | $\delta_{2,23}$ | $\delta_{2,24}$ | | | 1 | | | |
| 1MAT 10 | $-\mu_{11}$ | $-\mu_{12}$ | | | | | $-v_{11}$ | $-v_{12}$ | $-v_{13}$ | $-v_{14}$ | | $-\mu_{21}$ | $-\mu_{22}$ | | | | | $-v_{21}$ | $v_{22}$ | $-v_{23}$ | $-v_{24}$ | | | | | | |
| LAB1 11 | | | | | | | | | | | | | | | | | | | | | | | $-\lambda_{11}$ | $\lambda_{12}$ | $\bar{\lambda}_{11}$ | $-\bar{\lambda}_{12}$ | |
| LAB2 12 | | | | | | | | | | | | | | | | | | | | | | | $-\lambda_{21}$ | $-\lambda_{22}$ | $\bar{\lambda}_{21}$ | $\bar{\lambda}_{22}$ | |
| 2MAT 13 | | | | | | | | | | | | | | | | | | | | | | | $-\xi_1$ | $-\xi_2$ | $\bar{\xi}_1$ | $\bar{\xi}_2$ | |
| CAP 14 | | | | $-\bar{\varphi}_{11}$ | $-\bar{\varphi}_{12}$ | | | | | | | | | $\bar{\varphi}_{21}$ | $\bar{\varphi}_{22}$ | | | | | | | | $-\bar{\kappa}_1$ | $\kappa_2$ | $\bar{\kappa}_1$ | $-\kappa_2$ | |
| 0 15 | | | | | | | | | | | | | | | | | | | | | | | | | | | |

| | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1STP1 16 | | | | | | | 1 | | | | | | | | | | | | | | | | | | | | $l_{11}$ |
| 1STP2 17 | | | | | | | | -1 | | | | | | | | | | | | | | | | | | | $l_{12}$ |
| 1STP3 18 | | | | | | | | | 1 | | | | | | | | | | | | | | | | | | $l_{13}$ |
| 1STP4 19 | | | | | | | | | | -1 | | | | | | | | | | | | | | | | | $-l_{14}$ |
| 2STP1 20 | | | | | | | | | | | | | | | | | | -1 | | | | | | | | | $-l_{21}$ |
| 2STP2 21 | | | | | | | | | | | | | | | | | | | -1 | | | | | | | | $-l_{22}$ |
| 2STP3 22 | | | | | | | | | | | | | | | | | | | | -1 | | | | | | | $-l_{23}$ |
| 2STP4 23 | | | | | | | | | | | | | | | | | | | | | -1 | | | | | | $-l_{24}$ |
| 1LFX1 24 | $-\frac{1}{f_{11}}$ | | 1 | | | | | | | | | | | | | | | | | | | | | | | | |
| 1LFX2 25 | | $-\frac{1}{f_{12}}$ | | 1 | | | | | | | | | | | | | | | | | | | | | | | |
| 2LFX1 26 | | | | | | | | | | | | $-\frac{1}{f_{21}}$ | | 1 | | | | | | | | | | | | | |
| 2LFX2 27 | | | | | | | | | | | | | $\frac{1}{f_{22}}$ | | 1 | | | | | | | | | | | | |
| RFX1 28 | | | | | | | | | | | | | | | | | | | | | | | $-\frac{1}{g_1}$ | | 1 | | |
| RFX2 29 | | | | | | | | | | | | | | | | | | | | | | | | $-\frac{1}{g_2}$ | | 1 | |

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a) The symbols used are defined in the appendix to this study

200 units of capital and 200 units of foreign exchange is inserted on B′ to get B″ (D′). Note that this averaging point does not coincide with the averaging point B″ (A′). At D′ no further fixed costs need to be added since D′ already allows for the fixed costs of both production activities. The correct averaging line thus runs from B″ (D′) to D′.

Figure 27 indicates that some points of line B″ (D′) to D′ are inefficient. Thus point B″ (D′) itself and the points near it are inefficient because they use more capital and foreign exchange than B′ alone. They can therefore be superseded by B′ combined with a disposal activity for capital. It is more efficient to use B′ and to leave some capital unused than to use B″ (D′), no matter what the direction of optimization happens to be. Figure 28 gives the final correct isoquant obtained after the elimination of inefficient points. The area between the correct isoquant and the continuous isoquant is shaded in the figure.[118]

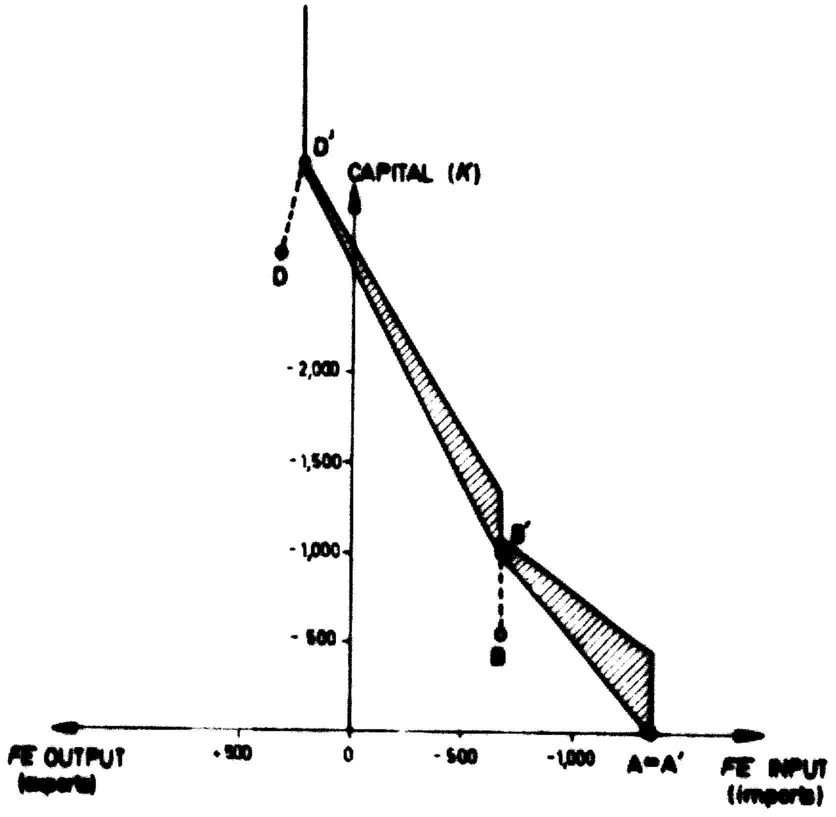

*Figure 28. The sectoral isoquant derived from the correct averaging line. Inefficient points eliminated*

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[118] The complex C has been ignored in deriving the correct isoquant. In general, an inefficient point of the no-fixed-cost problem will remain inefficient when the correct isoquant of the discrete problem is defined. It is therefore necessary to include such points in the correct averaging procedure until it can be shown that their correct averaging lines are everywhere inefficient.

given process.[97] This avoids the problem of representing endogenously the alternative degrees of complexity in the provision of tooling, jigs and fixtures. The problem is illustrated in figure 16, in which $x_1$ (as in models 1 and 2) represents the scale of the variable-cost activity in the production of the first listed product. There are now four alternative degrees of tooling, represented by four separate fixed investments $\varphi$, $\varphi'$, $\varphi''$ and $\varphi'''$ (in model 2 there is only a single $\varphi$ parameter associated with each productive process). Annual fixed costs are obtained by applying appropriate capital charges $i$ to these fixed investments. As the degree of tooling increases, the variable costs $k$ will decrease correspondingly as shown by the slope of the cost lines.[98] Over varying ranges of $x_1$ different degrees of tooling become most efficient (lowest cost). This is reflected by the broken line OEABCD, which represents the production-cost frontier attainable by all techniques jointly. With respect to this production-cost frontier, the models give only a single fixed-cost-to-variable-cost combination. Given sufficient empirical data, there is no difficulty in introducing alternatives into the models; in practice, however, it will generally be preferable to determine the optimal degree of tooling for a given $x_1$ by a side calculation. With exogenously given total demands, the appropriate $x_1$ for the calculation is the total yearly demand.[99]

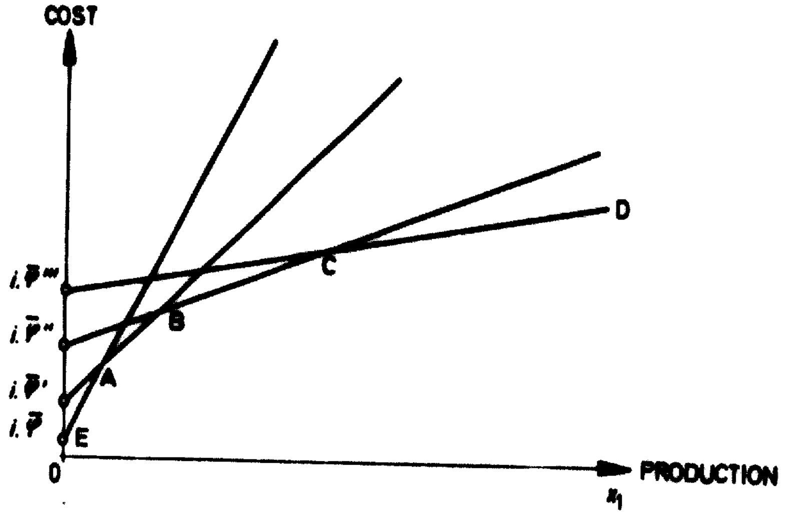

*Figure 16. The investment cost for tooling, jigs and fixtures, versus variable costs of production*

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[97] This does not exclude the possibility of two alternative techniques for producing a given product. Each alternative would have only one variable-cost activity and one fixed-cost activity.

[98] In model 2 variable costs are given in terms of resource inputs. These can be converted to equivalent $k$-values by applying appropriate prices to each resource input. Figure 16 shows only processes that are efficient (lowest cost) over some range of $x_1$. It is possible for a process to be inferior to some other processes at any $x_1$. Such a process would never be selected.

[99] Exogenous demands must be increased by the amount of intermediate-input requirements to arrive at total demands.

Fixed costs associated with set-up operations are now considered. If the fixed capacity requirements needed for setting up an individual run of a given listed product can be derived empirically, then the remaining information needed for specifying yearly set-up costs is the number of production runs per year.

A simple engineering formula for calculating the optimal number of production runs per year minimizes total set-up and inventory-carrying costs. Variable production costs and fixed investment costs for tooling, jigs and fixtures are excluded from the optimization formula because they are not affected by the length of the individual production run:

$$r = \sqrt{\frac{dk}{k}\left(\frac{1}{2}i\right)\frac{p-d'}{p}}\ ;$$

where $r$ is the number of production runs per year at optimum, $d$ the demand in physical units per year, $k$ the variable production cost in dollars per physical unit, $\bar{k}$ the set-up cost per run in dollars, $i$ the inventory carrying charge including interest, obsolescence, deterioration, handling, taxes, storage, insurance and pilferage, $p$ the production rate in physical units per day and $d'$ the demand in physical units per day.

The above expression gives the optimal number of runs per year.[100] The term $dk/k$ is the ratio of yearly variable costs to the set-up charge of a single run, and the term $(p-d')/p$ is the ratio of product accumulation to production. Total yearly set-up charges expressed as $rk$ thus

---

[100] Total cost per year can be expressed as follows:

$$TC = FC + dk + \bar{k}d/x_0 + x_0ki(p-d')/2p\ ,$$

where in addition to the previous notation, $TC$ is total cost (dollars/year), $FC$ is fixed cost (dollars/year — not affected by the length of the production series); and $x_0$ is the length of a production run. To optimize $TC$ as $x_0$ is varying,

$$0 = dTC/dx_0 = 0 + 0 + (-d\bar{k}/x_0^2) + ki\ (p-d')/2p\ ,$$

therefore

$$x_0 = \sqrt{\frac{dk}{k}\left(\frac{1}{2}i\right)\frac{p}{p-d'}}\ .$$

By $r = d/x_0$ the formula in the text follows immediately. In the expression for total costs $TC$, the four terms correspond to fixed costs, such as yearly charges on investment in tooling, jigs and fixtures; variable production costs; set-up charges and inventory-carrying costs. The latter are obtained from average stock carried, which is one-half of the peak stock at the end of a production run; it is calculated as the product of the daily accumulation $p-d'$ and the length of a run $x_0/p$ days. Average stock is multiplied by variable production cost to convert it into value terms, and an inventory-carrying charge (per cent per year) is applied to the latter.

The expression for $x_0$ can be rearranged after squaring to yield the equality at the optimum

$$dk/x_0 = x_0ki\ (p-d')/2p\ ;$$

thus yearly set-up charges are equal to yearly inventory-carrying costs at the optimum. For the derivation of the optimal length of series, see reference [70].

increase only as the square root of yearly demand, and the set-up charges per unit output correspondingly decrease with the square root of the demand. At the optimum, yearly set-up charges are exactly equal to yearly inventory-carrying costs; thus, by doubling the set-up charges, the inventory-carrying costs can be exactly accounted.

In models 1 to 3, yearly set-up charges have been treated as fixed. It has been assumed that if a given listed product is not produced, no set-up charges would be required; while if there is production, the entire yearly set-up charges would be incurred regardless of the actual production. This is an approximation to the more complex engineering description.

As yearly demands of the listed products, except those of intermediate inputs, are assumed to be exogenously given, the choice in regard to each listed product is generally narrowed to two alternatives; either the product is not produced at all or it is produced at the maximum possible scale corresponding to total yearly demand. Thus the optimal number of production runs per year can be determined by a side calculation based on total demand; this calculation will yield the yearly set-up costs. If doubled, the costs represent both set-up and inventory-carrying charges on a fixed, yearly basis. The maximal production in the fixed-cost constraints (for example, $f_{11}$ in figure 14) must now be set to a value that is larger than yearly demand to ensure that yearly set-up charges are incurred only once.[101]

The crucial simplifications employed in regard to the seriality of production in models 1 to 3 are now readily apparent. The first simplification is the constancy of yearly demand; if this were an endogenous variable of the system, alternate degrees of tooling as well as the square-root function connecting yearly set-up charges and yearly demand must be taken into account explicitly. The second simplification is the approximate anticipation of the productive structure for the determination of the yearly number of production runs by a side calculation. As the corresponding formula contains the daily production rate $p$, a feedback exists between the structure of productive facilities (which determines the production rate) and the optimal seriality. While this feedback is not recognized in the structure of the models, it is possible in the course of programming to make some allowance for the feedback by means of iterative revisions. Finally, the formula for the number of yearly production runs $r$ reduces all costs to common monetary terms. In a programming

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[101] An alternative procedure provides two fixed-cost activities, i.e. one for investments and another for set-up costs. The tie-in parameter for the former can be set to any value larger than the yearly demand, while the tie-in parameter for the latter is the length of the optimal series that is derived by a side calculation. The set-up costs will then be incurred in integer multiples depending on the ratio of yearly demand to the length of the optimal series. The procedure in the text is both simpler and more exact, since the number of runs per year need not be an integer, while the incurrence of yearly fixed set-up charges is inherently an integer (0–1) variable.

model, however, many prices are themselves variables that cannot be used for side calculations prior to solution of the problem as a whole. Moreover, in an integer programming problem, the role of prices becomes subject to further qualifications. Despite these observations, the side calculation is performed with assumed prices. Iterative revisions may be employed. The pricing problem is not peculiar to the representation of seriality in the models; it is present in many other aspects of the operation of the models.

### *The simplest representation of resource elements*

Resource elements have been defined and discussed in detail in Part I of this publication. In models 1 to 3, resource elements are included in the simplest possible manner with completely specified fixed and variable resource requirements. The procedure avoids the connexions with semiquantitative programming data and the local adaptation of resource elements (the selection of an optimal machine park, the adoption of a proper degree of mechanization and automation in response to varying capital/labour prices and the adaptation of the technology of production to a specific product assortment). The form of models 1 to 3 provides an orderly sequence of presentation, as there are so many complexities operating simultaneously that cannot be crammed into a single model that would still preserve some degree of overview of the problem.

In model 1, resource elements remain implicit; the cost of production for each product is presented in fixed and variable parts. All costs that can be referred to resource elements are already included in the variable parts of the dollar totals, thereby abstracting from all indivisibilities in resource-element investments. In model 2, the costs associated with maintaining capacities of specific resource elements are divided into physical input flows for labour and materials and into total capital requirements. Application of specific flow prices to the former and a capital charge to the latter converts them into yearly money costs. All of the costs are expressed on the basis of a unit of resource-element capacity which is being maintained and are assumed to be fully proportional to the total resource-element capacity; the postulate of complete divisibility (no lumpiness and no economies of scale) is still maintained for all resource elements. In addition, the machine park of a resource element (machine tools, hoists, furnaces and the like) and the required buildings are not itemized in the models. All individual capital goods and other capital assets are expressed in monetary values only. A generalization at a later stage will be required to take into account that capital goods required for future production lead to an earlier demand for metalworking products. (A lathe is an output of the machine-tools branch of the metalworking industry.) Implicit in the pricing process is the assumption of exogenously given prices for evaluating the investment requirements prior to the solution of the model, yet some of the required prices are included in the model itself and emerge only after the programming problem is solved. Thus the solution must be anticipated in part while formulating the model. This problem is analogous to the pricing problem discussed above and can be handled by approximate estimates of the anticipated prices in formulating the model that are revised in an iterative fashion after the solution is obtained. If it were desired to make the pricing process endogenous, all capital goods and construction would have to be itemized individually and balanced specifically in a multiperiod model.

In model 3 the assumption of perfect divisibility of resource-element capacity is superseded by the more realistic assumption that economies of scale exist in regard to such capacity. The economies of scale in the confines of a static model of a single period do not refer to the activity of constructing or expanding resource elements but only to the total yearly costs that are associated with maintaining the total resource-element capacities. Therefore total investments in the process facilities of the metalworking industries (and thus the yearly capital costs) are related to the size of these facilities (the total capacity of a single facility) by means of a relationship of constant, less-than-unitary elasticity of the form

$$K_1/K_2 = (S_1/S_2)^e \ , \quad 0 \leq e \leq 1 \ ,$$

where

$K_1$ and $K_2$ are the total investments in process facilities (resource-element capacity) at two different sizes (capacities),

$S_1$ and $S_2$ the corresponding resource-element capacities and $e$ the elasticity constant.

The relationship is shown in figure 17 in natural and in logarithmic scale units; in the latter, the relationship reduces to a straight line. Evidence of such a relationship is largely indirect; it has been firmly established in the chemical industries. [3], [31], [71] There is quantitative evidence of a general trend toward lower unit costs in larger metalworking processing facilities based on USSR data [15] and a correlation of exactly the form given for a single kind of metalworking facility (jet engine production). [72] Assuming that the form of the relationship is correctly specified, the programming problem is to include it in the model by means of an approximation that is easy to handle. Two possible approximations are shown in figure 18. The first relies on a fixed cost plus a single linear approximation and has been included in model 3; in the approximation the total investment (for example, for the first resource element) equals $\varkappa_1 x_{25} + \varkappa_1 x_{23}$, where $x_{25}$ is an integer variable. In both cases it is further postulated that the relationship representing economies of scale is not valid at some practical maximal size (capacity). If the total capacity requirements exceed this limit, there must be a duplication of productive facilities. The problem is handled by setting the $g$-parameter (for example, at the intersection of row 28 and column 23 in model 3) at the maximal capacity of a single facility. If approximation by three linear segments is desired, the variable $x_{23}$ that represents the resource-element capacity requirement must be divided into three new variables, for example $x_{23}^1$, $x_{23}^2$ and $x_{23}^3$: each variable represents a marginal amount of capacity with corresponding marginal investment requirements of $\varkappa_1^1$, $\varkappa_1^2$ and $\varkappa_1^3$ which decrease in this order. Total investment equals $\varkappa_1^1 x_{25}^1 + \varkappa_1^2 x_{25}^2 + \varkappa_1^3 x_{25}^3$. The capacity limit $g_1$ must be divided into three corresponding parts $g_1^1$, $g_1^2$ and $g_1^3$ (see figure 18); two integer variables $x_{25}^1$ and $x_{25}^2$ are needed. The following relationships must hold in order to ensure that the marginal amounts of investment are incurred in the proper sequence:

$$\frac{x_{23}^1}{g_1^1} \geqslant x_{25}^1 \geqslant \frac{x_{23}^2}{g_1^2} \geqslant x_{25}^2 \geqslant \frac{x_{23}^3}{g_1^3} .$$

Thus four separate inequalities involving two integer variables are required to represent this approximation: after complementation by a surplus variable, each inequality enters the model and the four inequalities jointly replace the single tie-in constraint between $x_{23}$ and $x_{25}$ in model 3 (row$'_b$28).

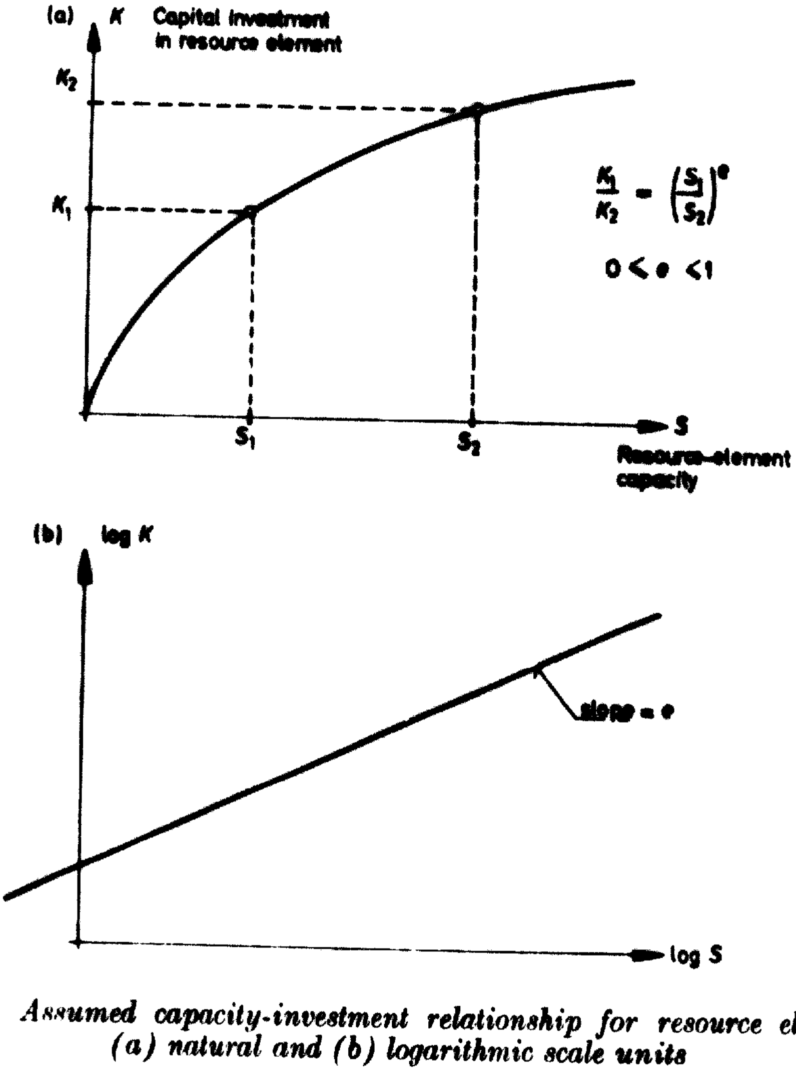

*Figure 17. Assumed capacity-investment relationship for resource elements in (a) natural and (b) logarithmic scale units*

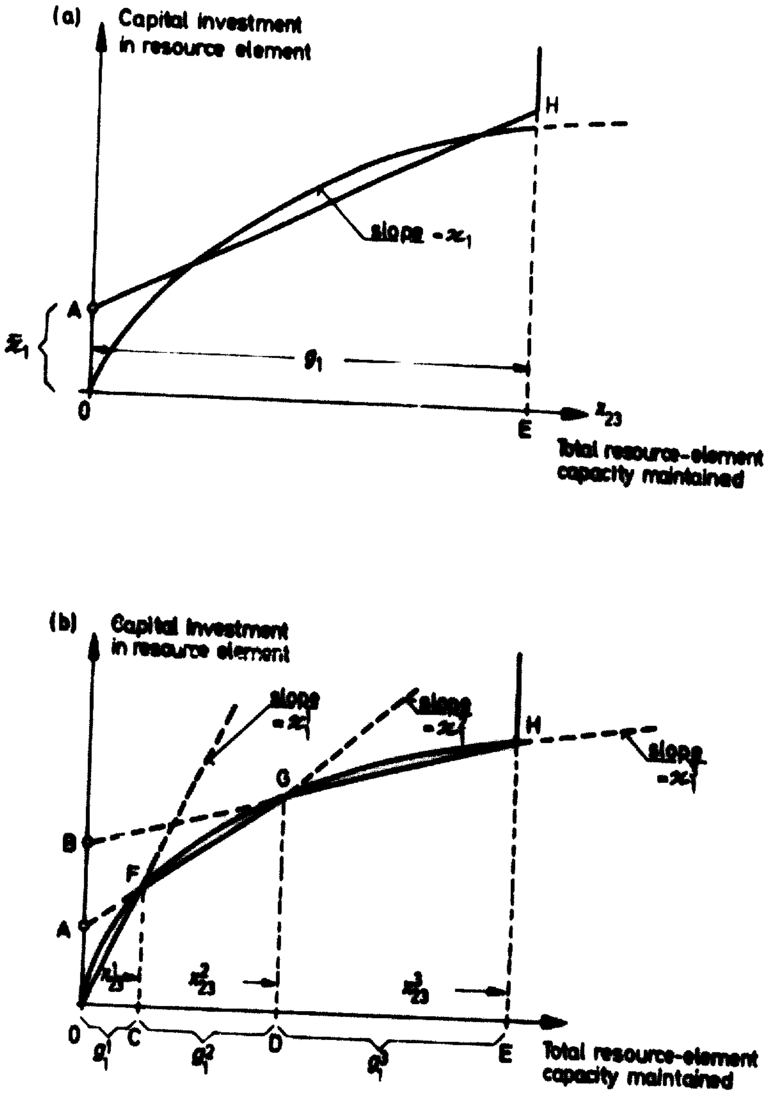

*Figure 18. Two linear approximations to a smooth function representing constant elasticity of investment relative to size: (a) fixed cost and a single linear segment; (b) three linear segments*

The interpretation of the sequencing constraints is straightforward. Assume, for example, that the total capacity requirement is greater than OE and leads to a duplication of facilities, and that the second facility must operate at a capacity between OC and OD (see figure 18). In the absence of sequencing constraints, $x_{23}^3$ (which has the lowest marginal cost $\varkappa_1^3$) would provide the entire required capacity at this marginal cost (with no fixed costs of any kind); the procedure is contrary to common sense. The sequencing constraints, however, force both $x_{23}^1$ and $x_{23}^2$ to be larger than zero as soon as $x_{23}^3$ is used. At this point the integer variables force $x_{23}^1/g_1^1$ and $x_{23}^2/g_1^2$ to unity (the first two segments are used completely). If $x_{23}^3/g_1^3$ rose above unity, both of the earlier segments must be incurred twice; to avoid this, $x_{23}^3/g_1^3$ is held exactly to unity, $x_{23}^2/g_1^2$ is set to a value between 1 and 2 and thus $x_{23}^1/g_1^1$ is forced up to 2.

The first segment is incurred twice, the second segment in the required amount between one and two times and the third segment once in accordance with natural sequencing.

## 5. THE CHOICE BETWEEN DOMESTIC PRODUCTION AND IMPORTS WITH FIXED COSTS

In the simplest case presented by model 1, the initial foreign-exchange constraint of row 9 is relaxed and replaced by the inclusion of the foreign-exchange cost in the objective function at an exogenously given foreign exchange rate. Thus the objective becomes the minimization of total money cost including the cost explicitly represented in row 10 and the domestic-currency equivalent of foreign-exchange inputs[102] appearing in row 9.

Given these assumptions, the alternatives of domestic production and imports can be individually considered for each product in the branch represented by model 1. In particular, the full production cost, including fixed cost and the variable cost at the level of total demand, must be compared with the import price *m* for each individual product.

Figure 19 shows that the choice between domestic production and imports is dependent on the level of total demand if domestic production costs and import prices are taken as given. If total demand is at the level 0A, imports will be preferred; if it is at 0C, domestic production will be preferred. At 0B the two alternatives are equivalent. If the listed product is marketed only to exogenous demand (it is not used as an input in any other production in the model), and if it has no inputs of other listed products, the conclusion for this product in isolation is immediate. Often, however, the above restrictions are not valid, especially if several branches are considered simultaneously, and they thereby increase the importance of intermediate transactions in the model. In such cases it is still possible to arrive at certain conclusions before referring back to formal integer programming solutions.

Figure 20 represents the choice between domestic production and imports for the entire branch when the simplifying restrictions are valid. The listed products of the branch are given in the order of their domestic production costs per unit import value; production cost is shown at the scale of exogenously given demand for each product. The costs are average costs at the latter scale. The hyperbolically falling trend of average costs (see figure 19) for each product is not shown in figure 20; it is replaced by a straight line drawn at the level of average costs at the stated scale. The horizontal axis measures the cumulative foreign-

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[102] The exogenous foreign-exchange supply *b* does not affect the solution, since it is a constant.

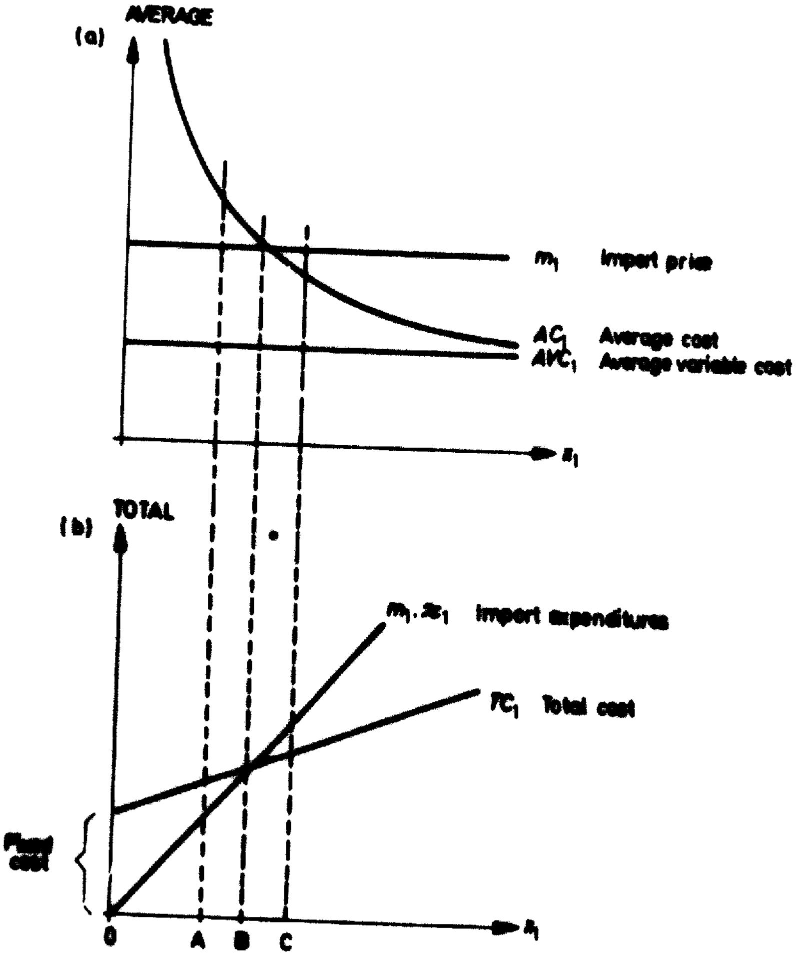

*Figure 19. Domestic production cost and import cost of listed products*

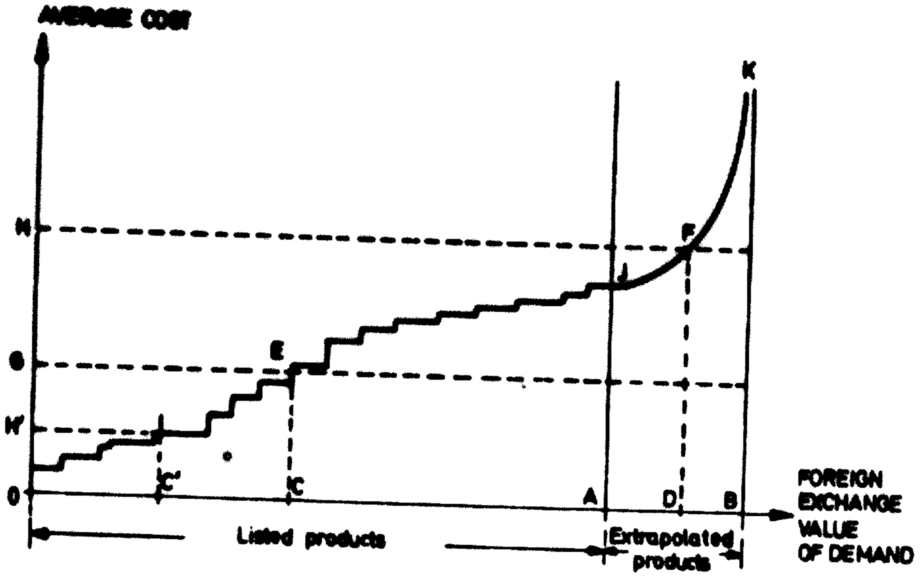

*Figure 20. Profile of domestic production costs per unit import value for a given branch, including extrapolated products*

exchange value of exogenous demand. The length of each step in the graph represents the foreign-exchange value of exogenous demand for the listed product. Thus the distance 0A represents the total foreign-exchange value of demands for all listed products in the branch measured at import prices, while the distance AB represents the total foreign-exchange value of demands for extrapolated products (the remaining products in the branch) measured at import prices. The distance 0B would be the total foreign-exchange expenditure if the demand in the branch were supplied entirely from imports with no domestic production at all. Note that the extrapolated products generally represent the most specialized and lowest-seriality products in each branch, which in the developing countries are likely to be almost entirely imported. Moreover, in statistical sources, such products will almost never appear as individual items but rather as a residual (for example, "other machine tools"). Thus the total foreign-exchange value at import prices (total import value) is a convenient representation of these products in the aggregate.

In figure 20 average costs are measured in national currency; they are standardized by reduction to a unit of import value. For example, if an electric motor costs 200 pesos to manufacture domestically,[103] weighs 25 kg and can be imported for £100, then the domestic manufacturing cost is $200/25 = 8$ peso/kg of weight, or (calculating in the same way) $200/100 = 2$ peso/£ of import value. When the foreign-exchange rate is at the level 0G, the production-cost profile of the branch immediately indicates the products which are cheaper to produce domestically and those which are cheaper to import. If the foreign-exchange rate changes to a higher level, more products become attractive for domestic production. In fact, all listed products and about one-half of the extrapolated products (measured at import value) should now be produced domestically. The crucial question of how to derive the part of the production-cost profile that represents the extrapolated products without the (almost impossible) technique of listing and analysing them individually is discussed in chapter 6.

Figure 20 illustrates a related but somewhat more difficult problem. Assume that the foreign-exchange rate is not given but is an endogenous variable of the system and that instead the branch is provided with a foreign-exchange allocation: how is the choice between domestic production and imports now to be undertaken? It can be assumed that the foreign-exchange allocation in figure 20 is CB. The problem now becomes similar to the well-known mathematical "knapsack" problem[104] and can

---

[103] Peso is used as a national-currency unit and the pound (£) as the unit of foreign exchange.

[104] See for example, reference [49], pp. 517 ff. The difference between the knapsack problem and the present problem is that production at a reduced scale (and elevated average costs) would not be possible in the knapsack problem; the choice for each product would be everything or nothing.

be solved approximately by starting with full domestic production and successively selecting products for import in the order of decreasing domestic production costs until the foreign-exchange allocation is exhausted. In figure 20 this occurs at C; the foreign-exchange allocation CB coincides with a step "riser" in the profile of domestic production costs, and thus the solution is exact. The corresponding foreign-exchange rate can be anywhere in the limits of the riser near the level OG. If, however, no such coincidence occurs as with the allocation C′B that cuts a step over its horizontal stretch, the domestic production of the corresponding product must be at a scale that is less than the full exogenous demand, and the level of average costs will rise.

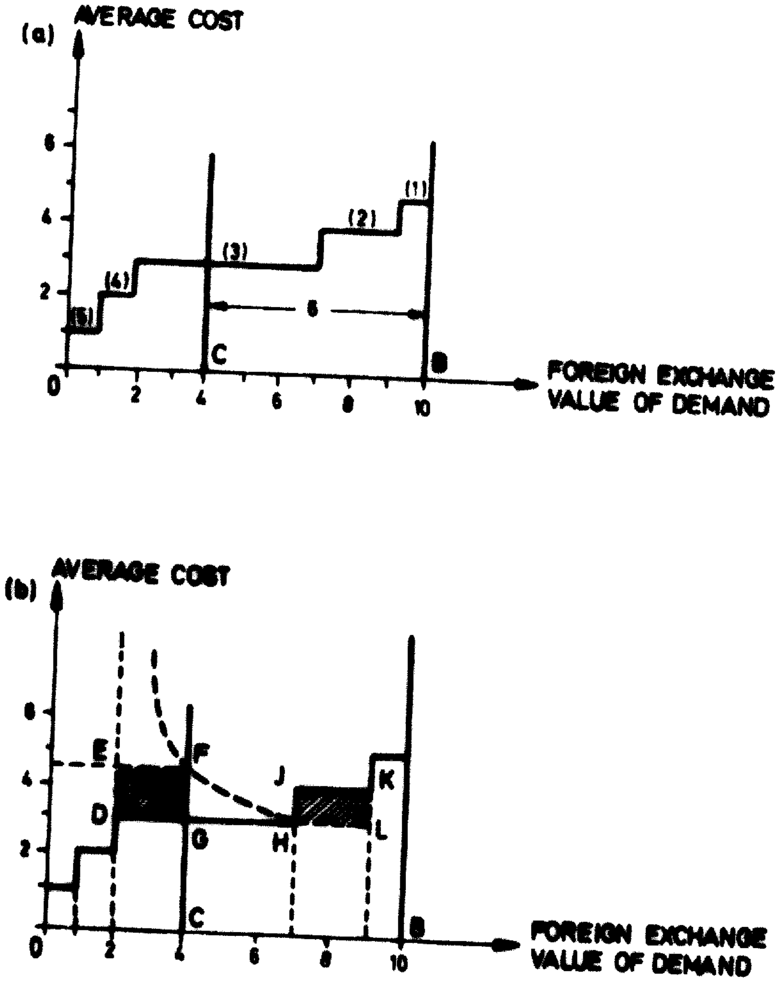

*Figure 21. Approximate and optimal solution to foreign-exchange allocation problem: (a) profile of average costs for branch; (b) comparison of alternate solutions*

The approximation is a good one as long as the production rate of the last domestically produced product is close to the total demand for the product. In fact, the rise of average cost times the actual output of this product provides an upper limit or "bound" on the size of the error which might be committed. Figure 21 is a numerical illustration of the kind of error that can occur. With a foreign-exchange allocation CB of six units, the approximate solution is to produce products (5) and (4) at full scale and product (3) at a reduced scale of two units. If the average cost of product (3) did not increase, the total production cost for the three products (the area under the average-cost profile) would be nine units; with the indicated rise DEFG in figure 21, the total cost is twelve units. Thus, in this case, nine units give a lower bound on the current optimal solution and the twelve units an upper one. The selection of products (5), (4) and (2) for domestic production at full scale shows that the latter solution is not optimal because these products jointly provide just enough domestic production to meet the foreign-exchange limit, and their total production cost is only eleven units, which is the optimal solution. In figure 21 the shaded area DEFG represents the cost increase over the lower bound caused by the rise of average costs at a reduced production scale of product (3). This cost increase of three units is a bound on the possible error. The area HJKL represents the cost increase over the lower bound that occurs when the production of product (2) at full scale is substituted for the production of product (3) at its original average cost, which defines the lower bound. A comparison of HJKL with DEFG shows that the former is only two units; thus the corresponding solution is better than the solution obtained by the approximating procedure.

Figure 21 shows that the role of the foreign-exchange rate as a guide to resource allocation is compromised in both solutions. If the approximation is used, the exchange rate rises to 4.5 units; at this level it directs the inclusion of product (2) in domestic production. If the latter is included, the foreign-exchange rate drops to four units, and the production of product (3) is discontinued. However, at this exchange rate, the production of product (3) at its full scale (average cost = 3) appears attractive. In a decentralized, decision-making situation, the production will be continued even though this leaves a large foreign-exchange slack and raises total production costs to eighteen units. Specific quantitative controls must be introduced in both solutions. In the approximate solution, it is necessary to restrict the production scale of product (3) to two units; there is no production of product (4). In the optimal solution, product (3) should not be produced at all. None the less, the exchange rate still offers a valid guide for products (1), (2) and (5). If the problem was enlarged by extending the cost profile upward and downward by a number of additional steps, the exchange rate could reliably control the majority of decisions with the exception of products (3) or (4), which would still require quantitative controls.

To determine the effect of intermediate inputs of listed products into each other requires knowledge of the choice between domestic production and imports at a given foreign-exchange rate. The problems are how to price intermediate inputs and how to determine the market expansion for a given product due to intermediate sales. Inputs of other listed products into a given listed product can be accounted for at import prices. The procedure places an upper limit on production costs, since in the programming models no product will be produced domestically at cost levels that exceed import prices. The cost comparison can be made at the level of exogenous demand, which cannot be lower than the level of total (including intermediate) demand. Under these conditions any product showing a cost advantage for domestic production will certainly be domestically produced.

Table 12 illustrates these principles. The model in this table is organized in accordance with model 1 except for the omission of the extrapolated products. The maximum production scale for each domestic production activity is assumed to be lower than 100; thus $f_{kj}$ is 100 for all products. In the approximation computations, however, $f_{kj}$ is always equal to the actual production scale, which equals the known or estimated demand. Thus average cost is $\bar{k}/d$, where $d$ is initially the exogenous demand. The values of all intermediate inputs are given at import prices. Under these conditions, only production activity (2) attains a domestic production-cost estimate that is below import cost; namely, 4.07 as compared with 5. Thus product (2) will be domestically produced.

Products that fail to meet the above test can still meet the import-cost line if either their average variable costs are sufficiently reduced by accounting for intermediate inputs at lower domestic production costs rather than at import costs, or if their seriality is sufficiently increased by selling to other production lines. The adjustments can be performed in combination in several steps until no further improvement is possible by the technique. In table 12 there are two adjustment steps. In table 12B intermediate inputs are re-priced to allow for a decrease of the cost of product (2) from 5 to 4.07 units, which reduces the production cost of product (1) to a cost that is lower than the import price of the product; namely 3.47 as compared with 3.50. The production cost of product (4) also is reduced but not sufficiently to meet the import-price line. In the next step, the intermediate input requirements of both products (1) and (2) are added to exogenous demands, and intermediate inputs are valued at their domestic production costs. The result is that the estimates of production costs for products (3) and (4) decrease, but since neither product meets the import-cost line, the adjustment process ends.

Nevertheless, this is not necessarily the final solution, for several products in combination may provide an advantage for domestic production. This occurs when the intermediate markets permit the expansion of production sufficiently to reduce the costs of the intermediate inputs below the import prices and, at the same time, owing to the cost savings achieved by using lower-cost intermediate inputs, to reduce the prices of the resulting products below the import prices (a condition for the

## TABLE 12. A NUMERICAL ILLUSTRATION WITH INTERMEDIATE INPUTS

| | *Domestic production* | | | | | | | | *Import* | | | | *Exogenous demands* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Variable cost* | | | | *Fixed cost* | | | | | | | | |
| 1 Balance for listed products (1) | 1 | | —0.2 | | | | | | 1 | | | | —17.2 |
| 2 Balance for listed products (2) | —0.2 | 1 | | —0.1 | | | | | | 1 | | | —13.0 |
| 3 Balance for listed products (3) | | —0.2 | 1 | —0.1 | | | | | | | 1 | | — 5.8 |
| 4 Balance for listed products (4) | —0.2 | —0.2 | | 1 | | | | | | | | 1 | —31.8 |
| 5 Balance for foreign exchange | | | | | | | | | —3.5 | —4 | —5 | —2.5 | |
| 6 Balance for money costs | —1 | —2 | —2 | —1.5 | —20 | —10 | —15 | —10 | | | | | |
| 7 Fixed-cost tie-in constraint (1) | $-\frac{1}{100}$ | | | | 1 | | | | | | | | |
| 8 Fixed-cost tie-in constraint (2) | | $-\frac{1}{100}$ | | | | 1 | | | | | | | |
| 9 Fixed-cost tie-in constraint (3) | | | $-\frac{1}{100}$ | | | | 1 | | | | | | |
| 10 Fixed-cost tie-in constraint (4) | | | | $-\frac{1}{100}$ | | | | 1 | | | | | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |

*A. Exogenous demand, import prices*

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| $m$ | 3.50 | 5.00 | 4.00 | 2.50 |
| $\bar{k}/d$ | 1.16 | 0.77 | 2.58 | 0.31 |
| $k$ | 1.00 | 2.00 | 2.00 | 1.50 |
| 1 | — | — | 0.70 | — |
| 2 | 1.00 | — | — | 0.50 |
| 3 | — | 0.80 | — | 0.40 |
| 4 | 0.50 | 0.50 | — | — |
| | 3.66 | 4.07 | 5.28 | 2.71 |

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| Demand, estimated | 17.2 | 13.0 | 5.8 | 31.8 |
| Production, gross | — | — | — | — |

*B. Exogenous demand; adjust prices to production of listed product (2)*

| | | | | |
|---|---|---|---|---|
| $m$ or $p$ | 3.50 | 4.07 | 4.00 | 2.50 |
| $k/d$ | 1.16 | 0.77 | 2.58 | 0.31 |
| $k$ | 1.00 | 2.00 | 2.00 | 1.50 |
| 1 | — | — | 0.70 | — |
| 2 | 0.81 | — | — | 0.41 |
| 3 | — | 0.80 | — | 0.40 |
| 4 | 0.50 | 0.50 | — | — |
| | 3.47 | 4.07 | 5.28 | 2.62 |

| | | | | |
|---|---|---|---|---|
| Demand, estimated | 17.2 | 13.0 | 5.8 | 31.8 |
| Production, gross | — | — | — | — |

*C. Add to exogenous intermediate inputs of products (1) and (2); adjust*

$m$ or $p$ 3.47 4.07

*C. Add to exogenous intermediate inputs of products (1) and (2); adjust prices to production of products (1) and (2)*

| | | | | |
|---|---|---|---|---|
| *m* or *p* | 3.47 | 4.07 | 4.00 | 2.50 |
| $\bar{k}/d$ | 1.16 | 0.61 | 1.79 | 0.26 |
| *k* | 1.00 | 2.00 | 2.00 | 1.50 |
| **1** | — | — | 0.69 | — |
| **2** | 0.81 | — | — | 0.41 |
| **3** | — | 0.80 | — | 0.40 |
| **4** | 0.50 | 0.50 | — | — |
| | **3.47** | **3.91** | **4.48** | **2.57** |

| | | | | |
|---|---|---|---|---|
| **Demand, estimated** ................ | 17.2 | 16.4 | 8.4 | 37.8 |
| **Production, gross** ................ | 17.2 | 16.4 | — | — |

*D. Simultaneous final solution: full production scales for all products*

| | | | | |
|---|---|---|---|---|
| **p** | 3.24 | 3.72 | 3.72 | 2.49 |
| $\bar{k}/d$ | 1.00 | 0.48 | 1.07 | 0.25 |
| **k** | 1.00 | 2.00 | 2.00 | 1.50 |
| **1** | — | — | 0.65 | — |
| **2** | 0.74 | — | — | 0.37 |
| **3** | — | 0.74 | — | 0.37 |
| **4** | 0.50 | 0.50 | — | — |
| | **3.24** | **3.72** | **3.72** | **2.49** |

| | | | | |
|---|---|---|---|---|
| **Demand, total** ................ | 20 | 21 | 14 | 40 |
| **Production, gross** ................ | 20 | 21 | 14 | 40 |

***Notes:*** The format of model 1 is used, except for the omission of extrapolated products. There are four domestic-production activities; each is complemented by a corresponding fixed-cost activity and four import activities. Exogenous demands of the listed products are given in column 13. Balances are provided for each listed product, foreign exchange and money cost; tie-in constraints connect each production (variable-cost) activity with the corresponding fixed-cost activity. The usual $f_{kj}$ coefficients in the tie-in constraints are 100 for every product. The objective is to minimize the sum of money costs and foreign-exchange costs where, for the sake of simplicity, the foreign-exchange rate is set at unity. Thus rows 5 and 6 can simply be merged into a single objective-function row.

In table 12.A, the demand for each product is the exogenous demand, and its price is the import price. Average fixed costs ($\bar{k}/d$) for each product are calculated by dividing fixed cost by exogenous demand. The symbol *k* represents variable money costs, and rows 1 to 4 represent costs of intermediate listed-product inputs; each is accounted for at its import price. The sum of production costs is then compared to the import price; for example, for product (2) the production cost is 4.07 and the import price 5.0; thus it is immediately selected for domestic production, while the other products are not.

In table 12.B, the price of product (2) is dropped to 4.07, while demands are regarded as unchanged (for the moment). Product (1) now also shows an advantage of production.

In table 12.C, allowance is made for the expansion of production due to intermediate demands and for price reductions. The calculation of total production scales and of prices of domestically produced commodities generally requires a simultaneous solution for the latter, but the input-output structure here is simple enough to permit a step-by-step derivation. Products (3) and (4) are still cheaper to import.

In table 12.D, the results of the optimal solution are given. To obtain this solution, it is necessary to assume that the simultaneous production of products (3) and (4), in addition to products (1) and (2), will make production of both (3) and (4) preferable to imports. This is confirmed by the calculations.

creation of the postulated intermediate markets). Unless the interrelations between products are sparse, the number of possible combinations will be too large for consideration without formal integer programming techniques. The programming problem can be greatly furthered through a preliminary selection of obvious domestic production possibilities. The corresponding import activities can then be eliminated and the fixed costs of domestic production made exogenous in the tie-in constraints to reduce the number of integer variables. In the problem presented in table 12, after the decision that products (1) and (2) will be domestically produced, the only remaining combination is the simultaneous production of products (3) and (4), since the third step of calculations excludes both of these from being added singly. Table 12D shows the results of a simultaneous solution for the domestic production of all four listed products. The resulting domestic production cost for each product is now below the import price.[105]

One feature of the computations calls attention to the nature of pricing in the presence of fixed costs. The obvious procedure of adding average fixed costs to variable production costs for each production activity has been followed. However, it is not necessarily in formal accord with the specification of the model in linear programming format. In the latter format (see model 1) the fraction $1/f_{kj}$ of fixed costs is added to the variable costs;[106] this equals the average fixed cost only if the solution value of the scale $x$ of the corresponding variable-cost activity coincides with the pre-set value of the parameter $f_{kj}$. Such a coincidence can be achieved by hindsight if the $f_{kj}$ parameters (all of which are 100 in table 12) are re-set to 20, 21, 14 and 40, respectively, which are the production scales in the simultaneous solution. If this is not done and the model is solved by integer programming with the original $f_{kj}$ parameters, the production scales will be the same and all fixed costs will be incurred as required, but the quite different price solution will not have the simple resource-allocating functions ascribed to prices in linear (and generally, in convex) models.[107]

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[105] A similar numerical model of fixed-cost interaction in the iron and steel industry based on Latin-American data has been discussed in reference [73].

[106] If a product is actually produced, the price-variable calculated for the fixed-cost tie-in row will equal the fixed cost itself; this price will then enter the value balance of the variable-cost activity.

[107] With the $f_{kj}$ parameters re-set by hindsight, the linear programming model will achieve an optimal solution in which all fixed-cost incurrence activities appear with integer (unit) scales without any special mathematical devices to exclude fractional values. Otherwise fractional solutions must be progressively eliminated by introducing new constraints (see reference [49], chapter 26). Each new constraint introduces a new price variable into the solution; these variables are ambiguous from the point of view of resource allocation. [74]

The following question now arises: Is it possible or useful to recur to the simple analysis of the production-cost for a branch (as shown in figure 20) in the presence of intermediate inputs? The practical answer depends on the degree of interconnexion between the products. In the metalworking sector, the interconnexions are known to be very few. The majority of metalworking products are not required in the production of most other metalworking products, with a few specific exceptions. Semi-fabricates thus form a chain in which the linkage is highly specific, and there are only a few branchings; for example, a certain clutch assembly may be used in more than one machine, but it will not be used in all the other thousands of metalworking products. Some products are much more widely used, such as nuts, bolts, bearings and electric motors. Their wide distribution is advantageous; their requirements can be related to aggregate levels of branches in the sector rather than relating them individually to specific products. Thus the input requirements of many metalworking products can be costed out on the basis of reasonable preliminary guesses about the choice between production and imports which can be confirmed or corrected in a second step of calculations.

The method of constructing a production-cost profile for each branch is thus a highly useful pragmatic approximation that can relieve the formal programming models from a large part of the detailed solution. There will be only comparatively few cases in which large interactions between specific products will be sufficiently evident to suggest the need for a simultaneous solution; these parts of the total problem can be relegated to solution by formal integer programming models. After an import-production choice has been effected by the latter means, the production-cost profile of each branch can still be traced for purposes of foreign-exchange allocation (if required) or for a branch-by-branch consideration of extrapolated products.

## 6. SPECIFICATION OF PROGRAMMING MODELS

### *Extrapolated products*

The extrapolated products of a branch are shown in figure 20. An appropriately high foreign-exchange rate (or low foreign-exchange allocation) will push import substitution in the branch beyond the individually listed products and will cut into the extrapolated range AB. If (and this is the crucial point) the trend of domestic production costs per unit of import value for the extrapolated range is known, it is immediately possible to identify the desirable extent of import substitution AD; moreover, if there is a foreign-exchange allocation (rather than a fixed rate) the now variable foreign-exchange rate can be determined.

Inclusion of the continuous cost trend represented by the curve JFK in the models would transform them into non-linear programming models. There are several convenient methods for their solution (provided they are still convex as in the present case). For purposes of presentation (and often for computational purposes as well) it is just as satisfactory to approximate the curve JFK by a step function (not shown). The closeness of the fit can be adjusted to the requirements of precision imposed on the model. In model 1, the approximation involves just four steps. Formally, the cost profile for the branch is then transformed into a step function along its entire length: the steps, however, have a different meaning in the listed-product range than in the extrapolated range. In the latter they play the role of "virtual" products whose number, cost level and step length ("demand") can be adjusted to the requirements of an acceptable fit: in the former, they are specific individual products with given levels of demand.

How may the extrapolated part of the cost profile JFK be derived? It will be possible to list individually those products in a branch that are predominant in production or imports. A sharp asymmetry is assumed in the frequency distribution of the individual products; if a branch contains 5,000 products, the first 100 (or 2 per cent) of the products might represent 60 to 70 per cent of the total demand. The total demand is expressed at import values in the form of total foreign-exchange requirements in figure 20. If the first 200 individual products are listed, they might cover some 85 to 90 per cent of the demand in the branch.[108]

The cost trend of the listed products is assumed to be rising for two fundamental reasons. First, as additional specialized products are considered for production, their seriality will be correspondingly lower, thereby raising their domestic production costs per unit of physical output (per ton). Nevertheless, this by itself would not be sufficient to give a rising cost trend (as plotted) per unit of import value if import prices per ton also rose correspondingly. It is, however, a reasonable supposition that import prices will not rise to the same extent, for in most developing countries the domestic demand for each product will be considerably less than the output of typical units that produce for the world market. Thus, while there is a seriality decrease both in the domestic market and in the world market, the decrease is likely to be sharper in the domestic market; only the largest industrialized countries are exempt from this generalization. Second, as a product becomes more specialized and sophisticated, it embodies a larger proportion of higher-grade technical production skills. They are assumed to be proportionately higher priced in a developing country than in the industrial areas that serve the world market. For both of these reasons domestic production costs can be expected to rise more sharply than import prices, and thus the cost profile of a branch plotted on the basis of unit import value will

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[108] A pilot study [69] has confirmed this demand for the electric-motor branch.

rise. The regularity of this rise can be assured by ordering products in the proper sequence.

The previous considerations apply to listed and extrapolated products. If the most frequent and highest-value products are listed individually and ordered according to increasing production costs per unit of import value, there is good reason to expect that the remaining products which are not listed will cost more to produce and will continue approximately the trend observed to the left of point J on the cost profile. (This can, of course, be subjected to empirical testing in a number of individual cases.)[109] It is more difficult to anticipate the change of the trend at other points in the extrapolated range. In figure 20 the trend turns upwards sharply as 100 per cent import substitution is approached. The tendency is based on the common-sense consideration that 100 per cent import substitution in one of the smaller African or Latin American countries would involve the production of items, such as jet aircraft, whose cost would certainly be ridiculous. In any given instance it should be possible to arrive at a reasonable estimate of the order of magnitude of production costs for groups or classes of products in the extrapolated range by relying on the combined judgement of economists, planners, enterprise managers and other persons familiar with the local economy and in close contact with current operations of the metalworking sector. While this admittedly brings planning for the branch back into the realm of judgement and intuition (from which formal planning techniques were to rescue it), the range of exclusive reliance on this art is limited decisively; there is an improved basis for judgement and intuition. In any event, the break-off point appears in many branches before the extrapolated range is entered; in those branches where this is not the case an effort can be made to expand progressively the list of individually listed items until the amount of extrapolation is reduced or eliminated.

In both models 1 and 2, the activities associated with the step function of extrapolated products are not tied to any fixed-cost activity. Of course, this does not imply that extrapolated products have no fixed costs; on the contrary, high domestic production costs for individual items often depend on high fixed costs in relation to the length of the potential production run. However, in the section JFK of the cost profile, each item contributes only a vanishingly short cost step of its own, over which (as in the range 0A) production costs per unit import value are assumed to remain constant with unit fixed costs at the level determined by total demand for the item. The decision is whether to produce the item at the full scale of its available demand or not to produce it at all. Because of the very short step associated with each item (not with the approximating step function), less-than-full-scale production

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[109] A similar trend for capital requirements in a branch has been postulated in a model [29] based on Italian data.

(as in the range 0A) need not be considered. Thus fixed costs are merged with variable costs over the entire stretch JFK; when this stretch is approximated by a rough step function, the approximating steps no longer require fixed-cost tie-ins.

In model 3 the balancing of limited resource-element capacities makes it necessary to estimate resource-element use by the extrapolated products. The same problem occurs in model 2, but there it can be treated by assigning a direct money cost to resource-element capacity use, since by assumption such capacity can be provided in the model in any fractional amount. This is not the case in model 3, where the demand for certain capacities generated in the extrapolated range of a number of branches, if ignored, might seriously affect the resource-element capacity balances. All of the problems that have been mentioned in connexion with the extrapolation of money costs will be present to an even greater extent when requirements for individual resource-element capacities and direct material inputs are extrapolated. It is probably best to omit this problem in deriving a tentative solution, which will then call attention to the resource-element capacities for which an accurate estimate is essential. In a second step, maximum effort can be concentrated on improving the accuracy of the corresponding estimates, and a new solution will accordingly incorporate an allowance for the capacities used by extrapolated products.

### *Organizational resource elements*

A very important oversimplification in all three models is the omission of organizational resource elements. They include engineers, technicians, administrators and market specialists that perform the engineering, design, marketing, research and development, planning and administrative functions in individual enterprises and branches of the sector, or in the sector as a whole. The exact location of some of the functions is somewhat ambiguous. In every country, even in those with the strongest commitment to a market economy, there are important research functions that are supported by resources in the public domain that benefit many industrial enterprises. For example, in the United States, the Bureau of Mines of the Department of the Interior is engaged in industrial research and development work. Many kinds of public support are channelled to the universities, which are prime sources of fundamental technological advances. Many of the above functions, on the other hand, are located in individual enterprises.

A group of skilled technicians must form a "critical mass" of a certain size and diversity before the functions can be properly discharged. For example, the production of agricultural machinery demands technical competence in the operation of a variety of productive processes, adequate research and design skills and contact with markets and sales channels. There is some flexibility in the requirements; for example, design skills can be replaced by reliance on the licensed production of foreign designs, and the group of skills as a whole can be scaled down if aspirations toward meeting world market standards are lowered to simple import-substitution goals. The size of the group, however, is more or less independent of output up to a fairly large total volume and cannot be scaled down in proportion to reduced output needs: hence the concept of critical mass is derived.

The simplest way of including these functions in the model is to treat them analogously to resource elements that serve specified groups of production activities. Thus a unique organizational resource element may be associated with each branch so that every activity of the branch draws on the capacity of the resource element. The critical-mass aspect can be readily represented by providing for large fixed-resource components tied to the capacity-maintenance activities for the resource elements. This still allows for an arbitrary marginal cost for maintaining larger capacity and permits a cut-off at some maximum capacity in the same way as with physical processing capacities.

Rows 8 and 9 of model 3 can be re-interpreted as organizational resource elements associated with the two branches. If row 8 represents the organizational resource element associated with the first branch, then the entries in row 8 between columns 12 and 22 are dropped; analogously, if row 9 is associated with the second branch, entries in row 9 between columns 1 and 11 are dropped. Direct material inputs now become irrelevant, and all entries in row 10 are likewise dropped. (It is now assumed that there are no scarce physical-processing resource-element capacities. In a practical model, of course, the organizational resource elements would be added to the model rather than replacing existing physical-processing resource elements.) Columns 25 and 26 represent the fixed resource inputs. Among them, capital will now play a more subordinate role (associated with such items as typewriters or computers), and the principal entries will be new coefficients in more detailed labour-classification rows (at present there are only two classes of labour in rows 11 and 12). The fixed labour resources represent the critical-mass aspect. In an extreme example, where a technical group of a given size with no expansion at all can service any volume of production in the branch up to a stated limit $g$, all resource-requirement coefficients in columns 23 and 24 (the variable-cost activities for capacity maintenance) would be zero in the resource rows 11 to 15. In a less extreme illustration it may be assumed that there will be some expansion of the technical group with the volume of production in the branch; thus the same coefficients are somewhat larger than zero. In both cases $g_j$ represents the capacity limit of the technical group serving branch $j$: beyond this limit the technical group must be duplicated rather than being further expanded. All of these aspects are simple extensions of the behaviour of ordinary physical-processing resource elements.

It is not necessary to tie technical groups to individual branches. Some may be tied to groupings less comprehensive than a branch; others may connect several branches. The principles involved are not affected by these pragmatic variations.

### *Discontinuity and feedback in the models*

A crucial programming principle concerns economies of scale and indivisibilities. It is the principle of minimum unavoidable discontinuity:[110] namely, that no variable in a model or in a programming procedure should be treated as a discontinuous (indivisible, integer) variable unless the estimated error in treating it as a rounded continuous variable exceeds the permissible error limit.

This principle is justified on three grounds. The most obvious, but not necessarily the most important one, is the computing aspect. Integer variables impose disproportionate burdens on computing facilities. It is not difficult to find relatively small problems (with about 50 integer variables) that will run for hundreds of hours on the largest available computers without arriving at a precise optimal solution. Since most of the data included in programming models as parameters are subject to considerable errors of their own, it is senseless to expect solutions in integers when solutions that are no worse in terms of over-all reliability can be arrived at with greatly reduced effort.

The second and more fundamental reason is connected to price mechanism and decentralization. Forced integer solutions (in which certain variables are forced by special mathematical devices to assume integer values) generally ruin the simple resource-allocating functions of a price system. Even after such solutions are obtained, it is not possible to define prices that will effectively decentralize all detailed decisions without relying on specific quantitative controls that will limit the options open to the decision units. The more variables can be treated as continuous, the fewer will be the instances in which quantitative controls must play a key role.

The final reason is related to the specification of programming models and follows from the discussion of the role of prices in the models. It has become clear while discussing the detailed operation of the models that many aspects of reality can best be approximated by trial-and-error solutions. There are many feedbacks between the variables and the parameters of the models that could be made endogenous (modelled explicitly) only at the cost of introducing intolerable complications into the models that would make them almost impossible to compute and

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[110] Such a principle is implicit in reference [52].

very difficult to understand. Many practical planners prefer to use models that can be understood from a common-sense basis. The trial-and-error approaches depend on preliminary guesses concerning the solutions of the models. The guesses which are built into the specifications of the models prior to the solution almost always involve prices. It is of the greatest importance to safeguard (in so far as possible) the role of prices in the model, even when there is added error, rather than to disorganize the simple resource-allocating functions of a price system by insisting on precise combinatorial solutions.

The principle is translated into practice by treating as many as possible fixed-cost incurrence scales as continuous variables. In regard to the production of listed products, the effect of the procedure is to reduce average costs to level steps, such as those shown in the cost profile of figure 20, which distribute fixed costs over the largest estimated production scales. The procedure permits the required capacity of resource elements to be provided as well as skilled technical groups that can be treated as "organizational" resource elements. Thus, early in the practical definition of the models, trial solutions should approximately segregate the fixed costs that will be treated as continuously divisible variables from those for which this would result in excessive error. As error estimates are possible only for the model as a whole, this must be done largely on a common-sense, pragmatic basis by comparing solutions that are optimized in the presence of insufficient restrictions,[111] (and thus contain fractional values for inherently integer variables) with other solutions that observe all constraints including those of integrality but that are not necessarily fully optimal.[112] The difference between the bounds is an estimate of the over-all error. No recognized method exists for estimating errors due to individual variables that are treated as continuous even though they are inherently of the integer kind; thus the reduction of the over-all error to tolerable limits by a skilful selection of those variables that are actually treated as integer variables involves a considerable exercise of judgement and skill. The derivation of the multiplicity of trial solutions involved in such a procedure is greatly aided by a high-speed computer.

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[111] Technically, such solutions are termed as "dual-feasible". Linear programming solutions to integer programming models are always of this kind, as are solutions obtained by certain integer programming algorithms (the Gomory cutting-plane or all-integer methods) [75] when these algorithms are interrupted before they reach the optimal solution. Since the latter converge rapidly near the optimal solution and slow down more and more the closer they get to it, they are particularly well suited to refining the bound on the possible error.

[112] Rounded fractional solutions are always of this kind. There are also other algorithms for identifying near-optimal solutions, for example, steepest-ascent methods modelled on convex programming, "branch-and-bound" methods based on a clever narrowing of potential combinations and others [76].

### *The resource-element definition and the semiquantitative stage*

Thus far, the machine park and other characteristics of each resource element have been assumed to be exogenously given. However, the selection of the proper resource elements according to the development of a given country is a key aspect of the planning of the metalworking sector and should therefore be an integral part of the programming process.

The detailed specification of resource elements connects the programming models to the earlier semiquantitative stage that served as preliminary orientation with regard to advantageous new lines of production and new productive facilities in the sector. [69] The task of specifying resource elements requires precise representations of the more general and comprehensive categories of processing facilities (resources) with which the semiquantitative stage is concerned. In particular, it is necessary to specify the weight and seriality ranges of workpieces that a resource element can handle, the typical assortments of output that it can produce and the features of local adaptation, such as the degree of mechanization, which depend on the comparative prices of labour and capital. Moreover, the machine park and the material, labour and other flow input requirements of each resource element must be specified.

At the semiquantitative stage, programming data are developed which associate individual listed products with inputs of intermediate commodities (subassemblies and components) and with the requirements of processing facilities stated in terms of the resources mentioned above. The available reserve capacities of the latter resources are then surveyed for a country, and clusters of promising new lines of production are selected by matching the reserve capacities of resources against the processing requirements of various products. If the capacities of proposed new facilities are added to the existing reserve capacities, then the resulting clusters of products, whose production becomes advantageous with the investment in new facilities, can be used to judge the kind of capacity expansion that is likely to be of the greatest over-all benefit from the point of view of the sector of the economy. As some of the most immediately useful empirical information concerning the metalworking sector is now available at the semiquantitative level, it is essential to connect the model-building stage to the preceding semiquantitative stage.

Each resource (casting, forging, heat treatment and the like) of the semiquantitative stage will generally give rise to several resource elements in the model-building stage. Each corresponding resource element will be adjusted to some range of each key processing parameter (usually the weight of the workpiece and seriality). Given these ranges, it is still necessary to specify the degree of mechanization and the typical output assortment of a resource element before it is possible to proceed with its engineering design and with the specification of its machine park. Since many partially overlapping ranges of the key parameters are possible with many degrees of mechanization and many kinds of product assortments, it is clear that there could be dozens, hundreds or perhaps even thousands of meaningful variants of resource elements associated with a given semiquantitative resource. If it is desired to keep the number of resource elements within reason, say to a total of perhaps 100 to 150, then only a few major categories of resource elements can be associated with each resource, and the other variants must be suppressed. The question is how to perform this selection most effectively without prejudging the entire development of the sector.

To illustrate the problems involved, consider a cluster of products that have emerged from the semiquantitative stage as promising candidates for further consideration. Assume that the addition of medium-heavy forging capacity for handling low to medium seriality of output to the existing light forging capacity would permit the domestic manufacture of products in this cluster. At the semiquantitative stage, however, these preliminary indications have not been translated into quantitative cost estimates, and the precise interrelations between various products and capacities have not yet been explored.

One of the first tasks in model building is the specification of the kinds of resource elements that will appear in the model. Thus the immediate question is how to proceed from the resources of the semiquantitative stage to the required resource elements, since the choice of resource elements may prejudge issues related to the degree of capital/labour intensity, local adaptation and the possibilities of being abreast of technological change. Even if the kind of resource can be approximately characterized by weight class, seriality and product assortment, the precise machine park included in its design will still depend on the most frequently encountered product weights, the most characteristic lengths of production runs and the nature of the particular products on which price pressure is strongest and for which top efficiency in production is most essential.

The problems of resource-element specification are illustrated in table 13. The candidate products suggested by the semiquantitative stage are represented here by just four items (A, 75 kg; B, 120 kg; C, 200 kg; and D, 350 kg). Although this is an exceedingly small number as compared with the dozens or even hundreds that might be contained in typical clusters, it will suffice to demonstrate several points. Among the various criteria of resource-element specification, the weight range of products handled by the "medium-heavy forge" has been singled out for attention. It is assumed that, when this is the sole criterion, there is a choice of three variant resource-element designs. Each has a specified machine park and flow-input pattern labelled RES1 ... RES3. The corresponding assumed weight ranges of output are 50 to 250 kg, 75 to 350 kg and 100 to 500 kg. The illustrative example contains all three variants in a simplified model patterned on model 3. It postulates that the alternative variants of resource elements are included side by side in a model of the usual kind. It is emphasized at the outset that this is not intended as the suggested operational approach to the problem; if it were, the models would grow in practice to a size that would deprive them of all usefulness. The purpose of the example is precisely to point out some available short-cuts.

The model in table 13A has been greatly simplified by including only variable capacity inputs for listed products; moreover, variable costs for the resource element variants are set to zero and thus the latter are characterized by a single fixed cost that yields a specified capacity (in this case 60,000 effective machine hours per year for each of the three variant-resource elements). As usual these appear in the denominator of a fraction in the tie-in constraints (rows 9 to 11) connecting the fixed-cost and variable-cost activities for each variant-resource element. Fixed costs are given in millions of dollars. Since the cluster of products contains candidates for domestic production, imports are omitted. The model is written with two alternative exogenous demands in columns 17A and 17B. Only one of these demands may be used in deriving a particular programme; the scale of the other must be set to zero.

The scales of activities RFX1 ... RFX3 (columns 14 to 16) are integer variables. The objective is the minimization of total dollar costs, which in this case consists entirely of fixed costs (row 5).

In table 13 B, the numerical example is dominated by the very large demand for product B in both exogenous demand structures.[113] Working with the exogenous demand structure A, the 20,000 units of demand for product B can be translated into individual variant resource-element requirements which are calculated as 400,000, 300,000 and 60,000 hours respectively or (in fractions of total capacity) as 6.667, 5.000 and 1.000. Thus it would take 6.667 variant 1 resource elements to produce product B, 5 variant 2 resource elements or just one variant 3 resource element. Comparing fixed costs, the total for resource-element variant 1 would be (6.667) (1.0) if fractional facilities could be built; in reality, however, the next larger integer number would have to be installed, that is, 7. Owing to the simplicity of interrelations in the model, similar calculations can be performed for each product resource-element variant combination independently of all the others. These are summarized both for the fractional solutions that assume the resource-element variant scales to be continuously variable and for the rounded solutions in table 13C.

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[113] The demand for product B can be said to be large because the input requirements of product B are of the same order as those of the other products; thus the large number describing the extent of demand is not counteracted by an unusually small product size (or value).

## TABLE 13

### A. *Resource element definition*[a]

| | *Listed product* | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *A (75 kg)* | | *B (120 kg)* | | | *C (200 kg)* | | | *D (350 kg)* | | *RES1* | *RES2* | *RES3* | *RFX1* | *RFX2* | *RFX3* | *EXOG.A* | *EXOG.B* |
| 1 A (75 kg) | 1 | 1 | | | | | | | | | | | | | | | | |
| 2 B (120 kg) | | | 1 | 1 | 1 | | | | | | | | | | | | 1,000 | 10,000 |
| 3 C (200 kg) | | | | | | 1 | 1 | 1 | | | | | | | | | 20,000 | 200,000 |
| 4 D (350 kg) | | | | | | | | | 1 | 1 | | | | | | | 3,000 | 30,000 |
| | | | | | | | | | | | | | | | | | 200 | 2,000 |
| 5 Million dollars | | | | | | | | | | | | | | —1 | —1.5 | —4 | | |
| 6 RES1 (50—250 kg) | —15 | | —20 | | | —25 | | | | | 1 | | | | | | | |
| 7 RES2 (75—350 kg) | | —10 | | —15 | | | —20 | | —25 | | | 1 | | | | | | |
| 8 RES3 (100—500 kg) | | | | | —3 | | | —5 | | —7.5 | | | 1 | | | | | |
| 9 RFX1 | | | | | | | | | | | $-\frac{1}{60,000}$ | | | 1 | | | | |
| 10 RFX2 | | | | | | | | | | | | $-\frac{1}{60,000}$ | | | 1 | | | |
| 11 RFX3 | | | | | | | | | | | | | $-\frac{1}{60,000}$ | | | 1 | | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17A | 17B |

### TABLE 13 (*continued*)

### B. *Continuous solutions*

| *Product* | *Plant* | *Exogenous A* | | | | *Exogenous B* | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | *Hours* | *Scale* | *Cost* | *Cost* | *Hours* | *Scale* | *Cost* | *Cost* |
| A | 1 | 15,000 | 0.250 | 0.250 | | 150,000 | 2.500 | 2.500 | |
| | 2 | 10,000 | 0.167 | 0.250 | 0.250 | 100,000 | 1.667 | 2.500 | 2.500 |
| B | 1 | 400,000 | 6.667 | 6.667 | | 4,000,000 | 66.667 | 66.667 | |
| | 2 | 300,000 | 5.000 | 7.500 | | 3,000,000 | 50.000 | 75.000 | |
| | 3 | 60,000 | 1.000 | 4.000 | 4.000 | 600,000 | 10.000 | 40.000 | 40.000 |
| C | 1 | 75,000 | 1.250 | 1.250 | | 750,000 | 12.500 | 12.500 | |
| | 2 | 60,000 | 1.000 | 1.500 | | 600,000 | 10.000 | 15.000 | |
| | 3 | 15,000 | 0.250 | 1.000 | 1.000 | 150,000 | 2.500 | 10.000 | 10.000 |
| D | 2 | 5,000 | 0.083 | 0.125 | | 50,000 | 0.830 | 1.250 | |
| | 3 | 1,500 | 0.025 | 0.100 | 0.100 | 15,000 | 0.250 | 1.000 | 1.000 |
| | | | | | 5.350 | | | | 53.500 |

### C. *Rounded solutions*

| *Plant* | *Continuous* | *Rounded* | *Cost* | *Continuous* | *Rounded* | *Cost* |
|---|---|---|---|---|---|---|
| 1 | 0.250 | 1 | 1.000 | — | — | — |
| 2 | — | — | — | 1.667[b] | 2 | 3.000 |
| 3 | 1.275 | 2 | 8.000 | 12.750 | 13 | 52.000 |
| | | | 9.000 | | | 55.000 |

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[a] See text for explanation of symbols.

[b] Alternative: # 1 at a scale of 2.50, rounded to 3, same cost.

For exogenous demand structure A, the continuous solution (which is surely an underestimate) is 5.35, while the rounded solution (which may be an overestimate) is 9. Thus the maximum possible error is 3.65 units or 68 per cent of the lower bound. For exogenous demand structure B, the continuous solution (53.5) and the rounded solution (55) together offer a far more favourable error bound of 1.65 units or about 3 per cent of the continuous cost estimate.

The optimal solution for exogenous demand A can be derived simply by enumerating all plant combinations starting with single plants (resource-element variant capacities of unity taken individually) up to three plants (where the sums of resource-element variant capacities are equal to 3). There are three single plants, six double combinations and ten triple combinations. (In table 13 B the optimal solutions are indicated by a check mark.) Each of these can be rapidly checked to verify if the plant or plant combination suffices for servicing the stated exogenous demands of all four products. In this way the combination (1, 2, 3) emerges as the best one with a total fixed cost of 6.5 units,[114] which is substantially below the cost of 9 estimated by rounding off the fractional solution.

Depending on the structure and size of demand, the example demonstrates that one particular resource-element variant among a number of closely related variants can dominate to such an extent that it practically eliminates the other variants from further consideration. The scale of the resource-element variant can be treated as a continuous variable, for any error introduced by so doing will evidently be small. Resource-element variants 1 or 2 can be retained for producing product A, but if these are omitted and product A is eliminated from further consideration, this is probably just as favourable a practical alternative. A final verdict depends on import prices, but at this stage of model specification it appears justified to concentrate on the investigation of the opportunities offered by resource-element variant 3.

The situation is more difficult with exogenous demand structure A. Resource-element variant 3 predominates here because, if it were omitted, the production of product B alone would require a minimum (fractional) fixed cost of 6.667. There are, however, much more advantageous alternatives than sole reliance on this resource-element variant, since the latter would still fail to provide for the production of A and is a high-cost

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[114] Any combination that does not contain resource-element 3 can be immediately excluded, since the other two resource elements require very large capacities for producing product B. This eliminates 9 of the 13 combinations preceding combination (1, 2, 3) where these combinations are ordered in terms of ascending fixed costs. The remaining four are eliminated on almost as simple criteria. Since (1, 2, 3) with a cost of 6.5 proves feasible, subsequent combinations with higher costs need not be tested at all.

alternative. A combination of 3 and 2 appears favourable. It is low in cost (5.5 units) and eliminates the production of A and D, both of which are low in demand; this may be acceptable in practice.[115]

After consideration of the semiquantitative programming results, it is not necessary to use this kind of model in decision-making processes for resource-element specifications. Models similar to model 3, with full allowance for fixed costs for listed products and variable costs in representing the economies of scale of resource-element capacity-maintenance activities and all the other complications discussed earlier, would generally become unworkable if exhaustive variations of all resource elements were included in them: they would become entirely too large; and they would impose an impossible burden of data collection by requiring scores or hundreds of variant resource-element designs with completely specified machine parks and flow inputs. The method clearly leads to a dead end.

The model of table 13 indicates, however, that an approximate approach can be defined to attain reasonably specified resource elements. Some of the features introduced in table 13 for numerical simplification can now be postulated for purposes of approximation. Resource-element variants can thus be characterized approximately by their estimated annual fixed costs and capacities without an exact description of their economies of scale and detailed design and specification of machine parks, input flows and so on. On this basis, individual products can be tested singly to estimate the resource-element variant which would allow their production at the lowest annual charge attributable to processing-capacity maintenance. In this estimate, fixed and variable capacity requirements of products (the coefficients *r* and *c* in model 3) may be merged into appropriate total capacity requirements at the given level of demand. Direct material inputs and inputs of intermediate commodities can be ignored as these typically have little influence on the choice of a resource-element variant. The variable inputs of resource-element capacity-maintenance activities (type RES1) can likewise be ignored, since they reflect not a trade-off of fixed against variable costs in production but of economies of scale in regard to the resource elements.[116] Thus the choice depends on the annual costs of maintaining the fraction of the fixed capacity of the resource element that a product actually requires. This fixed annual cost includes capital charges, labour and indirect material costs attributable to operating the resource element at its full capacity for an entire year.

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[115] The combination (3, 2) is, of course, not a solution to the problem as stated in the model.

[116] If the data permit, the latter economies of scale can, however, be taken into account.

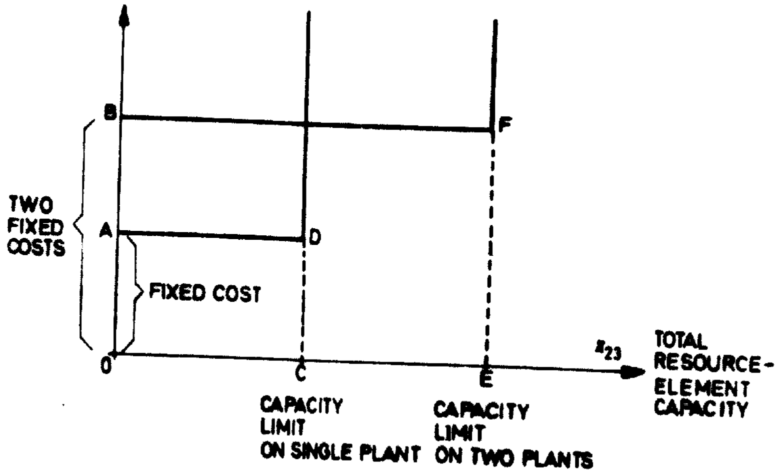

*Figure 22. Resource element with zero variable costs for capacity maintenance*

Figure 22 illustrates zero variable costs in resource-element-capacity maintenance; it corresponds closely to figure 15, except that the supply elasticity for resource-element capacity is assumed to be infinite at the stated fixed level up to the capacity limit, at which point it becomes zero (the supply line rises vertically). The facility can be duplicated; but this implies double fixed costs and double capacity limit. The variable on the horizontal axis is designated as $x_{23}$ by reference to the numbering of activities in model 3; correspondingly, the scale of fixed-cost incurrence is $x_{25}$. It is the variable required to assume integer values in any feasible solution; fractional values appearing in a so-called continuous optimal solution always imply an underestimate of costs.

The approximation is closely analogous to the numerical illustration given in table 13 with the stated assumptions. Thus the testing of individual products against each separate resource-element variant derives its justification from the properties of the illustrative model. As long as there is sufficient demand for multiple facilities, the rounded continuous solutions are likely to be good approximations to the optimal integer solutions, and individual testing is a reliable approximation. If this is not the case, individual testing can lead to a larger error. Even in difficult cases, individual testing can be used to detect and remove the less favourable variants. Then an improved estimate can be obtained from a small preliminary integer programming model, such as shown in table 13, or a very limited number of the most strategic resource-element variants can be included as explicit alternatives in the specification of a major programming model similar to model 3.

If there is a critical shortage of cost data for resource-element variants, the entire procedure described above can be further shortened by matching product demands against ranges of resource-element characteristics. Each resource element can then be defined to centre on the most frequently occurring weight, or seriality; the resource elements must jointly cover the entire range of variation under consideration even if some of these resource elements are eliminated as candidates for investment in the course of programming. This short-cut will not help to decide optimal degrees of mechanization in response to capital/labour price variations and other issues of local adaptation: they are studied as part of the more elaborate preliminary estimates that have been discussed above. If the short-cut is used, they must be decided either on an intuitive basis or by special studies.

The formulation of programming models, such as models 1 to 3, assumes that the resource elements are specified in advance. Their specification connects the programming models with the earlier semiquantitative stage. Resource elements must be defined by detailed weight and seriality ranges, product assortments and other features of local adaptation, such as the degree of mechanization. Specific machine parks and flow inputs further define each resource element. It is necessary to use approximation procedures that either result in the direct specification of the resource elements or at least drastically reduce the number of alternatives. Two simple procedures have been suggested to bridge the gap between the semiquantitative and model-building stages of programming.

## 7. GLOBAL-SECTORAL DECOMPOSITION MODELS

The relationship between sectoral and global programming can be studied analytically through input/output tables, linear programming models and computer simulation. A linear programming framework has been chosen for the present discussion because it is particularly well adapted to an intuitively clear presentation. Dantzig-Wolfe [12] decomposition models indicate the key features of the sectoral-global relationship.

Table 14 presents the parameters and summarizes the key features of a global model with two sectors. Its organization follows the principles of table 11. The distinguishing feature of the model is that the parameters of the two sectors follow a block-diagonal format (rows 3 to 6) except for the presence of two rows (rows 1 and 2) in which both sectors have entries. The connecting rows represent requirements of the primary factors, namely, labour and capital; the remaining rows represent balances of goods that are specific to one of the sectors. The activities of the model are production activities except for the last one which is the exogenous activity.

The model does not represent a generalization; in practice there is not the clear-cut separation of sectoral coefficient into groups as in table 14. The usual structure of input-output models would give an approximately triangular structure rather than the diagonal structure

TABLE 14. A TWO-SECTOR DANTZIG-WOLFE-TYPE DECOMPOSITION MODEL (LINEAR PROGRAMMING)

*Parameters*

| | *Sector 1* | | | | *Sector 2* | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *Product A* | | *Product B* | | *Product C* | | *Product D* | | *Exogenous* | |
| 1 | —1.1 | —1.25 | —0.3 | —2.5 | —1.0 | —2.5 | —0.6 | —3.0 | 350 | Capital requirements |
| 2 | —12.5 | —7.5 | —6.0 | —7.0 | —15.0 | —5.0 | —4.0 | —1.0 | 2,000 | Labour requirements |
| 3 | 1 | 1 | —0.5 | —0.2 | | | | | —50 | Product A balance |
| 4 | | —0.25 | 1 | 1 | | | | | —50 | Product B balance |
| 5 | | | | | 1 | 1 | —0.8 | | —25 | Product C balance |
| 6 | | | | | —0.2 | —0.5 | 1 | 1 | —25 | Product D balance |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | |

*Feasible basic solutions for each sector*

| *Complex* | *Sector* | *Activities and scales* | | | *Labour requirement* | *Capital requirement* |
|---|---|---|---|---|---|---|
| A | 1 | 1,3 | 75.0 | 50.0 | —1,238 | — 98 |
| B | 1 | 2,3 | 85.7 | 71.4 | —1,071 | —129 |
| C | 1 | 1,4 | 60.0 | 50.0 | —1,100 | —191 |
| D | 1 | 2,4 | 63.2 | 65.8 | — 934 | —243 |
| E | 2 | 5,7 | 53.6 | 35.7 | — 946 | — 89 |
| F | 2 | 5,8 | 25.0 | 30.0 | — 705 | —115 |
| G | 2 | 6,8 | 25.0 | 37.5 | — 788 | —138 |
| H | 2 | 6,7 | 75.0 | 62.5 | — 625 | —225 |

of the model. Nonetheless, its simple properties serve as a suitable beginning for later modifications.

Table 14 lists eight different complexes which can be derived from the production activities of the model. The complexes represent different ways of satisfying the final demands of each sector by using the least number of different production activities. The final demands are represented by negative entries in the exogenous column. For example, in sector 1 the final demands for goods A and B are 50 units each. Goods A can be produced by activity 1 or 2 and goods B by activity 3 or 4. Thus there must be at least two activities to satisfy the final demands for the two goods. The choices are 1 and 3 (complex A), 1 and 4 (complex B), 2 and 3 (complex C) and 2 and 4 (complex D). A similar choice can be made in sector 2. Note that while sectoral final demands cannot be satisfied by a single activity, if desired, three or even all four activities of a sector could be used. However, the restriction of each complex to two activities results in the simplest productive structure. Technically, the complexes are referred to as feasible basic solutions to the sectoral subproblems.

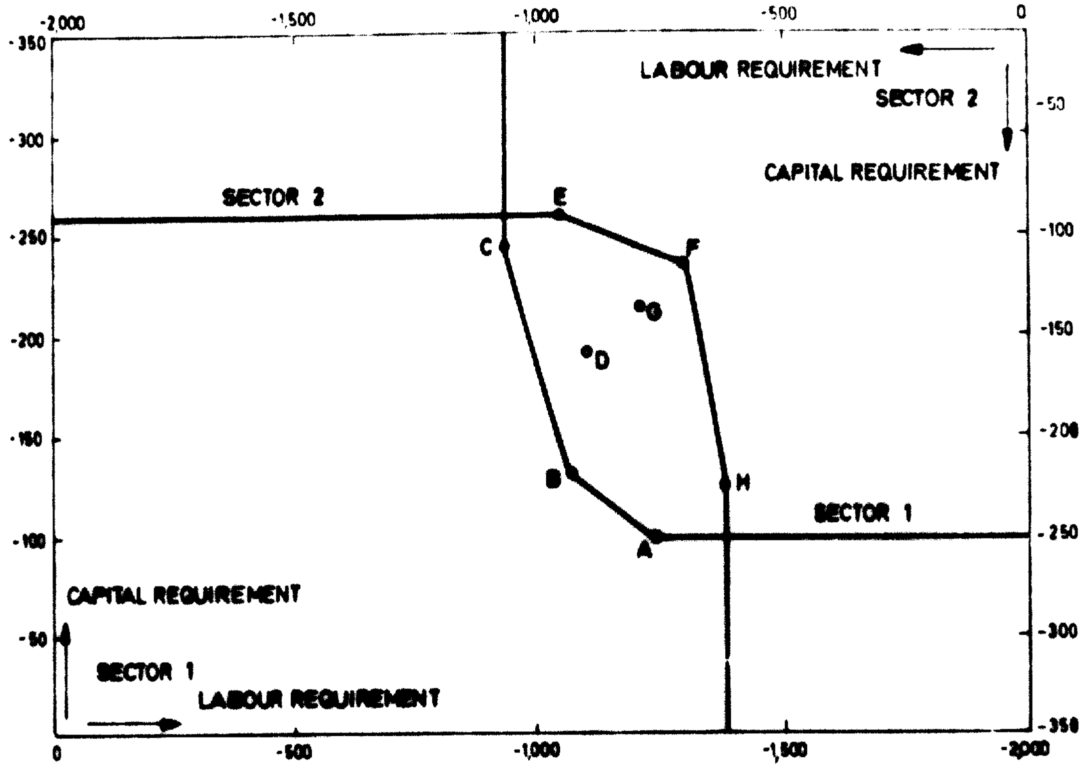

*Figure 23. Interrelation of sectoral isoquants of an Edgeworth-Bowley decomposition model*

Figure 23 has been drawn to scale from the data of table 14. Each complex is drawn as a point representing capital and labour input requirements, but the requirements are measured from the opposite corners of a box. Thus the capital and labour needs of sector 1 are measured for the lower left corner and the corresponding requirements of sector 2 from the upper right corner. This is an Edgeworth-Bowley box diagram in which the dimensions of the box represent the combined availabilities of the two factors in the economy as a whole. It is particularly well suited for studying the allocation of the two factors in the very simple two-sector economy considered here. Clearly, joint allocations of either factor to the two sectors should remain in the limits of total availability.

The complexes are used to define the sectoral isoquants shown in the diagram. These lines connect points representing "efficient complexes". The notion of "efficiency" is best interpreted in terms of its converse. Complexes D and G are inefficient because they use more capital (without saving labour) and/or more labour (without saving capital) than some efficient complex. Thus complex D uses more labour and capital than complex B, and similarly complex G in relation to F. The economic meaning of the connecting line for a given sector is a production structure obtained by a mixture of two complexes with varying weights. Thus the midpoint between B and C is a 50—50 average of complex B and C, while the point three-quarters of the distance from F to H is an average consisting of $\frac{3}{4}$ H and $\frac{1}{4}$ F. The average pertains not only to factor inputs but also to all other characteristics of the complexes. Beyond the complexes, the isoquants are extended horizontally and vertically, e.g. to the right of A. These extensions can be interpreted as signifying factor-disposal activities; thus the extension to the right of A represents the use of complex A, with varying amounts of freely available labour.

The sectoral isoquant is a generalization of the conventional production function to the operations of an entire sector. All points on the isoquant are in a sense equivalent, since they represent the job performance of the sector. In the present case this means meeting sectoral demands as specified by the exogenous activity. In other cases it might mean remaining within specific sectoral supply or capacity limitations (which can also be specified in the exogenous activity). Thus the isoquant is a device for suppressing information with regard to sectoral detail such as precise activity levels while conveying information on two items vital for analysing the global interrelations between sectors, namely, the quantitative requirements (or supplies) of the basic resources connecting the sectors (labour and capital in the present case) and the implied information that all underlying sectoral demand, supply or other specific balances and limitations are met.

Points that are not on the isoquant itself differ sharply in interpretation according to the side of the isoquant on which they appear. Points on the hollow side (above the isoquant of sector 1 and below that of sector 2) are feasible from the technical/economic point of view but are not efficient, since there is always some point on the isoquant that uses less labour and capital. Conversely, the points on the other side of the isoquant are not attainable, since they signify a smaller use of labour and capital than some point on the isoquant that represents the best possible combination.

Global resource allocation can be represented in the diagram by choosing one allocation point for each sector and by checking whether the resulting allocation is both attainable and efficient. For example, if point B is chosen for sector 1 and point F for sector 2, the resulting allocation is efficient at the level of each sector and is globally attainable, since it uses less than the available amount of labour or capital. In order to specify the criterion of global efficiency, an objective function must be selected. In table 14, for example, the top row (capital) of the model can be selected as the objective-function row; the objective then is to maximize the surplus (minimize the use) of capital. In figure 23 this objective can be served by maximizing the vertical separation between sectoral allocation points. Points B and F are clearly not the most efficient combination for this purpose; upon inspection, the combination AF is found to be more efficient. Note, however, that both the combinations BF and AF leave some unused labour. Intuitively it is attractive to attempt full use of labour for greatest efficiency in capital use. For this objective, two precisely vertical points are selected, since the sum of labour allocations will then exhaust the available global supply. When a ruler is passed across the diagram while being held in a vertical position, the largest vertical separation is attained when the line passes through A and cuts the EF segment of sector 2. If minimizing the use of capital is the criterion, the optimal solution is the use of complex A for sector 1 and a weighted average of E and F in sector 2. A similar optimum is found for a different objective function, namely, the minimization of labour; in the latter case the horizontal separation between allocation points is maximized.

The geometric representation given above is intuitively transparent and focuses attention on some of the key conceptual problems that arise in embedding sectoral programming decisions in the context of resource allocation for the economy as a whole. Nevertheless, it drastically limits the number of sectors and the number of connecting resources are restricted to two. Practical programming must rely on a purely algebraic formulation of the model that generalizes to any number of sectors and connecting resources. The Dantzig-Wolfe algorism is such a general, efficient computing device for obtaining rapid, exact solutions. The need for some such computing device is essential as it is generally impossible to proceed by the enumeration of sectoral complexes whose number rises combinatorially with the number of distinct activities in the sectoral subproblems. Thus, the general computational method uses a drastic short-cut and enumerates a few very highly selected sectoral complexes instead of defining sectoral isoquants and relating them to each other.

Sectoral subprogrammes that are used to locate previously unknown sectoral isoquants form the basis for the short-cut. From a beginning with a few complexes (for example, one per sector — there are methods to locate even these starting complexes if they are not initially known), additional complexes accumulate in the course of the calculation. The sectoral isoquants can always be approximated by connecting the already known complexes. Even a single complex will give an approximation of a sectoral isoquant; for example, when only complex B of sector 1 is known, the estimate of the sectoral isoquant is an L-shape with the angle of the L located at B. It is clear that approximations of the isoquant based on omitting some of the complexes will always be entirely on the attainable (technically feasible) side of the correct isoquant; they will thus be composed of feasible but generally inefficient points. The approximation improves as more complexes are identified; eventually, the method locates all complexes needed for defining the correct isoquants in the neighbourhood of the optimum. The short-cut consists in not identifying the overwhelming majority of the complexes in those regions of the correct isoquant that are not required for defining the optimum.

The sectoral subproblems used for locating new complexes consist of the intersection of the columns of the sector with the rows of the sector and the interconnecting rows. Thus the subproblem for sector 2 consists of the intersection of columns 5 to 8 with rows 1 and 2 and 5 and 6 (table 14). The intersection with rows 5 and 6 indicates the constraints specific to the sector, while the intersection with rows 1 and 2 is used to define a sectoral objective function which consists of a weighted sum of the rows. Since the coefficients in the connecting rows represent primary factor requirements (labour and capital), the weights can be interpreted as prices and the weighted sum be regarded as the total factor cost for the sector. Thus the objective of the sectoral subprogrammes is the minimization of factor costs in each sector at given factor prices.[117]

The factor prices and the new complexes that are found in the course of sectoral suboptimization form the connecting links of the entire computational procedure. At each step a provisional optimum in the Edgeworth-Bowley box diagram is determined on the basis of the estimated isoquants that connect the complexes already identified in each sector. The provisional optimum identifies a corresponding set of factor prices, which are then used as weights for the objective functions of sectoral suboptimization problems. The latter identify new complexes which allow for a closer estimate of the sectoral isoquants, and the entire

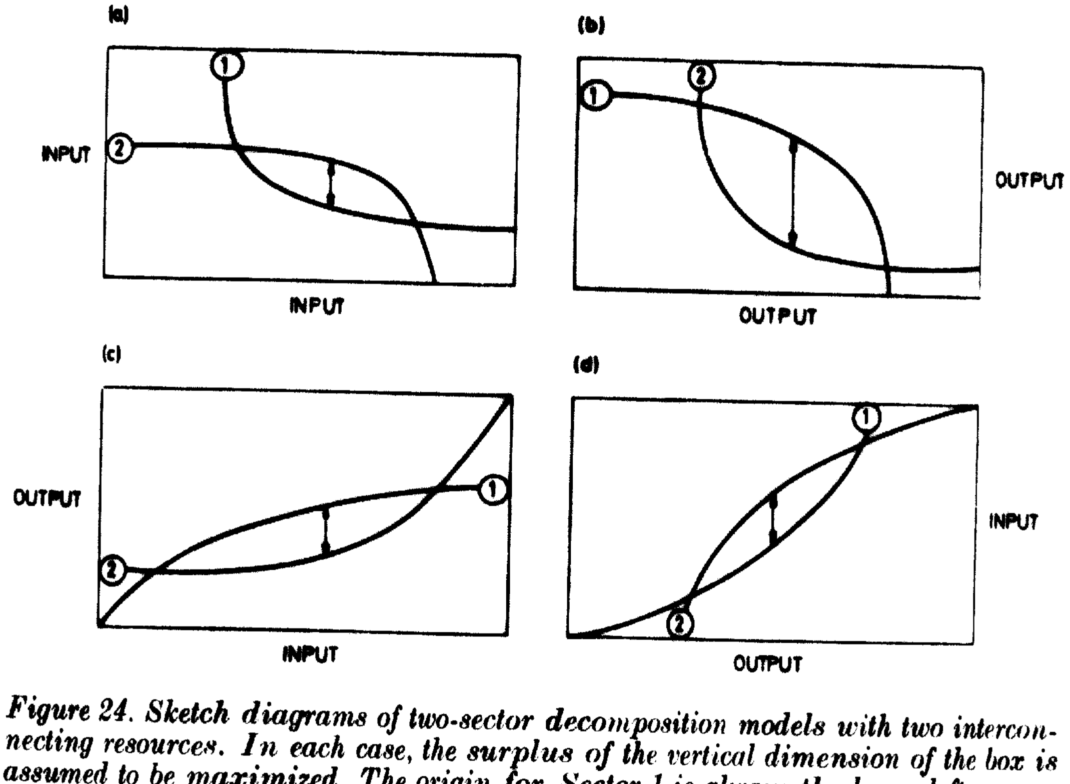

*Figure 24. Sketch diagrams of two-sector decomposition models with two interconnecting resources. In each case, the surplus of the vertical dimension of the box is assumed to be maximized. The origin for Sector 1 is always the lower left corner, for Sector 2 the upper right corner. The connecting lines are in each case labelled with the number of the sector*

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[117] In the two-dimensional diagram (figure 23) the labour/capital factor price ratio is interpreted as the slope of a budget line connecting points of equal factor cost.

procedure is repeated. As long as the estimates of the isoquants improve, the provisional optimum also improves. The procedure ends when no further improvement is possible.

In the present case both of the connecting resources represent primary inputs. This need not always be the case. Figure 24 indicates the schematic structure of input-input, output-output and input-output combinations, where the segmented connecting lines are replaced by smooth curves. Figure 24a corresponds to figure 23. In this case the sectoral connecting lines correspond to the isoquants of neoclassical production functions. If both connecting resources are outputs, the sectoral connecting lines have the shape of neoclassical production possibility curves; in the case of one output and one input, the lines correspond to neoclassical factor input-product output diagrams that are best known from applications to linear homogeneous production functions.

## 8. MODEL FOR THE METALWORKING SECTOR IN AN INTERSECTORAL DECOMPOSITION SYSTEM

Table 15 presents the parameters and other pertinent information for a decomposition model specifically aimed at the requirements of the metalworking sector. The small size of the model will permit the gradual introduction of additional complexities.

TABLE 15. A SMALL MODEL FOR THE METALWORKING SECTOR IN AN INTERSECTORAL DECOMPOSITION SYSTEM[a]

| | *Product 1* | | *Product 2* | | | |
|---|---|---|---|---|---|---|
| | *Production* | *± Imports* | *Production* | *± Imports* | *Exogenous* | |
| 1 | 1 | 1 | | | —80 | Product 1 balance |
| 2 | | | 1 | 1 | —30 | Product 2 balance |
| 3 | —20 | | —15 | | | Capital requirement |
| 4 | | —10 | | —20 | | Foreign exchange balance |
| 5 | | 1 | | | 20 | Export limit, product 1 |
| 6 | | | | 1 | 6 | Export limit, product 2 |
| | 1 | 2 | 3 | 4 | 5 | |

| *Complex* | *Imports* | *Exports* | *FE(1)* | *FE(2)* | *ΣFE* | *K(1)* | *(K2)* | *ΣK* |
|---|---|---|---|---|---|---|---|---|
| A | 1,2 | — | —800 | —600 | —1,400 | 0 | 0 | 0 |
| B | 1 | 2 | —800 | +120 | —680 | 0 | —540 | —540 |
| C | 2 | 1 | +200 | —600 | —400 | —2,000 | 0 | —2,000 |
| D | — | 1,2 | +200 | +120 | +320 | —2,000 | —540 | —2,540 |

[a] See text for explanation of symbols.

The model shows only two products (goods 1 and 2) for the sector. Each product may be imported or produced domestically. The required inputs are capital for domestic production and foreign exchange for imports. The import activity is reversible; at the prevailing world market price, it is assumed that it is not only possible to import a commodity but also to engage in negative imports (to export it). This export opportunity, however, depends on the special quantitative limitation for each good given in rows 5 and 6. The logic of the model permits the ready addition of further export activities at lower export prices. The procedure represents export demand in the form of a step function with prices falling by steps as exports increase.

The complexes characterizing the model are given in table 15. There are only two significant alternatives for each product; it should either be imported entirely or produced domestically and exported. The alternative of domestic production without any exports or imports is subsumed in the former alternatives. Thus there are four complexes that must be considered individually. The capital *(K)* and foreign-exchange *(FE)* requirements of each complex are given for each product. The total requirements for capital and for foreign exchange are, respectively, $\Sigma K$ and $\Sigma FE$.

Capital and foreign exchange are regarded as the connecting resources for the purposes of intersectoral analysis. Accordingly, the complexes must be represented in an Edgeworth-Bowley diagram with capital on the vertical axis and foreign exchange on the horizontal one. The usual diagram, however, must be slightly modified since both net surpluses (exports) and net deficits (imports) of foreign exchange in each sector must be given consideration.

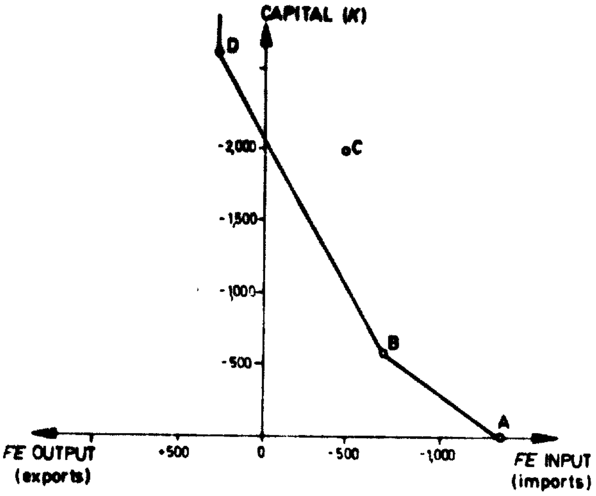

*Figure 25. A small model for the metalworking sector*

Figure 25 presents the corresponding diagram. Complexes A, B and D are found to be efficient. Note that the right side of the diagram corresponds to the isoquant configuration shown in figure 23 or figure 24(a), while the left side of the diagram corresponds to the input-output configurations given in figures 24(c) and (d). The vertical line supplied as an extension from point D upward corresponds as usual to disposal or non-use of a factor (capital in this case). Note that resource requirements are denoted by negative numbers: figures 23 and 25 carry such negative numbers on the customary horizontal and vertical axes. In figure 25, the opposite direction of the horizontal axis becomes meaningful and carries positive numbers to denote net foreign-exchange *(FE)* outputs.

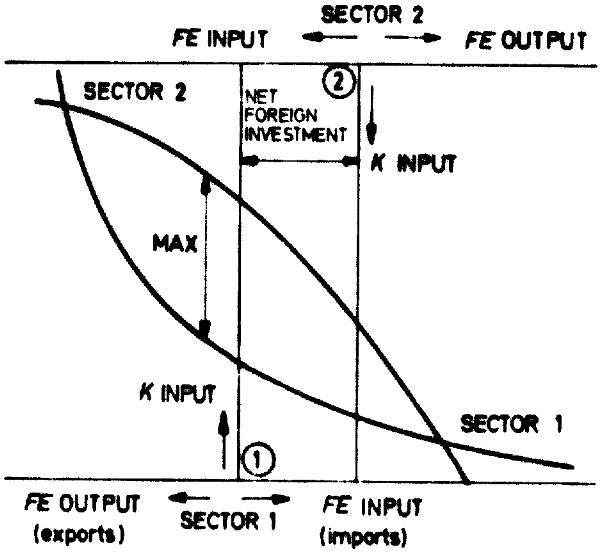

*Figure 26. Two-sector decomposition model in which each sector may run either a net export or a net import surplus. Sector 1 corresponds to the numerical model diagrammed in figure 25*

Figure 26 illustrates the interaction between the metalworking sector (sector 1) and the rest of the economy. It is assumed that the rest of the economy is capable of operating either on a net import or on a net export basis; thus the course of the sectoral connecting line for sector 2 is similar to that for sector 1. It is further assumed that a net positive balance of foreign-exchange *(FE)* representing a net inflow of foreign investment is available to the economy. This is the extent to which imports as a whole (foreign-exchange requirements) are permitted to exceed exports as a whole (endogenous foreign-exchange supplies). This net foreign investment defines the horizontal dimension of the Edgeworth-Bowley box; however, in the present case, the box is extended beyond the usual corner at which the net resource input of a sector becomes zero. The vertical dimension of the box is normal and represents the availability of capital $(K)$. In order to achieve the greatest possible capital economy, sector 1 must operate on a net export basis (see the position of the vertical arrow between the two sectoral lines), while sector 2 operates on a net import basis. If net foreign investment becomes zero, the horizontal dimension of the Edgeworth-Bowley box collapses to a point, but the extensions to the net-export regions still operate. In the latter case it can thus be decided which sector will be a net exporter: the other sector must then have an equal net import. Finally, the diagram can accommodate net foreign investment (capital outflow). In this case the origin for sector 2 (the upper right corner of the box) moves to the left until it passes beyond the origin for sector 1 (the lower left corner). The box thus has a negative horizontal dimension. This may appear unusual but the interpretation is very simple; either both sectors must have net export surpluses, or the net export surplus of one of the sectors must be sufficiently large to offset the net import surplus of the other and still leave sufficient foreign exchange to comply with the exogenous foreign-exchange requirement. In each case the diagrammatic representation of a single sector follows the principles illustrated by the small numerical model, and the determination of the optimal position invariably rests on the identification of the vertical cut that gives the largest separation between the sectoral connecting lines.

### *Fixed costs*

The factors of indivisibilities and economies of scale can now be introduced in the model. They are indispensable for a realistic model, since they play a key role in planning decisions affecting the sector. Some of their effects at the intrasectoral level have been discussed. However, it is essential to place them in a context that explicitly takes into account intersectoral relationships.

The simplest way to introduce indivisibilities and economies of scale is by adding fixed costs. The formulation of the model in linear programming notation is essentially unchanged, except that some variables are restricted to integer values. The following parameters are added to the small model for the metalworking sector:

| | *Capital* | *Foreign exchange* | *Capacity limit* |
|---|---|---|---|
| Fixed cost for production of product 1 . . . . . . . . . . . . . | 200 | 200 | 160 |
| Fixed cost for production of product 2 . . . . . . . . . . . . . | 500 | 0 | 80 |

The model with these additions is shown in table 16. The definitions of fixed-cost activities and tie-in constraints follow exactly the principles stated previously. The scales of activities 2 and 5 are integer variables.

The effect of the fixed costs is an increase of the sector's capital and foreign-exchange requirements in a way that depends on the productive structure. The list of complexes in table 15 indicates that complex A

TABLE 16. A SMALL MODEL FOR THE METALWORKING SECTOR IN AN INTERSECTORAL DECOMPOSITION SYSTEM WITH FIXED COSTS

|  | *Product 1* |  |  | *Product 2* |  |  |  |  |
|---|---|---|---|---|---|---|---|---|
|  | *Production* |  | ± | *Production* |  |  |  |  |
|  | *Variable* | *Fixed* | *Imports* | *Variable* | *Fixed* | *Imports* | *Exogenous* |  |
| 1 | 1 |  | 1 |  |  |  | 80 | Product 1 balance |
| 2 |  |  |  | 1 |  | 1 | 30 | Product 2 balance |
| 3 | −20 | −200 |  | 15 | 500 |  |  | Capital requirement |
| 4 |  | 200 | 10 |  |  | −20 |  | Foreign exchange balance |
| 5 |  |  |  |  |  |  | 20 | Export limit, product 1 |
| 6 |  |  |  |  |  | 1 | 6 | Export limit, product 2 |
| 7 | $-\frac{1}{160}$ | 1 |  |  |  |  |  | Fixed-cost tie-in, product 1 |
| 8 |  |  |  | $\frac{1}{80}$ | 1 |  |  | Fixed-cost tie-in, product 2 |
|  | 1 | 2 | 3 | 4 | 5 | 6 | 7 |  |

consists entirely of import activities with no production in the sector; this complex will not be affected by the introduction of fixed costs in production. Complex B, however, contains a productive activity for product 2 and accordingly must incur the fixed cost for this activity (500 units of capital). Thus the capital requirement of complex B rises from 540 to 1,040 units, while the foreign-exchange requirement remains the same.

In figure 27 the new complexes, including the specified fixed costs, are designated by A′, B′ and D′. (Ignore for the moment the A″, B″ and D″ that occur in this figure.) It can be seen that A coincides with A′, while B′ (designated by an arrow) is obtained from A by a vertical movement of 500 units corresponding to the fixed capital requirement. From table 15, complex D has both productive activities and is therefore assigned both fixed costs. These fixed costs total 700 units of capital and 200 units of foreign-exchange *(FE)*. In figure 27, to obtain D′ from D, move vertically 700 units (capital) and to the right 200 units (foreign-exchange).

It may be thought that the new complexes A′, B′ and D′ could be connected to yield a new isoquant. This is not the case, however, since to do so would imply averaging the fixed costs. For example, the midpoint between A = A′ and B′ would imply incurring half the total resource requirements of B′, which is quite correct as far as the variable costs are concerned, but the fixed costs must be incurred only once as soon as there is any production of product 2. However, the averaging procedure falsely assumes that the fixed costs to the same extent as the variable costs can be cut in half in the latter case; the averaging treats fixed costs not as integer but as continuous (divisible) variables and will therefore be

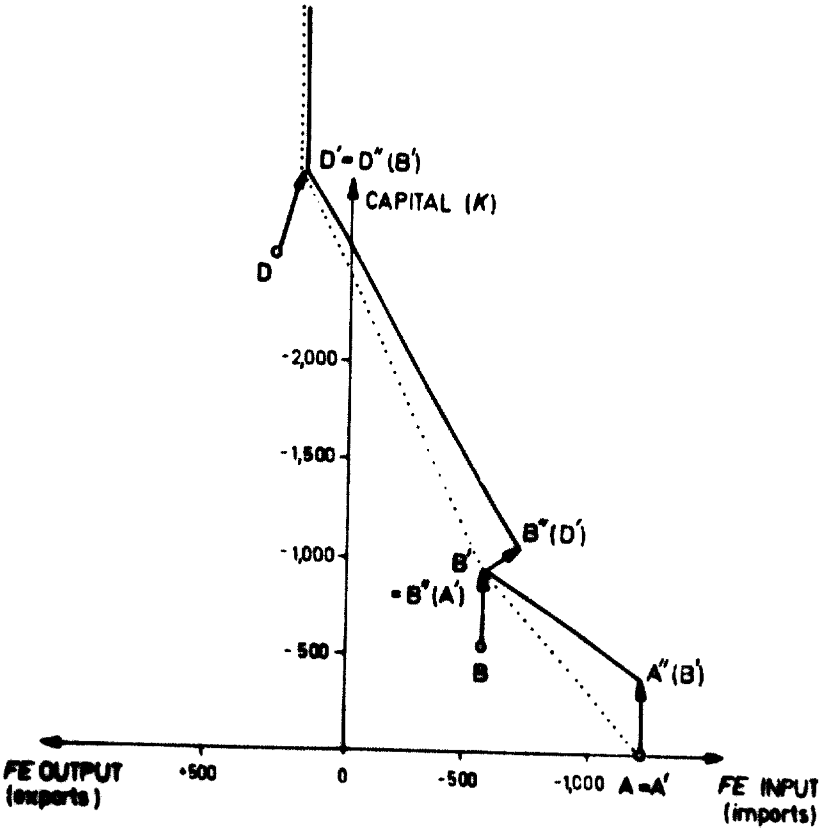

*Figure 27. The introduction of fixed costs. The complexes* **A**, **B**, **D** *are carried by the fixed costs into points* **A'**, **B'**, **D'**. *These points cannot be directly averaged. The correct averaging points are shown as* **A''**, **B''**, **D''**

referred to as continuous averaging. The resulting continuous isoquant is denoted in figure 27 by the dotted line connecting complexes A', B' and D'.

For correct averaging the respective fixed costs of any production activity must be included as soon as any production is begun. Thus, in averaging complexes A' and B', the fixed costs of production of product 2 (500 units of capital and no foreign exchange) must be added for all averaged points with the exception of point A itself, where the production of product 2 actually equals zero. The procedure is indicated in figure 27 by inserting a fixed-cost arrow on A'. The end-point of this arrow is A'' (B'), which will be referred to as the correct averaging point A'' for B'. In figure 27 the correct averaging line is seen to connect A'' (B') with B' itself, since there are no fixed costs at A', and therefore the correct averaging point B'' (A') coincides with B'. Starting with A' (which coincides with A, where no fixed costs are incurred), the correct averaging line first rises to A'' (B') (which corresponds to the smallest non-zero production level of product 2) and then proceeds to B'.

At B' the fixed costs for producing product 1 have to be added before the averaging with D' can begin; accordingly an arrow representing

## 4. FIXED AND VARIABLE RESOURCE REQUIREMENTS

### *Economies of scale*

The economies of scale due to the seriality of production is represented in models 1 and 2 by fixed costs (or fixed resource inputs) tied to the scales of the respective production activities that embody variable costs. The two kinds of fixed costs are those associated with investment in tooling, jigs and fixtures and those associated with set-up operations for each production run.

The first kind of fixed costs creates no particular problems at the present stage of analysis. Later, it will be necessary to recognize these costs as leading to output requirements in the metalworking sector proper and thus to a feedback between the required production scales of metalworking activities at a future date and the corresponding output of tools, jigs and fixtures intended for investment purposes during an earlier time period *t*. Fixed costs connected with a production activity include set-up charges which are incurred for each separate production run. Thus the total set-up charges depend on the connexion between the yearly demand and the length of an individual production run.

In model 1 all fixed costs, including set-up charges, are expressed in monetary terms. In models 2 and 3, investments in tooling, jigs and fixtures are given as capital requirements in lump sums, while set-up charges are approximated by giving the capacity requirements of resource elements corresponding to the actual yearly set-up time. Thus, if a given resource element with a machine part of 50 units has a total of 300,000 effective yearly machine hours, set-up charges can be expressed as the number of machine hours required per run multiplied by the number of runs per year. The product is subtracted from the total number of effective machine hours available for production. Since models 2 and 3 distribute a variety of yearly charges of resource elements (labour, investment and indirect material inputs) over the total effective machine hours, this way to handle set-up charges is equivalent to the assumption that not only investment costs but also labour and indirect material costs per hour are the same for set-up operations and production. This is probably a tolerable simplifying approximation. The main reason for separating direct from indirect material inputs is to avoid the more gross error of assuming that the metal requirements were also proportional to the total used resource-element capacity without discrimination between the fixed and variable parts of the latter.

An important simplification introduced into the models is the fact that only one fixed investment in tooling, jigs and fixtures is provided for each productive process; there is only one variable-cost activity and one fixed-cost activity for the manufacture of each listed product by a

The correct isoquant quantifies capital and foreign-exchange requirements of the sector. The precise meaning of the quantification must be stated with some care, however, because of the jagged outline of the isoquant once fixed costs are introduced. Thus the correct isoquant is defined in either of two equivalent ways; as the geometrical locus of least capital requirements corresponding to given foreign-exchange requirements or outputs, or as the geometrical locus of least foreign-exchange requirements (where they are algebraically extended to include negative requirements, that is, net outputs of foreign exchange) corresponding to given capital requirements. The correct isoquant provides the implied information that all specific sectoral balances and constraints are correctly observed, including the fixed-cost tie-in constraints and the specifications that restrict certain variables to integer values. Evidently, the continuous isoquant violates the latter condition since it treats integer variables as continuously divisible.

Given the correct isoquant for the metalworking sector, an intersectoral model can be defined on the same principles as the purely linear case. With reference to figure 26, the general structure of the problem remains the same as before with the simple modification that the isoquant of the metalworking sector (and possibly of the other sector as well) will now exhibit the kind of jagged indentations that occur in figure 28. The optimum is still found geometrically by identifying the largest vertical separation between the two isoquants (for an objective function of capital-requirements minimization). The only essential difference is the result of the possibility for several local minima owing to the indentations of the isoquant. Once this occurs, purely local optimality criteria are no longer adequate for the identification of the optimal solution: methods of finding such a solution are based on gradual improvements and consequently will not be valid. Note that the geometrical method of identifying the optimum by the criterion of the largest vertical separation between the isoquants relies on a complete scan of all possibilities summarized by the two isoquants.

This key fact determines the different order of difficulties encountered in the linear and the discrete cases. In the purely linear case there are short-cut methods which avoid scanning all the combinatorial possibilities and find the optimum directly. In the discrete case the simple short-cut methods cannot be used; a number of mathematical procedures show considerable improvements over the exhaustive enumeration of combinatorial possibilities, but they involve much greater difficulties than the ones associated with the purely linear case. The simple relationships between resource allocation and pricing in the purely linear case (and also in non-linear but convex models which do not involve indivisibilities and economies of scale) do not hold for the discrete problem.

Fortunately, in practical planning tasks exact solutions are not required. The parameters of the problem are themselves subject to considerable margins of error, and in any event a great many uncertainties about the future intrude upon exact formal solutions to programming models. The practical planner is quite willing to accept approximations if he is provided with an adequate measure of control of the margins of error involved in such approximations.

Primal approximations always remain on the attainable (technically feasible) side of the correct isoquant, for example, on the upper side in figure 28. Thus they observe all constraints of the problem, but they may be inefficient. The search for the optimal solution based on such approximations will fall short of the true optimum; thus, in the case of the minimization of capital requirements, the solution will be one that uses more capital than the attainable minimum. Many approximate solution methods to integer programming problems give such feasible but typically suboptimal solutions. Figure 29 shows a solution method which found points A and D but missed point B; a correct averaging procedure might be used between the latter two points. The corresponding line would run higher than the correct isoquant, since it would connect D′ with point Z and add the height of the step above B′ to the step above A′. Taking this line as an approximation to the correct isoquant will necessarily result in suboptimal solutions (see line D′ZA′ in figure 29). Another primal approximation might omit averaging altogether and simply piece together solutions from unaveraged complexes. An isoquant corresponding to this strategy would connect A′, B′ and D′ by large horizontal-vertical steps (see line $D'X_1B'X_2A'$ in figure 29). If in addition some complexes remained unidentified, the steps would run at an even higher level (for example, line D′YA′ in figure 29). To keep the errors in bounds, it is clearly desirable to perform a correct averaging operation on complexes which have already been identified and to avoid missing complexes that would permit significant improvements of the approximation.

The essence of the dual approximations is that they approach the correct isoquant from the unfeasible (technically unattainable) side. The simplest approximation of this kind ignores fixed costs altogether and operates with the original isoquant ABD in figure 25 (see also figure 30). A closer dual approximation takes fixed costs into account but distributes them evenly over all units of available production capacity. A third and even closer approximation treats the fixed costs of the complexes as fully divisible for averaging purposes and leads to the continuous isoquant.

It is important to clarify the distinction between the second and the third approximations. To this end, the following average fixed costs per unit of production capacity were calculated: product 1, 1.25 units of capital and 1.25 units of foreign exchange; product 2, 6.25 units of capital and no foreign exchange.[119] The average fixed costs can be added

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[119] The calculations were made by dividing the fixed costs (200, 200) by the stated capacity of 160 for the product 1 and likewise dividing (500, 0) by 80 for product 2.

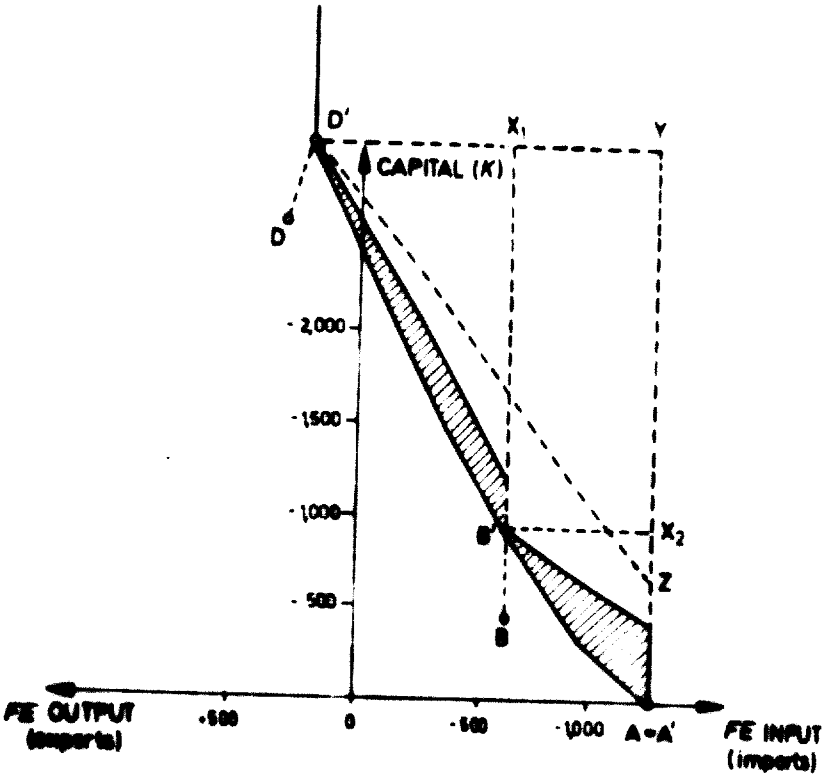

*Figure 29. Primal approximations to the correct sectoral isoquant*

to variable costs for each production process, and the resulting purely linear model can then be solved in the conventional way. Note, however, that this approximation generally understates the fixed costs associated not only with the averaged complexes but also with each complex in isolation. For example, complex B (see table 15) involves the production of 36 units of product 2 (30 for domestic demand, 6 for export); thus a fixed cost of $(36) \times (6.25) = 225$ units of capital is calculated instead of the actual 500 units. Likewise, for complex D the calculation yields $(100) \times (1.25) + (36) \times (6.25) = 350$ units of capital and $(100) \times (1.25) + (36) \times (0) = 125$ units of foreign exchange instead of the correct figures of 700 and 200 respectively. The underestimated resource requirements for each complex will be denoted by the symbols B* and D*. Note that as A involves no fixed costs, $A = A' = A^*$. Thus the isoquant estimated by the second dual approximation runs through A*, B*, D*, while the isoquant estimated by the third dual approximation is the continuous isoquant A'B'D'. It can be seen in figure 30 that the third approximation is closer than the second, because it is exact (has no error) at the points representing individual complexes and is in error only over the averaging stretches connecting the complexes. The second approximation is in error except at complexes such as A that have no fixed costs at all, while the error is larger than the one characterizing the third approximation over the averaging stretches.

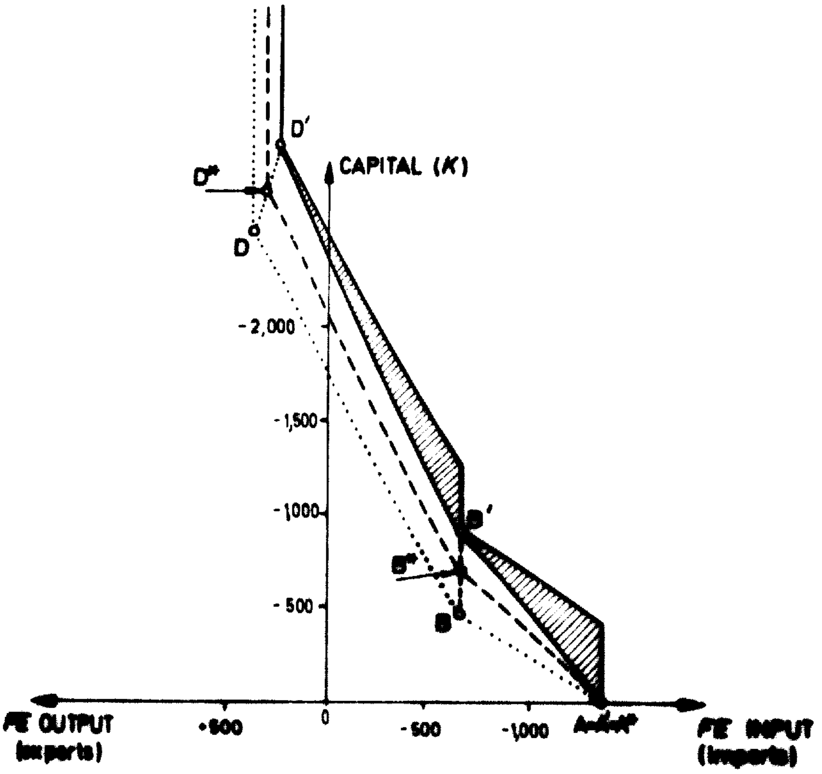

*Figure 30. Dual approximations to the correct sectoral isoquant*

In the general case the three dual approximations can be derived by mathematical programming techniques. The first is obtained when the sectoral subproblem is optimized while fixed-cost activities are omitted, the second when fixed-cost activities are retained together with their respective tie-in constraints but the integrality conditions on the fixed-cost incurrence variables are suspended, and the third by integer programming and strict observance of the above-mentioned integrality conditions.[120]

The difference between the second and third dual approximations can be summarized as follows, although both use average rather than marginal costs because they take into account fixed costs which are ignored in the derivation of marginal costs. The average costs are obtained by distributing fixed costs over the units of available capacity in the second approximation and by distributing the fixed costs over the

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[120] In all three cases, the entire course of the approximating isoquant can be obtained only when the optimization is carried out repeatedly with gradually changing capital/foreign-exchange price ratios inserted in the sectoral objective functions, since each such optimization will lead to only one extreme point (complex) along the isoquant. This repetitive procedure can be formalized and shortened in the case of linear programming and is technically referred to as parametric programming.

actual units of production characterizing each complex in the third approximation.

The primal and dual approximations jointly permit a satisfactory pragmatic approach to the programming of individual sectors in an over-all intersectoral model. The primal approximations will yield feasible solutions that are generally not optimal but close to the optimum: the dual approximations will permit placing an upper bound on the error and the approximate pricing of the connecting resources.

### *A more comprehensive model*

The model representing the metalworking sector in the global sectoral decomposition system is now enlarged to bring it closer to the three models already discussed. In particular, some of the key features of model 3 that arise from the independent presence of economies of scale are represented; at the level of the individual product (economies of long series) and at the level of resource elements (economies of large scale). The interaction of these two indivisibilities in the derivation of the sectoral isoquant must be studied. In addition, variable exports that have been omitted in model 3 are included. In models 1 to 3, exports have been treated as exogenously determined, whereas in the small model, exports were already endogenous, because the scale of the import activity was treated as a free variable. Negative values were assigned to the variable exports, and a specific limit was imposed on their extent. In the more comprehensive model, exports will be treated as a falling step function of export price with separate limits on the extent of exports at each of two price levels.

The model is specified in table 17 in purely linear form without fixed costs. Separate production activities are given for each product using one of two resource elements. There are two activities representing the maintenance of resource-element capacity (columns 9 and 10). For each product there are the following significant production-and-trade choices: imports, production by activity 1 and export to a limit of the first step (row 7), production by activity 1 and export to a limit of the second step (row 8), production by activity 2 and export to a limit of the first step and production by activity 2 and export to the limit of the second step. The number of joint combinations for the two products is $(5) \times (5) = 25$; there are thus 25 complexes with the main characteristics listed in table 18. The capital/foreign-exchange *(FE)* isoquants implied by the 25 complexes are plotted in figure 31, which can be regarded as a generalized version of figure 25. As the diagram indicates, there are only five efficient points with the given choice of parameters which determine the isoquant for the sector. Apart from pure imports for both goods (complex 1), the efficient choices always involve production by means of resource element 2 and comprise the following: imports of product 1

### TABLE 17. A MORE COMPREHENSIVE MODEL FOR THE METALWORKING SECTOR IN AN INTERSECTORAL DECOMPOSITION SYSTEM

| | Product 1 | | | | Product 2 | | | | Resource element | | Exogenous | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Production | | ± | | Production | | ± | | | | | |
| | Activity 1 | Activity 2 | Imports | Exports | Activity 1 | Activity 2 | Imports | Exports | 1 | 2 | | |
| 1 | 1 | 1 | 1 | —1 | | | | | | | —90 | Product 1 balance |
| 2 | | | | | 1 | 1 | 1 | —1 | | | —30 | Product 2 balance |
| 3 | —20 | | | | —15 | | | | 1 | | | Resource element 1 capacity balance |
| 4 | | —15 | | | | —10 | | | | 1 | | Resource element 2 capacity balance |
| 5 | | | | | | | | | —1 | —1.25 | | Capital requirement |
| 6 | | | —10 | +8 | | | —20 | +15 | | | | Foreign exchange balance |
| 7 | | | 1 | | | | | | | | 20 | Export limit, product 1, step 1 |
| 8 | | | | —1 | | | | | | | 50 | Export limit, product 1, step 2 |
| 9 | | | | | | | 1 | | | | 6 | Export limit, product 2, step 1 |
| 10 | | | | | | | | —1 | | | 20 | Export limit, product 2, step 2 |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | |

TABLE 18. COMPLEXES FOR THE MODEL GIVEN IN TABLE 17

| Complex | Activity for product 1 | Activity for product 2 | Product 1 FE | Product 1 R1 | Product 1 R2 | Product 2 FE | Product 2 R1 | Product 2 R2 | Total ΣFE | Total ΣR1 | Total ΣR2 | Total ΣK |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  | Resource requirements (—) or supplies (+) |  |  |  |  |  |  |  |  |  |
| 1 | *I* | *I* | —800 |  |  | —600 |  |  | —1,400 |  |  |  |
| 2 | *I* | *P1E1* | —800 |  |  | +120 | —540 |  | — 680 | — 540 |  | — 540 |
| 3 | *I* | *P1E2* | —800 |  |  | +420 | —840 |  | — 380 | — 840 |  | — 840 |
| 4 | *I* | *P2E1* | —800 |  |  | +120 |  | —360 | — 680 |  | — 360 | — 450 |
| 5 | *I* | *P2E2* | —800 |  |  | +420 |  | —560 | — 380 |  | — 560 | — 700 |
| 6 | *P1E1* | *I* | +200 | —2,000 |  | —600 |  |  | — 400 | —2,000 |  | —2,000 |
| 7 | *P1E1* | *P1E1* | +200 | —2,000 |  | +120 | —540 |  | + 320 | —2,540 |  | —2,540 |
| 8 | *P1E1* | *P1E2* | +200 | —2,000 |  | +420 | —840 |  | + 620 | —2,840 |  | —2,840 |
| 9 | *P1E1* | *P2E1* | +200 | —2,000 |  | +120 |  | —360 | + 320 | —2,000 | — 360 | —2,450 |
| 10 | *P1E1* | *P2E2* | +200 | —2,000 |  | +420 |  | —560 | + 620 | —2,000 | — 560 | —2,700 |
| 11 | *P1E2* | *I* | +600 | —3,000 |  | —600 |  |  | 0 | —3,000 |  | —3,000 |
| 12 | *P1E2* | *P1E1* | +600 | —3,000 |  | +120 | —540 |  | + 720 | —3,540 |  | —3,540 |
| 13 | *P1E2* | *P1E2* | +600 | —3,000 |  | +420 | —840 |  | +1,020 | —3,840 |  | —3,840 |
| 14 | *P1E2* | *P2E1* | +600 | —3,000 |  | +120 |  | —360 | + 720 | —3,000 | — 360 | 3,450 |
| 15 | *P1E2* | *P2E2* | +600 | —3,000 |  | +420 |  | —560 | +1,020 | —3,000 | — 560 | —3,700 |
| 16 | *P2E1* | *I* | +200 |  | —1,500 | —600 |  |  | — 400 |  | —1,500 | —1,875 |
| 17 | *P2E1* | *P1E1* | +200 |  | —1,500 | +120 | —540 |  | + 320 | — 540 | —1,500 | —2,415 |
| 18 | *P2E1* | *P1E2* | +200 |  | —1,500 | +420 | —840 |  | + 620 | — 840 | —1,500 | —2,715 |
| 19 | *P2E1* | *P2E1* | +200 |  | —1,500 | +120 |  | —360 | + 320 |  | —1,860 | —2,325 |
| 20 | *P2E1* | *P2E2* | +200 |  | —1,500 | +420 |  | —560 | + 620 |  | —2,060 | —2,575 |
| 21 | *P2E2* | *I* | +600 |  | —2,350 | —600 |  |  | 0 |  | —2,250 | —2,813 |
| 22 | *P2E2* | *P1E1* | +600 |  | —2,250 | +120 | —540 |  | + 720 | — 540 | —2,250 | —3,353 |
| 23 | *P2E2* | *P1E2* | +600 |  | —2,250 | +420 | —840 |  | +1,020 | — 840 | —2,250 | —3,653 |
| 24 | *P2E2* | *P2E1* | +600 |  | —2,250 | +130 |  | —360 | + 720 |  | 610 | 3,263 |
| 25 | *P2E2* | *P2E2* | +600 |  | —2,250 | +420 |  | —560 | +1,020 |  | —2,510 | —3,513 |

*FE*, foreign exchange; *R1*, *R2*, resource element capacity 1 or 2;
*I*, imports; *P1*, *P2*, production activity 1 or 2;
*E1*, *E2*, export step (limit) 1 or 2; Σ, total requirement.
*K*, capital

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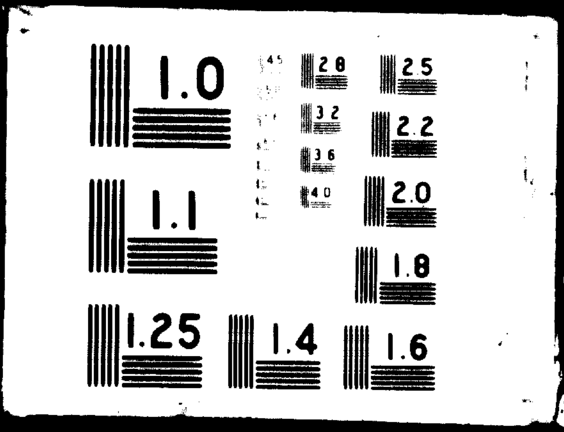

TABLE 19. A MORE COMPREHENSIVE MODEL FOR THE METALWORKING SECTOR IN AN INTERSECTORAL DECOMPOSITION SYSTEM WITH FIXED COSTS ADDED

| | *Product 1* | | | | | | *Product 2* | | | | | | *Resource element* | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Production* | | | | ± | | *Production* | | | | ± | | | | | | | |
| | *Activity 1* | | *Activity 2* | | *Im- ports* | *Ex- ports* | *Activity 1* | | *Activity 2* | | *Im- ports* | *Ex- ports* | *1* | | *2* | | *Exo-* | |
| | *Variable* | *Fixed* | *Variable* | *Fixed* | | | *Variable* | *Fixed* | *Variable* | *Fixed* | | | *Variable* | *Fixed* | *Variable* | *Fixed* | *genous* | |
| 1 | 1 | | 1 | | 1 | —1 | | | | | | | | | | | —80 | Product 1 balance |
| 2 | | | | | | | 1 | | 1 | | 1 | —1 | | | | | —30 | Product 2 balance |
| 3 | —20 | | | | | | —15 | | | | | | 1 | | | | | Resource element 1 balance |
| 4 | | | —15 | | | | | | —10 | | | | | | 1 | | | Resource element 2 balance |
| 5 | | —100 | | —200 | | | | —50 | | —100 | | | —1 | —250 | —1.25 | —100 | | Capital balance |
| 6 | | | | | —10 | +8 | | | | | —20 | +15 | | | | | | Foreign exchange balance |
| 7 | | | | | 1 | | | | | | | | | | | | 20 | Export limit, product 1, step 1 |
| 8 | | | | | | —1 | | | | | | | | | | | 50 | Export limit, product 1, step 2 |
| 9 | | | | | | | | | | | 1 | | | | | | 6 | Export limit, product 2, step 1 |
| 10 | | | | | | | | | | | | —1 | | | | | 20 | Export limit, product 2, step 2 |

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11 | $-\frac{1}{160}$ | 1 | | | | | | | | | | | | | | | | Fixed-cost tie-in constraints |
| 12 | | | $-\frac{1}{160}$ | 1 | | | | | | | | | | | | | | |
| 13 | | | | | | | $-\frac{1}{80}$ | 1 | | | | | | | | | | |
| 14 | | | | | | | | | $-\frac{1}{80}$ | 1 | | | | | | | | |
| 15 | | | | | | | | | | | | | $-\frac{1}{2000}$ | 1 | | | | |
| 16 | | | | | | | | | | | | | | | $-\frac{1}{500}$ | 1 | | |

with production of product 2 to either the first or the second export step (complexes 4 and 5); and production of product 2 up to the second export step with production of product 1 either to the first or the second export step (complexes 20 and 25). All other complexes are inefficient. The isoquant has three sloping linear segments in the net import region and two in the net export region.

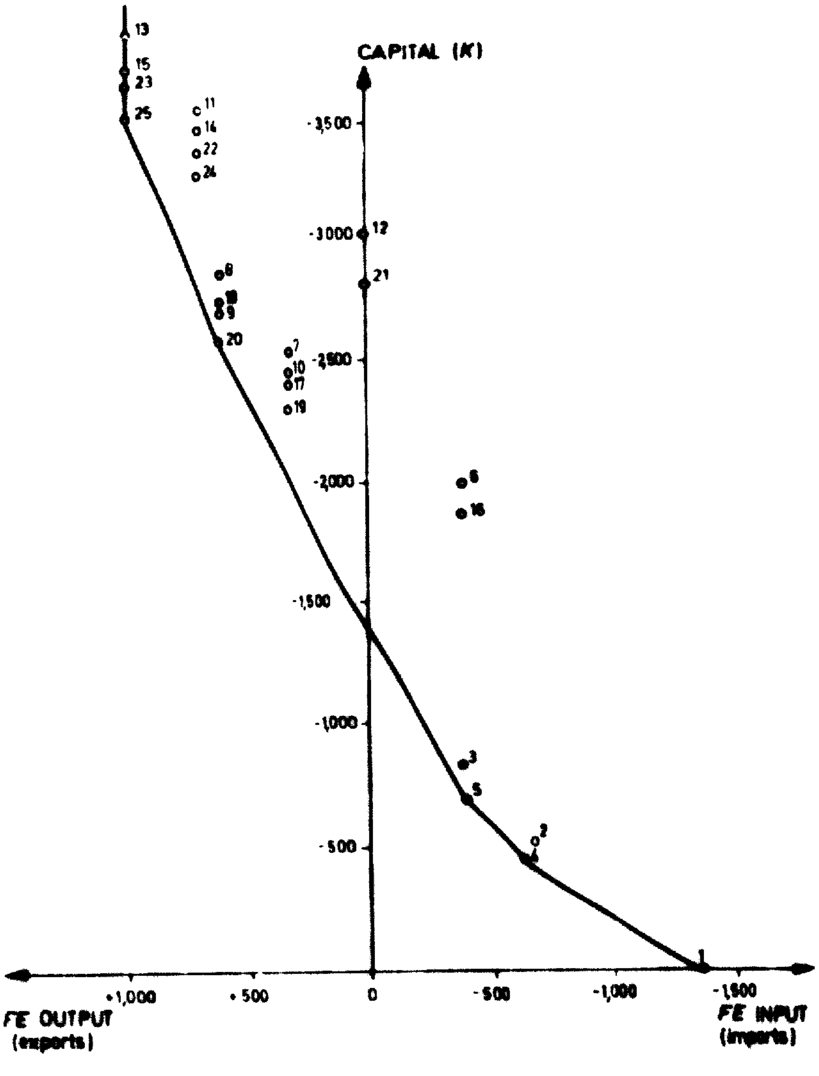

*Figure 31. Diagrammatic representation of a more comprehensive model for the metalworking sector. The numbers refer to individual complexes*

The model is extended by the introduction of fixed costs in table 19. Fixed costs of 100 and 200 units, respectively, are associated with the production activities for product 1, with a corresponding bound of 160 units of production for each activity. The bound is not exceeded by any of the complexes. The corresponding parameters for product 2 are 50 and 100 units of fixed cost with a production bound of 80 units. For the sake of simplicity, all fixed costs are given in terms of capital alone, even though it would be economically meaningful to define some fixed costs in terms of foreign exchange (necessarily imported components of productive capacity) or in terms of resource-element capacities. Similarly, fixed costs are also associated with resource elements; again they are given in terms of capital alone. The respective fixed costs are 250 and 100, units with corresponding capacity limits of 2,000 and 500 units. The limits are not bounds; for many complexes it becomes necessary to duplicate resource elements, since total required capacity exceeds the limit associated with a single fixed-cost incurrence. Thus the integer variables for activities 14 and 16 will at times assume values of 2, 3, 4 and so on.

Table 20 lists the fixed costs of the complexes needed for drawing the sectoral isoquant diagrammed in figure 32. It will be noted that this figure is a more elaborately detailed variation of figure 28.

The derivation of figure 32 is laborious but straightforward. There are only two new features that emerge when it is compared with figure 28. First, it is no longer true that the continuous isoquant will necessarily

TABLE 20. FIXED COSTS FOR COMPLEXES OF A MORE COMPREHENSIVE MODEL FOR THE METALWORKING SECTOR

| | | | | | *Resource element* | | |
|---|---|---|---|---|---|---|---|
| *Complex* | *Activity 1* *100* | *Activity 2* *200* | *Activity 1* *50* | *Activity 2* *100* | *1* *200/200* | *2* *100/500* | *Total* |
| 1′ | | | | | | | |
| 2′ | | | 50 | | 250 | | 300 |
| 3′ | | | 50 | | 250 | | 300 |
| 4′ | | | | 100 | | 100 | 200 |
| 5′ | | | | 100 | | 200 | 300 |
| 6′ | 100 | | | | 250 | | 350 |
| 7′ | 100 | | 50 | | 500 | | 650 |
| 8′ | 100 | | 50 | | 500 | | 650 |
| 9′ | 100 | | | 100 | 250 | 100 | 550 |
| 10′ | 100 | | | 100 | 250 | 200 | 650 |
| 11′ | 100 | | | | 500 | | 600 |
| 12′ | 100 | | 50 | | 500 | | 650 |
| 13′ | 100 | | 50 | | 500 | | 650 |
| 14′ | 100 | | | 100 | 500 | 100 | 800 |
| 15′ | 100 | | | 100 | 500 | 200 | 900 |
| 16′ | | 200 | | | | 300 | 500 |
| 17′ | | 200 | 50 | | 250 | 300 | 800 |
| 18′ | | 200 | 50 | | 250 | 300 | 800 |
| 19′ | | 200 | | 100 | | 400 | 700 |
| 20′ | | 200 | | 100 | | 500 | 800 |
| 21′ | | 200 | | | | 500 | 700 |
| 22′ | | 200 | 50 | | 250 | 500 | 1,000 |
| 23′ | | 200 | 50 | | 250 | 500 | 1,000 |
| 24′ | | 200 | | 100 | | 600 | 900 |
| 25′ | | 200 | | 100 | | 600 | 900 |

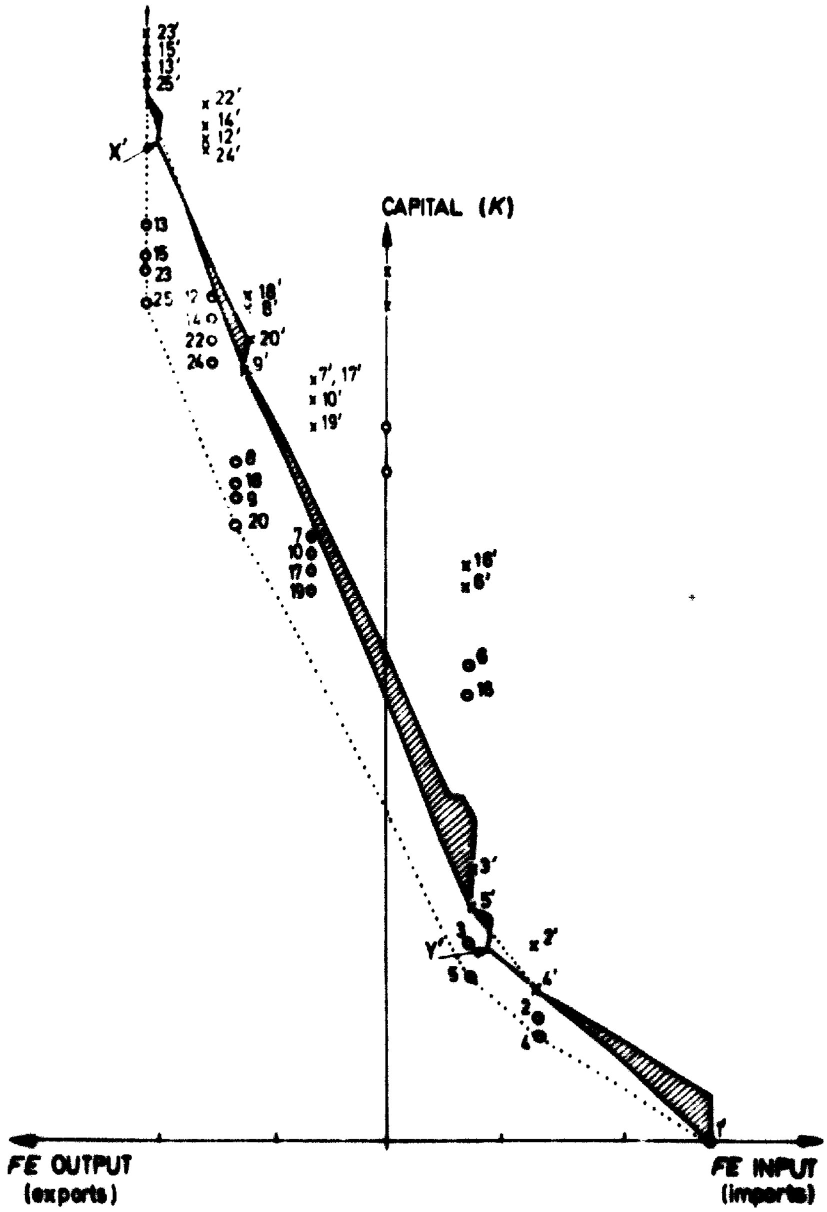

*Figure 32. Sectoral isoquants derived from the model presented in table 19 showing effects of fixed costs*

remain on the infeasible side of the correct isoquant. The former connects 1′, 4′, 5′, 9′ and 25′, and as is readily seen it runs between 4′ and 5′, and again between 9′ and 25′, above the correct isoquant over a short distance. In the case of 4′ and 5′. the complexes have identical fixed costs, except for resource element 2, which must be duplicated in complex 5′, while it appears only once in complex 4′. If it were not for this duplication in 5′, the complexes 4′ and 5′ could be averaged correctly by a simple linear connexion. The linear connexion would run to a point 100 units below point 5′ (if 5′ had only 1 unit of resource element 2). As it is, the same line will be correct for 70 per cent of the distance from 4′ to 5′ because over this stretch the total required capacity of resource element 2 remains below 500 units, which is the limiting capacity for a single fixed cost. It is only at this point that an additional 100 units of fixed cost must be incurred to permit the continuation of the correct averaging process. Thus there is a sudden jump of 100 units 70 per cent of the way from 4′ to 5′, after which the correct isoquant maintains the same slope as before the jump and runs into 5′. The direct route from 4′ to 5′, on the other hand, starts by anticipating the final effect of this jump and thus runs above the correct isoquant until the jump actually occurs. Such a situation can arise only when the fixed costs of a complex can be incurred stepwise.

As a result, the definition of the continuous isoquant must be tightened for this case. As can be seen in figure 32, the addition of new subcomplexes at X′ and Y′ allows a redefinition of the continuous isoquant. The redefinition satisfies the condition of having the continuous isoquant remain entirely on the infeasible side of the correct isoquant: the continuous isoquant will now connect the points 1′4′Y′5′9′X′25′. Such subcomplexes occur at integer multiples of the capacity limit associated with a single incurrence of a specific fixed cost of a given complex up to the number of actual incurrences minus one. When points along the continuous isoquant are identified by integer programming in the sectoral subproblems, the process will correctly identify subcomplexes such as X′ and Y′ that occur along the continuous isoquant.

The complexes that define the continuous isoquant may not suffice to define the correct isoquant. It is between 9′ and 20′ and is not obtained by correctly averaging 9′ and 25′ but by using 20′ instead of 9′ in the correct averaging process, because the latter averaging line runs at a lower level than the former. When using 9′ there is an immediate jump of 200 units, whereas when using 20′ there is no such jump, as 20′ and 25′ have an almost identical fixed-cost structure (see table 20). Inasmuch as 20′ is only 250 units higher than 9′, the latter is efficient when used alone but becomes inefficient as soon as averaging with 25′ is undertaken.

### *Allocations and pricing in the presence of fixed costs*

The precise definition of sectoral isoquants in the intersectoral model with two sectors and two resources (shown for the continuous case in figure 26) permits the identification of the optimal solution by scanning the diagram for the largest separation between the isoquants. If the least use of capital is the objective, the largest separation is required in the vertical direction. No matter how jagged the correct isoquant of each sector becomes as a result of correct averaging between complexes that have fixed costs, the search for the largest vertical separation is still a simple and quick operation (see figure 33). Typically there will be multiple local optima (in figure 33 six of them are identified by check marks) which must be compared to find the over-all optimum, which is identified by a double check mark.

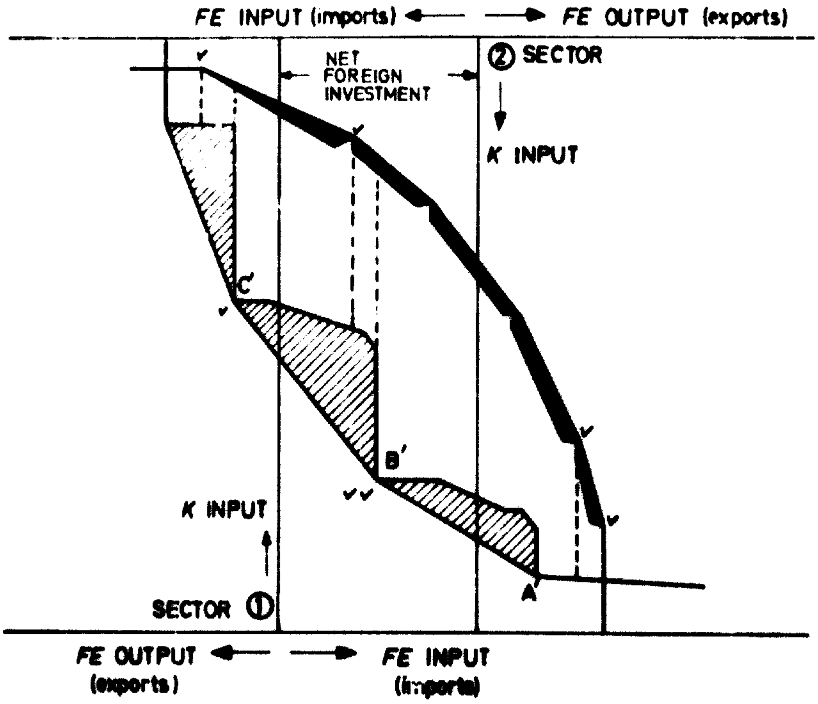

*Figure 33. Diagram of two-sector decomposition model with fixed costs*

The separation between the correct isoquant and the continuous isoquant is indicated as usual by shading. Figure 33 shows the large indivisibilities in sector 1 and the much smaller ones in sector 2. If the continuous isoquant is used as a programming approximation to represent the correct isoquants of the sectors, the error committed in sector 2 will be considerably smaller on the average than the error in sector 1. At the same time, since correct local maxima tend to occur at complexes in one of the sectors (because at these points there is no averaging and many fixed costs are saved) the approximation to the optimal solution based on the continuous isoquants will be burdened with less error originating in the sector with the larger indivisibilities than the average error in the sector. In figure 33, for example, the maximum separation between the continuous isoquants occurs at B' which is also the point at which the correct over-all optimum is found. The difference between the value of the correct optimum and the approximation based on the continuous isoquant is determined only by the small error in sector 2, and there is, in fact, no error in sector 1, even though the latter sector has a much larger average error over the course of the isoquant as a whole.

If there are more than two sectors and several of these have large indivisibilities that give rise to deeply indented isoquants, there is no longer any guarantee that the continuous isoquants of the sectors will give a fair approximation to the optimum. It is essential, therefore, to complement this approximation by estimates of the optimum based on primal approximations, which will tend to underestimate rather than overestimate the optimum. The difference between the optimum derived from the primal approximation and that derived from the dual one yields an upper bound on the possible error. The relationship between primal and dual approximations to the sectoral isoquants is of fundamental importance both to the construction of programming models and to practical planning decisions in the sector and in the intersectoral system.

Consider now the problem of small indivisibilities. To the extent that the difference between the correct isoquant and the dual approximation is within permissible limits of error, the correct isoquant can be replaced by the dual approximation. In practice this means that minute indivisibilities need not be included in the sectoral model. A model that treats the major indivisibilities in a discrete fashion while it uses dual-type approximation for the minor ones is acceptable. Of the three dual approximations, the first ignores fixed costs altogether, while the second and third distribute fixed costs either over full capacity or over actual production quantities in the complexes. The last two approximations are variants of an average-cost type of approach, and are suitable as guides for the suppression of small indivisibilities. Both of the approximations are strictly of the dual type (they remain at all times on the infeasible side of the correct isoquant). When using them to eliminate small indivisibilities from further consideration in the model, it is best to modify them slightly and to distribute fixed costs over a production rate based on estimated capacity utilization, which will generally be less than 100 per cent. Even at points represented by individual complexes, the capacities associated with fixed costs are typically less than fully used. With reference to table 18, for example, complex 5 uses 560 units of capacity of resource element 2, and the fixed cost associated with this resource element in the model of table 19 is 100 units with a capacity limit of 500 units. Thus, to satisfy the capacity requirement of 560 units, fixed cost must be incurred twice; this leaves 440 units of unused capacity. When separate complexes are averaged, capacity utilization drops below 100 per cent, even when the isolated complexes use the capacity fully. While it is not possible to predict accurately the capacity utilization of a particular resource element (as the estimate is required prior to the formulation of the model), the approximate relationship of total demand for capacity to the capacity for a single fixed cost does give an idea of capacity utilization. The larger the number of units required, the higher the probable capacity utilization can be set. For $n$ identical units, capacity utilization (assuming equal loading of all facilities) will be at least $1 - (1/n)$.

Given the estimated capacity utilization, fixed costs can be distributed over the corresponding units of production and added to variable costs. If the estimates are approximately correct, an isoquant runs on the average above the third dual approximation but below the correct isoquant. This approximation is neither a pure dual nor a pure primal approximation but it is within the error limits of both. It has the merit of corresponding closely to the ordinary managerial practice of distributing fixed costs for accounting purposes over the anticipated production rate. If all fixed costs can be treated in this manner within prescribed limits of error, the resulting model will be purely linear. In the solution of such a linear model all activities actually used will break even; thus the price solution of such a model will reflect complete rather than marginal costs. Break-even at *ex ante* estimated capacity utilization levels is of course not the same as break-even at *ex post* realized levels. As the model is formulated exclusively in terms of the former, there is no feedback in the model between the *ex post* realized and the *ex ante* postulated capacity utilization. In an actual decentralization mechanism based on average-cost pricing, the experience in regard to the use of capacity during a given period will modify the anticipated capacity utilization levels for the following period, and thus it becomes possible to define the behavioural prerequisites at the level of the managerial decision of the firm for an adaptive elimination of all *ex post* profits and losses.

The elimination of small indivisibilities from the model by means of an average-cost type approximation is referred to as the bridging of small indivisibilities. Thus, in formulating a model for the metalworking sector, production processes and resource elements are classified into two groups; i.e. continuous (within error limits) and discrete. In the case of continuous production processes and/or resource elements, indivisibilities must be bridged by an average-cost type approximation.

Indivisibilities that are too large to be bridged when formulating the model will enter it in a discrete way with their fixed costs specifically and separately accounted for in the manner indicated in the models discussed (see, for example, table 19). The resulting model containing continuous and discrete activities may well be much too large to be solved directly by integer programming. In this case, the primal and dual approximations to the sectoral isoquants help to define approximate optimizing procedures that will yield feasible but suboptimal solutions as well as upper bounds on the possible optimum. For example, the use of the third approximation for the sectoral isoquants involves the solution of integer programming models in the sectors that are much smaller than the intersectoral model as a whole. Each solution contributes a point along the continuous isoquant. (The second approximation is even simpler; it involves only the solution of linear programming models, but it is less close.) These points can then be interrelated by a purely linear programming technique which is the exact counterpart of the Dantzig-Wolfe procedure (in which no fixed costs occur). The reason for this is that use of the continuous isoquant effectively linearizes the intersectoral problem by bridging all indivisibilities, no matter how large they may be. The solution to this linearized intersectoral problem yields a set of prices for the connecting resources. The new set of prices is then used to define new objective functions for the sectoral subproblems. An integer programming solution for the latter will identify new complexes along the interconnecting isoquant.

Simultaneously, primal approximations for the sectoral isoquants can be used to obtain a feasible suboptimal solution to the intersectoral problem. In this task the difficulty is partly that of finding a sufficient number of sectoral complexes from which to construct approximate intersectoral programmes. In the simplest of these primal approximations such complexes are used singly for each sector without an attempt at averaging; in more sophisticated versions, explicit account can be taken of the fixed costs occurring in the individual complexes and correct averaging can be applied. In any event, candidate complexes for these tasks can be supplied from the dual approximation and the large indivisibilities when they are contained in a sector. The relevant complexes constructed from the latter will be relatively few in number, and a partial-enumeration strategy based on the knowledge of the structure of the sector can be expected to yield a good selection of candidate complexes. A comparison of solutions obtained by the primal and dual approximations will define a bound on the possible error. The approximations may have to be improved progressively until the optimal solution is obtained within an acceptable margin of error.

The problems of central allocations and decentralization by a price mechanism are now considered. The optimal solution to the intersectoral programming model identifies those discrete activities that must be undertaken and separates them from those that will not be used. The solution to this model is the basis for central-planning decisions with regard to fixed investments that are too large to be bridged by an average-cost type decentralizing mechanism. The prices that can be associated with either the dual or the primal integer-programming approximations are generally not suitable as guides to decentralized resource allocation decisions which will jointly arrive at the approximate optimum that has been identified either because the prices bridge excessively large indivisibilities or because (in the case of the prices occurring in integer programming models) they cannot be uniquely associated with the resources whose decentralized allocation is desired. It is thus inevitable that the planning decisions pertaining to discrete activities have to be undertaken centrally. Once it is decided on the basis of the approximate optimal solution to the programming model, which fixed costs will be incurred, the remainder of the problem becomes fully linear and can be decentralized by a price mechanism. To do this, reformulate that part of the model which remains after the central planning decision has been taken with regard to the discrete activities. Discrete activities whose fixed costs will not be incurred can be omitted, while those whose fixed costs will be incurred can be represented by their variable parts alone. The resource components of those fixed costs that will be incurred can then be subtracted from the respective exogenous resource availabilities (the sides of the Edgeworth-Bowley box). The model is now purely linear and can be solved by standard techniques. The price solution will yield correct decentralizing prices. The prices will prevail only on the assumption that the discrete part of the resource allocation problem has already been decided in one particular chosen manner.

The following planning strategy emerges from the discussion:

(1) Decide *ex ante* which indivisibilities can be bridged within the limits of error by an average-cost-type decentralizing mechanism. Estimate anticipated capacity use levels and distribute fixed costs over the corresponding number of units of the variable-cost activities. Thus the components of fixed cost are in effect added to the components of variable cost, and the resulting activities can be treated as continuously divisible.

(2) Build a model for each sector from the continuously divisible and the discrete activities. Relate these models to each other by means of connecting (intersectoral) resources (for example, foreign exchange and capital).

(3) Obtain an approximate optimal solution to the intersectoral model using primal and dual approximations. Estimate the margin of error by the difference between the primal and the dual approximations. Refine these approximations until an optimal solution is obtained within an acceptable margin of error.

(4) Use this solution as a basis for planning decisions with regard to the discrete activities. Decide which fixed costs will be incurred. The decision must be put into effect by means of central resource allocations.

(5) If desirable, the rest of the resource-allocation problem can be decentralized by means of an average-cost pricing approach that distributes fixed costs on the basis of estimated levels of capacity use. Profits or losses due to a divergence between anticipated and realized capacity use must be progressively eliminated by managerial decisions that adjust the estimates for a given period on the basis of the experience of past periods.

### *Capacity allocation and pricing over a period of time*

The policy conclusions have a corollary with regard to resource pricing. Since those fixed costs about which central decisions have to be taken do not enter the decentralizing price mechanism, they have no influence on the pricing of resources in the model; they are treated in effect as sunk costs for pricing purposes, while variable costs (including distributed costs in the case of small indivisibilities) alone determine the price structure. This does not mean that fixed costs have no effect on resource allocation. On the contrary, they have a crucial influence, but this influence cannot be exerted through the price mechanism (except for minor, bridged indivisibilities) and must be permitted to assert itself by means of a non-price-type, essentially combinatorial, centrally controlled resource-allocation mechanism. This mechanism not only complements but underlies the decentralized pricing mechanism, since differing central allocations will give rise to different specific price structures.

This analysis permits a simple resolution of the theoretical conflict between the relative merits of average-cost versus marginal-cost pricing. As far as small indivisibilities are concerned, average-cost pricing is found to be an attractive decentralizing device within the limits of error: the underlying rationale here is that the enormous savings of information handling, which accrue to decentralization, favour working with approximately optimal rather than exactly optimal outcomes. Larger indivisibilities must be handled by central decision-making based on models that summarize the main combinatorial alternatives open to the system as a whole. After the key decisions about the major fixed costs, further detail can be left to decentralized decision-making based on a price system that is built on pure marginal costs as far as the major fixed costs are concerned. However, these marginal costs already incorporate average fixed costs derived from the smaller indivisibilities. The distinction between small and large indivisibilities depends entirely on the acceptable limit of error with regard to the definition of the optimum.

All of the above conclusions are derived from static models. Dynamic features can be brought into the analysis by extending the models to cover several time periods. Model 4 has been constructed to illustrate some of these novel features while reducing the interrelations to the bare essentials. The notation of model 4 follows the notation for models 1 to 3 given in the appendix to this study except for the omission of most of the subscripts and superscripts of the parameters. There are two production activities in each time period (columns 1 and 2, 9 and 10, and 17 and 18): their fixed costs have been suppressed, to concentrate on resource-element capacities. Intermediate commodity inputs have also been suppressed. Resource-element capacity requirements per unit of production $c$ are shown in rows 5 and 6, 15 and 16, and 25 and 26. The next two activities in each time period represent the incurrence of fixed costs associated with the building of new resource-element capacities: the following two activities represent the corresponding variable building costs. Thus, before new capacity can be added, a fixed building cost must be incurred, and thereafter a variable building cost must be met for each unit of capacity built. The representation of economies of scale in regard to resource-element capacities has been discussed earlier. The

MODEL 4

| | Period 1 | | | | | | | | Period 2 | | | | | | | | Period 3 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Production | | Resource element capacity building | | | | Capacity hold over | | Production | | Resource-element capacity building | | | | Capacity hold over | | Production | | Resource element capacity building | | | | Capacity hold over | | Exog | | |
| | | | fixed | | variable | | | | | | fixed | | variable | | | | | | fixed | | variable | | | | | | |
| 1 | 1 | | | | | | | | | | | | | | | | | | | | | | | | $-d$ | Products | Period 1 |
| 2 | | 1 | | | | | | | | | | | | | | | | | | | | | | | $-d$ | | |
| 3 | | | $-\bar{\lambda}$ | $\enclose{circle}{-\bar{\lambda}}$ | $-\lambda$ | $-\lambda$ | | | | | | | | | | | | | | | | | | | $+l$ | Factors | |
| 4 | | | $-\bar{\lambda}$ | $\enclose{circle}{-\bar{\lambda}}$ | $-\lambda$ | $-\lambda$ | | | | | | | | | | | | | | | | | | | $+l$ | | |
| 5 | $-c$ | $-c$ | | | | | | | | | | | | | | | | | | | | | | | $H^0$ | Capacity (stock) | |
| 6 | $-c$ | $-c$ | | | | | | | | | | | | | | | | | | | | | | | $H^0$ | | |
| 7 | | | 1 | | | | | | | | | | | | | | | | | | | | | | $X^0$ | Tie-in | |
| 8 | | | | 1 | | | | | | | | | | | | | | | | | | | | | $X^0$ | | |
| 9 | | | | | 1 | | -1 | | | | | | | | | | | | | | | | | | $H^0$ | Capacity (flow) | |
| 10 | | | | | | 1 | | -1 | | | | | | | | | | | | | | | | | $H^0$ | | |

| | | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|11| | | | | | | | |1| | | | | | | | | | | | | | | |$d$|Products|Period 2|
|12| | | | | | | | | |1| | | | | | | | | | | | | | |$-d$| | |
|13| | | | | | | | | | |$-\lambda$|$\textcircled{\lambda}$|$-\lambda$|$\lambda$| | | | | | | | | | |$+l$|Factors| |
|14| | | | | | | | | | |$\lambda$|$\textcircled{\bar{\lambda}}$|$-\lambda$|$-\lambda$| | | | | | | | | | |$+l$| | |
|15| | | | | | |1| |$-c$|$-c$| | | | | | | | | | | | | | |$H^0$|Capacity (stock)| |
|16| | | | | | | |1|$-c$|$-c$| | | | | | | | | | | | | | |$H^0$| | |
|17| | | | | | | | | | |1| | | | | | | | | | | | | |$X^{\circ}$|Tie-in| |
|18| | | | | | | | | | | |1| | | | | | | | | | | | |$X^{\circ}$| | |
|19| | | | | | |1| | | | | |1| |-1| | | | | | | | | |$H^0$|Capacity (flow)| |
|20| | | | | | | |1| | | | | |1| |-1| | | | | | | | |$H^0$| | |
|21| | | | | | | | | | | | | | | | |1| | | | | | | |$d$|Products|Period 3|
|22| | | | | | | | | | | | | | | | | |1| | | | | | |$-d$| | |
|23| | | | | | | | | | | | | | | | | | |$-\lambda$|$\textcircled{-\lambda}$|$-\lambda$|$-\lambda$| | |$+l$|Factors| |
|24| | | | | | | | | | | | | | | | | | |$-\bar{\lambda}$|$\textcircled{-\bar{\lambda}}$|$-\lambda$|$-\lambda$| | |$+l$| | |
|25| | | | | | | | | | | | | | |1| |$-c$|$-c$| | | | | | |$H^0$|Capacity (stock)| |
|26| | | | | | | | | | | | | | | |1|$-c$|$-c$| | | | | | |$H^0$| | |
|27| | | | | | | | | | | | | | | | | | |1| | | | | |$X^{\circ}$|Tie-in| |
|28| | | | | | | | | | | | | | | | | | | |1| | | | |$X^{\circ}$| | |
|29| | | | | | | | | | | | | | |1| | | | | |1| |1| |$H^0$|Capacity (flow)| |
|30| | | | | | | | | | | | | | | |1| | | | | |1| |-1|$H^0$| | |
|31| | | | | | | | | | | | | | | | | | | | | | |$k_1$|$k_2$| |Terminal capacity values|Period 4|

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*) See text for definition of the symbols used

fixed and variable building costs are represented by the $\lambda$ and $\lambda$ parameters respectively, which refer to inputs of primary factors. It is assumed that the second resource element is continuous: it has no fixed building costs. For comparison, nevertheless, the fixed inputs have been denoted by parameters that are assumed to take on zero values. These parameters have been encircled.

Finally, model 4 includes a new kind of activity (columns 7 and 8, 15 and 16, and 23 and 24), representing the hold-over of existing capacity from period to period. Such activities are represented by a hypothetical purchase of capacity in period $t$: its rental in period $t+1$ and its sale in the latter period. There is such a hold-over activity for each resource-element capacity. Column 25 is the exogenous column as usual.

Among the rows of model 4, the first two in each time period are product balances with final demand in the exogenous column; the next two rows are primary-factor balances. Rows 5 and 6, 15 and 16, and 25 and 26 are capacity stock balances. They account for existing stocks inherited from the previous time period, which are available for use in current production. The exogenous $H^0$ entries in rows 5 and 6 represent stock inherited from the zero time period, while the stock availabilities of periods 2 and 3 depend on the scale of the hold-over activities in periods 1 and 2. The price variables associated with these rows are capacity rentals. Rows 9 and 10, 19 and 20, and 29 and 30 are capacity flow balances; they account for the difference between inherited capacities and capacities passed to the next time period. Since depreciation is suppressed, the above difference is the amount of capacity added during the period. The price variables associated with these balances are capacity flow prices, that is, the buying and selling prices of a unit of capacity. Row 31 is the objective function and represents terminal (fourth-period) evaluation of resource-element capacities using the relative prices $k_1$ and $k_2$. This choice for the objective function is in accord with the usual formulation of multiperiod stock (capacity) accumulation models. The $k_1$ and $k_2$ coefficients replace the capacity stock and flow balance entries which occur in each capacity hold-over activity in previous time periods.

Rows 7 and 8, 17 and 18, and 27 and 28 require special interpretation. Model 4 is taken to represent only the decentralized part of resource allocation after the central decisions with regard to major fixed costs. These rows are designated as tie-in rows after the usual tie-in constraints which they replace and set the scales of the fixed-cost activities to the predetermined integer values represented by $X^*$ parameters in the exogenous column.[121] Where a fixed-cost activity is set to zero, the corre-

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[121] In order to force exact equality between an $X^*$ parameter and the corresponding fixed-cost activity scale, no non-zero slacks are allowed in these rows. This can be handled by an elementary extension of the linear programming format.

sponding variable-cost activity is interpreted likewise as restricted to the zero scale.

Demand is represented by the exogenous entries in the product-balance rows and is assumed to increase from period to period. Instead of providing the extra capacity required for the additional demand of each period, it is generally advantageous to build ahead of demand, that is, to add a larger amount of capacity during a given period than that required for satisfying the demand increase of that period. This occurs in capacity building whenever there are economies of scale which reduce the average cost of new capacity as the scale of the addition increases. Offsetting this advantage is the fact that expenses must be incurred at an earlier time period than if some part of the additional capacity were built later, that is, if capital is tied up in idle, currently unnecessary, capacity. For highly simplified cases it is possible to derive analytical solutions for the problem of optimal capacity addition: [77] for more complex cases, such as the present one, integer programming must be used. The optimal solution to an integer programming formulation specifies the amount and kind of new capacity to be added in each period.

Given these results, it is interesting to analyse the corresponding price implications, especially with regard to the rental price of capacity. Whenever there is unused capacity, the associated rental price will be zero. However, owing to the steady exogenous increase of demand, no unused capacity will persist indefinitely. Eventually the capacity limit will become binding, and the rental price will rise above zero. In the intervening periods, however, the flow price of inherited and passed-on capacities of this particular kind will have remained constant, since in each two consecutive periods the stock (rental) price of capacity sets the difference between the corresponding flow prices. Thus, if the capacity of resource element 1 has been redundant for $n$ periods beginning with period $t$, the stock-rental price for these periods will be 0, and the flow price of capacity in period $t+n$ will be the same as in period $t-1$. In period $t+n+1$, when capacity becomes binding, the stock-rental price (see model 4) equals

$$y_s(t+n+1) = y_s(t+n) - y_f(t+n+1) = y_f(t-1) - y_f(t+n+1),$$

where $y_s$ and $y_f$ refer to capacity stock (rental) and flow prices, respectively, and the parentheses contain the index of the time period. Since the price solution of a multiperiod programming model can be interpreted as representing discounted prices, in current values the flow price of unused capacity increases at a compound-interest rate. If the flow price of the capacity of the second resource-element (which is continuous) is treated as the numeraire in each time period for defining current prices, the rate of interest in the model will coincide with the rental of this continuous capacity.

If the technology of model 4 is stable from period to period, the input requirements for producing additional capacity of resource-element 1 will be the same in a later period as in an earlier one; thus the current flow price of the capacity of this resource element will drop to its initial value as soon as there are additions. As a result, the drop in flow price must be compensated by a high rental to give a rate of return on the holding of this capacity equal to the rate of return on the other capacity. The rental price obtained during the period (or periods) when the capacity is binding compensates for unused periods when rentals are zero. The result is a fluctuating price pattern for the capacity of resource-element 1.

The flow price of the capacity of resource-element 1 allows only for the variable part of building cost. As in a static model, fixed building costs are treated as sunk and do not enter the decentralized price formation mechanism. The decisions pertaining to fixed costs of resource-allocation must be centralized. In more comprehensive models with a larger number of resource elements, there will probably be some resource elements whose fixed building costs are sufficiently minor to be bridged by an average-cost approach, as discussed in connexion with the static models 1, 2 and 3.

The amplitude of the price fluctuations on discontinuous resource-element capacities may be considerably reduced by secondary demands for these capacities. For instance, a large press may be indispensable for turning out refrigerator doors; the same press may, however, also be used for producing multiple units of smaller objects at a single stroke. If installed to make possible the domestic production of high-grade refrigerators, this press may well have unused capacity for several years; this capacity could be used to manufacture smaller objects which constitute the secondary demand for the capacity of the large press. The secondary demand can be reduced as the primary demand increases, since the small objects can be turned out on smaller presses. During a prolonged unused period the stock (rental) price of the capacity of the large press may well be zero. This condition encourages any production activity that can generate economic value from the unused resource. As all primary and secondary demands increase over time, the unused period will eventually end when the full range of production activities makes use of the press. When demand increases, however, it will be necessary to eliminate the lowest-grade uses and to reserve the existing capacity for the most economic activities. This is achieved by allowing the stock (rental) price of capacity to rise to the point at which the lowest-grade uses are eliminated by their inability to meet the rental price. Further increases in demand will successively eliminate higher-grade secondary demands until, finally, the scarcity of capacity will constrain even the primary demand that cannot be shifted to other capacities. At this point, if primary demand is inelastic, additional capacity must be provided.

The hierarchy of primary and secondary demands defines a composite derived-demand function that has a considerable price elasticity, even when the individual demand functions are totally inelastic. However, if these demands have some elasticity of their own, the elasticity of composite demand for the capacity will further increase. Moreover, if some of the demand for a product that requires a heavy use of capacity can be covered from imports during periods of greatest capacity shortage and, conversely, if the same product can be exported during periods of more ample capacity availability, a third influence is constituted that tends to make the composite demand for the discontinuous capacity more elastic. The greater the elasticity of this demand, the smaller will be the fluctuation of capacity rental prices for a fixed time-table of capacity additions. This analysis also suggests that the optimal size of capacity addition will increase with the improvement of capacity use.

The concept of interruptible secondary demand and of peak and off-peak load pricing is thoroughly familiar from studies on electric utilities, where the cycle is a daily one. In the present case the cycle exhibits a periodicity of several years between capacity additions, and this periodicity arises not from demand but from capacity fluctuations. None the less, the common element is the periodically fluctuating ratio of capacity to demand, and thus many of the familiar insights of the electric power-load cycle can be applied to the long-range planning of discrete industrial capacity utilization and pricing. In particular, moderate long-term fluctuations in capacity and product prices and structural fluctuations in the utilization of existing capacities and their complementation by exports and imports should be a normal part of long-range economic planning. The benefits that can be derived from such price and structural fluctuations must be balanced against the disruptions caused by the continuous readjustments in production. These need not, however, have exclusively adverse effects. Cyclical readjustments facilitate the braking of rigidities and vested inefficiencies with which a stable production process often tends to be saddled. Such readjustments may be very helpful in the progressive introduction of technological innovations on which much of the genuine development of an economy so decisively rests.

One question that must be left in a rather unsatisfactory state pertains to a practical price system. While it is suggested here that small indivisibilities are bridged, major fixed costs are still outside the price structure. For administrative and incentive reasons, however, it may be indispensable to distribute many of the major fixed costs that occur in the metalworking sector, even if they are subject to central decisions. It has been found inadvisable to provide enterprises with free resources. How then is the process of decentralization affected if major fixed costs are distributed over the units of capacity or of output after centralized decision-making? Since fixed cost incurrence is centrally decided, it will be unaffected by the change; however, the burdening of low-grade secondary activities with average fixed costs will discourage enterprises from using slack capacities and will thus not be economical. To what extent is the acceptance of such adverse effects justified for he sake of avoiding a wasteful capacity use that will gradually harden into a vested inefficiency? The answer to these questions leads well beyond the usual technology-centred formulation of the problem.

There are, of course, many other questions that remain in an equally unsatisfactory state. Problems of technical innovation, labour training, production scheduling, productivity and many others have not even been touched upon in this study. The centre of attention was occupied by the problem of technical-economic description of meaningful production alternatives for the sector under a given technology in a predominantly static framework and with no institutional constraints from the side of labour skills and the like. The framework of linear and integer programming was used to organize the available alternatives in one particularly simple and obvious fashion without an implied commitment to this framework as necessarily the last word in the organization of this kind of information. Despite a constant effort to simplify the problems, the very nature of the sector is such that it piles complication on complication in a seemingly endless way. Quite possibly it will be necessary to complement the essentially synoptic approach taken here with an adaptive-control type of approach having a totally different orientation, in that it would treat major parts of the system as "black boxes", whose internal workings are fundamentally inaccessible to description and analysis.

# APPENDIX

## NOTATION FOR THE MODELS

### *Rows*

| | |
|---|---|
| 1LIS1 . . . 1LIS7,<br>2LIS1, 2LIS2 | Listed-product balances. The first numeral is the serial number of the branch of the sector, the last is the serial number of the product in the branch. |
| 1EXT, 2EXT | Extrapolated products treated as a single item for each branch. The first numeral is the serial number of the branch. These rows refer to supply-demand balances of the extrapolated products. |
| FE | Foreign-exchange balance. |
| RES1, RES2 | Resource-element capacity balances. The numeral is the serial number of the resource element. |
| DMAT | Direct material input. Refers to material input into production that is accounted for directly in connexion with a product, rather than indirectly through the material input requirements of resource elements. |
| LAB1, LAB2 | Labour input into resource elements. The numeral is the serial number of the class of labour. |
| IMAT | Indirect material input through resource elements. Includes tools, lubricants, form, sand etc. Here only one item is carried in physical units, but several items may be added, or total cost may be carried as a single money sum. |
| CAP | Capital requirement. This is the total capital stock measured in money terms. The price applicable to this resource is the capital-carrying charge consisting of the rate of interest plus any other charges. |
| $ | Annual money cost, accounted directly (a flow). |
| 1STP1 . . . 1STP4, | Step function limits for extrapolated products. |
| 2STP1, 2STP4 | The first numeral refers to branch, the last to the serial number of the step. |

*Rows*

| | |
|---|---|
| 1LFX1...1LFX7,<br>2LFX1, 2LFX2 | Fixed-cost constraints for set-up charges in production of listed products. The first numeral refers to the branch, the last to serial number of product. |
| RFX1, RFX2 | Fixed-cost constraints for resource element capacities. The last numeral is the serial number of the resource element. |

*Columns*

| | |
|---|---|
| 1LIS1...1LIS7<br>2LIS1, 2LIS2 | Production of listed products. The first numeral refers to branch, the last to serial number of product. |
| 1LFX1...1LFX7<br>2LFX1, 2LFX2 | Fixed-cost incurrence activity for production of listed products. Represents the incurrence of set-up charges for a given production series. The first numeral refers to branch, the last to serial number of product. |
| 1LM1...1LM7<br>2LM1, 2LM2 | Import activities for listed products. The first numeral refers to branch, the last to serial number of product. |
| 1STP1...1STP4<br>2STP1...2STP4 | Production step in producing extrapolated products of a branch. Total production scale is sum of the successive steps. The first numeral refers to branch, the last to serial number of step. |
| EXTM (models 1 and 2) | Import of extrapolated products. |
| 1EXTM, 2EXTM<br>(model 3) | Import of extrapolated products. The numeral refers to the serial number of the branch within the sector. |
| RES1, RES2 | Resource-element capacity maintenance. These activities indicate the inputs needed for maintaining (not building) given resource-element capacities. In static one-period models, no building activities occur. The numeral is the serial number of the resource element. |
| RFX1, RFX2 | Fixed-cost incurrence for resource-element capacities. The scales of these activities measure the fraction of fixed cost actually incurred. The numeral is the serial number of the resource element. |
| EXOG | Exogenous activity specifying fixed supplies and demands of different resources. |

### *Indices*

| | |
|---|---|
| $i, j, k, l$ | These indices are dummy variables whose range of meaning is restricted to the definition in which they occur. The same index symbol, for example $i$, may be given different meanings in different definitions. Therefore the meaning of every index occurring in a particular definition is stated as a part of that definition. |

### *Parameters*

| | |
|---|---|
| $a_{ij}$ (models 1, 2, and 3) | Generic designations for all technical coefficients in the models. Subscript $i$ refers to the resource row, following the sequential numbering of all rows shown at the left margin of each model. Subscript $j$ refers to the activity column, following the sequential numbering of all activities shown at the top margin of each model. |
| $a_j^i$ (models 1 and 2) | Input of listed product $j$ into another listed product (serial number not specified). The superscript $i$ refers to the typical product from which the coefficients of the given listed product have been derived. As an input, this coefficient is provided with a negative sign. For example, in model 2, the coefficients in row 2 corresponding to columns 1 through 7 are, in order:<br>$-a_2^1, (1-a_2^1), -a_2^1, -a_2^1, -a_2^2, -a_2^2, -a_2^3.$<br>The positive unit term in the second coefficient, $(1-a_2^1)$, indicates one unit of gross output of listed product 1LIS2 by activity column 1LIS2; in order to arrive at net output, the intermediate input $a_2^1$ (of listed product 1LIS2 into activity 1LIS2) is deducted from the one unit of gross output. This intermediate input is identical for columns 1 through 4, except that only column 2 (activity 1LIS2) produces any output (positive entry) in row 2 (listed product 1LIS2). The four coefficients are identical because they are all derived from typical product 1.<br>In other words, the superscript $i$ does not refer to the serial number of the activity column, e.g. 1 through 4, but to an entirely different |

*Parameters*

| | |
|---|---|
| | series of typical products from which input information is transferred to listed products. It is assumed that columns 1 through 4 (the production activities 1LIS1 — 1LIS4) receive their numerical information from typical product 1, columns 5 and 6 from typical product 2 and column 7 from typical product 3. Conceivably, a situation might occur where two or more listed products are produced by the same process: in this case by-products would be designated by positive $a$ coefficients. |
| $a_{ij,kl}$ (model 3) | Input of listed product number $j$ of branch $i$ into another listed product number $k$ of branch $l$. Typical products from which the given listed product is derived are not distinguished in this notation. Other comments given above for $a_j^i$ also apply here. |
| A | Matrix of $a_j^i$ coefficients of order 7 × 7. |
| I | Identity matrix of same order (7 × 7) as A. The identity matrix has (+1) entries along the main (top left-lower right) diagonal. |
| $k^i$ | Portion of variable production cost of a listed product expressed in money terms per unit of output. Superscript, see $a_j^i$. |
| $k^i$ | Yearly fixed cost associated with production of given listed product. Consists of yearly capital charges of tooling, jigs and fixtures, and time (capacity) cost of setting up the required number of yearly production runs. Superscript, see $a_j^i$. |
| $c_j^i$ (model 2) | Variable capacity requirement of $j$-th resource element in the production of a given listed product. "Variable" means that portion of total capacity requirement that varies directly with scale of production as distinguished from fixed requirement. Superscript, see $a_j^i$. |
| $c_{i,jk}$ (model 3) | Analogous to parameter $c_j^i$. Subscripts: $i$ the serial number of the resource element, $j$ the branch of the listed product and $k$ the serial number of the listed product. |

## *Parameters*

| | |
|---|---|
| $c_j{}^i$ (model 2) | Fixed capacity requirement of $j$-th resource element in the production of a given listed product. Consists of share of time fund of given resource element devoted to setting up the required number of yearly production runs. Superscript, see $a_j{}^i$. |
| $c_{i,jk}$ (model 3) | Analogous to former parameter. Subscript, see $c_{i,jk}$. |
| $\delta_{j,il}$ | Resource element input coefficient into production step of extrapolated product. Subscripts: $j$ the branch, $i$ the serial number of the resource elements and $l$ the step number. |
| $\mu^i$ (models 1 and 2) | Direct material input into production of given listed product. That portion of all material inputs that is accounted for separately for each listed product as distinguished from indirect material inputs accounted for by resource-element capacity use. Superscript, see $a_j{}^i$. |
| $\mu_{jk}$ (model 3) | Analogous to parameter $\mu^i$. Subscripts: $j$, branch of listed product; $k$, serial number of listed product. |
| $\nu_{jl}$ | Material input coefficient into production step of extrapolated product. Subscripts: $j$ the branch and $l$ the step number. |
| $\bar{\varphi}^i$ (model 2) | Capital investment in tooling, jigs and fixtures required for production of a given listed product. Superscript, see $a_j{}^i$. |
| $\varphi_{jk}$ (model 3) | Analogous to parameter $\varphi^i$. Subscripts, see $\mu_{jk}$. |
| $m_j$ (models 1 and 2) | Foreign-exchange requirement in importing a given listed product per unit; that is, the foreign-exchange import price. The subscript refers to the serial number of the listed product. As an input, this coefficient is provided with a negative sign. At times, the corresponding activity might be permitted to run in reverse signifying an export; in this situation $m_j$ becomes the export price. |
| $m_{jk}$ (model 3) | Analogous to parameter $m_j$. Subscripts, see $\mu_{jk}$. |

*Parameters*

| | |
|---|---|
| $n$ (models 1 and 2) | Foreign-exchange requirement for importing a unit of the extrapolated products of the branch: that is, the import price of the extrapolated products treated as a single aggregate commodity. As an input, this coefficient is provided with a negative sign. At times, the corresponding activity might be permitted to run in reverse, signifying an export, in which case $n$ becomes the export price. |
| $n_j$ (model 3) | Analogous to parameter $n$. Subscript, $j$, branch of extrapolated product. |
| $\gamma_j$ | Production cost per unit of extrapolated products treated in aggregate terms. The subscript $j$ refers to the serial number of the step in the step-function used to represent the rising trend of these money costs. |
| $d_j$ (models 1 and 2) | Yearly demand for the $j$-th listed product. |
| $d_{jk}$ (model 3) | Analogous to former parameter. Subscripts: see $\mu_{jk}$. |
| $e$ (models 1 and 2) | Yearly demand for extrapolated products. |
| $e_j$ (model 3) | Yearly demand for extrapolated products of branch $j$. |
| $b$ | Exogenous foreign-exchange allocation to or availability for the model. If negative, it signifies a net requirement: in the latter case imports have to be treated as free variables that may have negative values in order to allow foreign-exchange generation by export. |
| $l_j$ (models 1 and 2) | Limit for individual step $j$ in step function for extrapolated products. See $\gamma_j$. |
| $l_{ij}$ (model 3) | Analogous to parameter $l_j$. Subscripts: $i$, branch of extrapolated product; $j$, serial number of individual step-in-step function. |
| $\lambda_{ij}$ | Variable part of labour of classification $i$ used per year in maintaining a unit capacity of resource element $j$. |
| $\lambda_{ij}$ | Fixed part of labour of classification $i$ used per |

### *Parameters*

| | |
|---|---|
| | year in maintaining any capacity of resource element $j$ in excess of zero. |
| $\xi_j$ | Variable part of indirect material input used per year in maintaining a unit capacity of resource element $j$. |
| $\xi_j$ | Fixed part of indirect material input used per year in maintaining any capacity of resource element $j$ in excess of zero. |
| $\varkappa_j$ | Variable part of capital stock tied up in maintaining a unit capacity of resource element $j$. |
| $\varkappa_j$ | Fixed part of capital stock tied up in maintaining any capacity of resource element $j$ in excess of zero. |
| $f_{kj}$ | Upper bound on production scale of listed product $j$ in branch $k$. |
| $g_j$ | Limit on capacity of a single resource element $j$. |

### *Additional notation for model 4*

| | |
|---|---|
| $X_j^*$ | Pre-set integer-valued scale of fixed-cost activity for building capacity $j$ (subscript omitted). |
| $t$ | Generalized reference to index of time period, $t=0, \ldots 4$. |
| $H_j^*$ | Amount of capacity $j$ inherited from time period $t=0$ (subscript omitted). |
| $k$ | Terminal (time period $t=4$) valuation of capacity $j$; $j=1, 2$. |

## ANNEX

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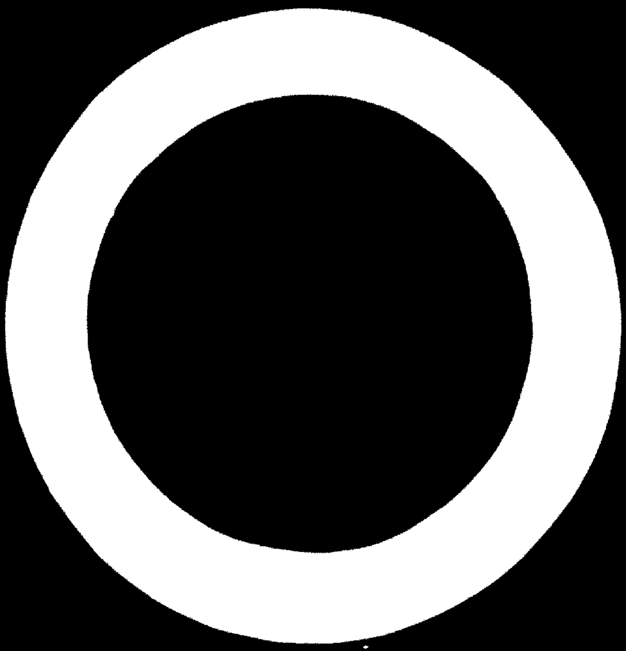

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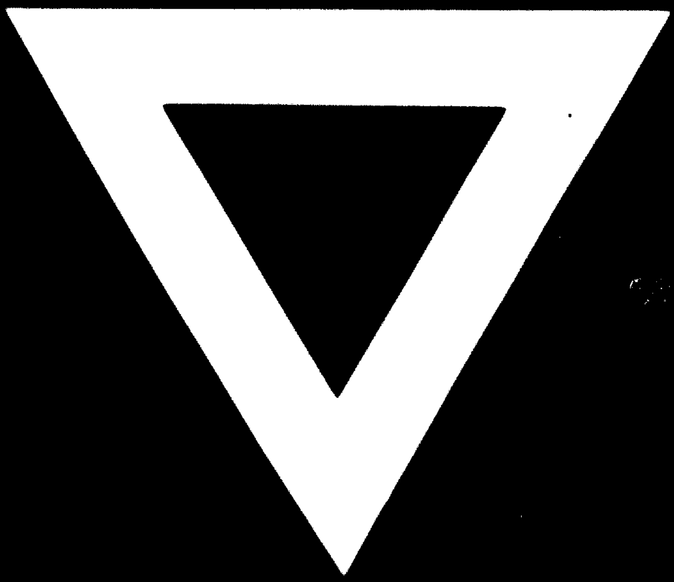

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