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"CYBERNETICS AND PUBLIC ORDER"

A paper presented at the Conference on
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Cybernetics and Public Order

Frederick B. Wood

Cybernetics is defined as the science of communication and control in the organism and the machine. There are two small books giving elementary reviews of cybernetics from different viewpoints. G.T. Guilbaud in his book, What Is Cybernetics? [1] gives an elementary explanation of cybernetics starting from a circuit or internal functioning viewpoint. Neville Moray in his book, Cybernetics,[2] deals more with the external behavior of cybernetic systems and with some of the potential psychological and philosophical implications.

In considering "public order", this paper will discuss the relevance of techniques from engineering cybernetics when used in appropriate models to help us maintain a balance between human FREEDOM and system STABILITY in social and economic life.

The problems of human freedom have traditionally been studied more deeply by the writers, poets, philosophers and religious leaders, while the problems of stability have been studied more thoroughly by engineers, political scientists, economists and military leaders. The intense specialization of our more complex society has led to a gap between the specialists on problems of human freedom closely related to the humanities and the specialists in system stability more closely related to the application of the physical sciences.

There are two ways known by which engineers can help bridge the gap between the humanities and the application of the sciences. First, many engineers could cast small threads across the gap by reviewing the impact of their own work. A second more powerful approach lies on the horizon, namely the extended use of analogies from cybernetics and information theory to bridge the gap between the humanities and the sciences and to bridge the gaps between the special fields within science. The first method promotes "inter-disciplinary" research, while the second is closer to initiating "multi-disciplinary" research.[3]

A Perspective of Cybernetic Models and Technologies

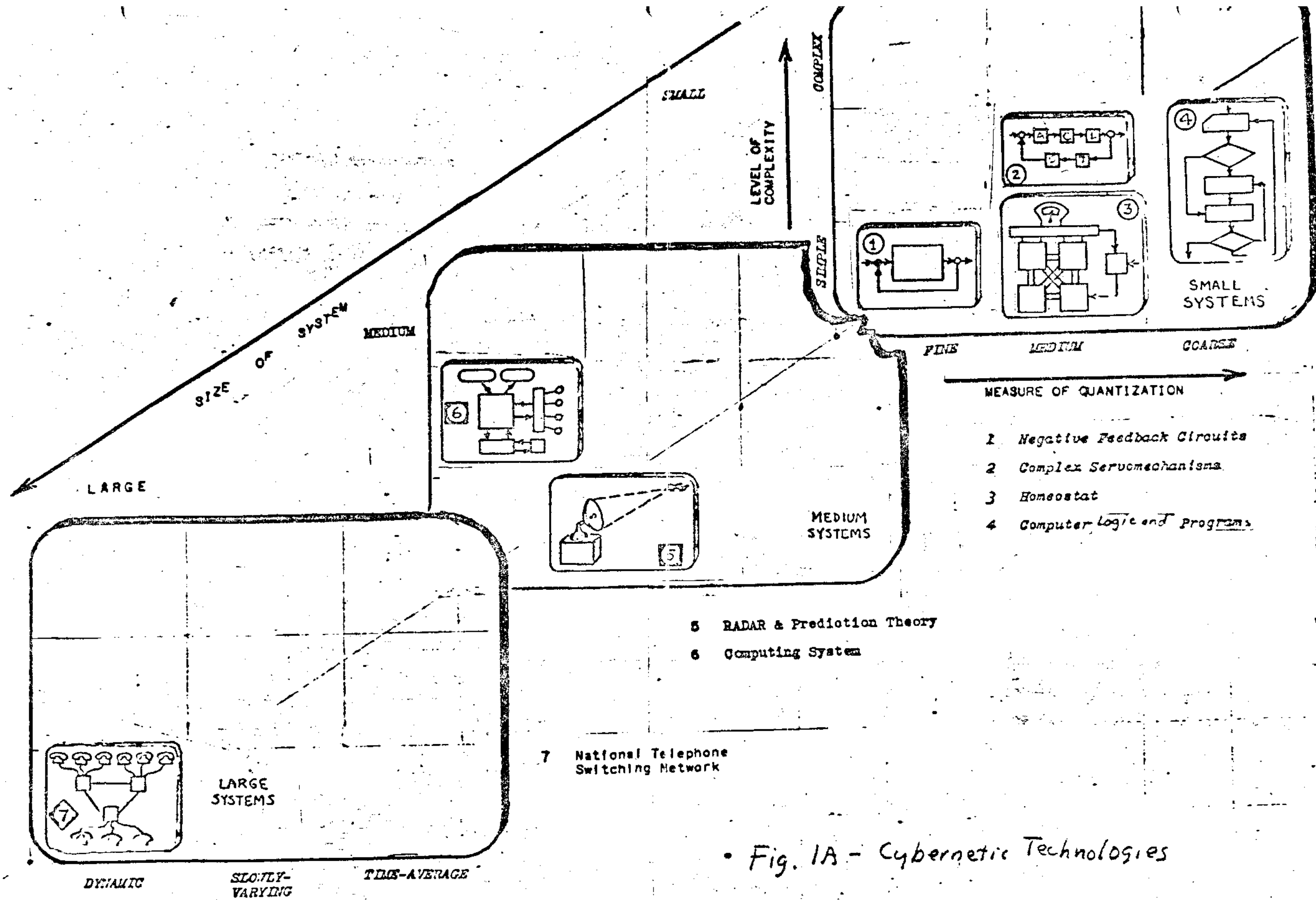
What is cybernetics? If we are to judge from Wiener's book, it includes at least information theory, with which we are now reasonably familiar; something that might be called smoothing, filtering, detection and prediction theory, which deals with finding the presence of and predicting the future value of signals, usually in the presence of noise; and negative feedback and servomechanisms theory, which Wiener traces back to an early treatise on the governor (the device that keeps the speed of a steam engine constant) published by James Clerk Maxwell in 1868. We must, I think, also include another field which may be described as automata and complicated machines. This includes the design and programming of digital machines.

Finally, we must include any phenomena of life which resemble anything in this list or which embody similar processes. This brings to mind at once certain behavioral and regulatory functions of the body, but Wiener goes much further. In his second autobiographical volume, I Am a Mathematician, he says that sociology and anthropology are primarily sciences of communication and therefore fall under the general head of cybernetics, and he includes, as a special branch of sociology, economics as well.[4]

Now the specialists in each field of science such as information theory, servomechanisms, automatic control, computers, sociology and economics do not generally accept Norbert Wiener's inclusion of their special field as a part of the general field of cybernetics. It is my position that in our more complex society with its exponentially growing output of scientific and engineering reports, we need an integrating philosophy around which to organize a framework for classifying the output and organizing the cooperation of the various specialists in the interdisciplinary work that the complexity of our civilization requires. Also we will need more "multidisciplinary" scientists to help organize our scientific ventures of the future. In connection with these problems I would like to mention a little book by Richards and Gibson, English Through Pictures, especially the sections on the processes of going from the whole to the part; the concepts of feedback; the perspective of the growing complexity of civilization and the exponential rise of related functions such as population and energy production.[5]

To start from the whole domain of cybernetics and work down to the specific models and technologies that can help us with the problem of public order, let us first examine a three-dimensional chart of cybernetic technologies and models shown as Fig. 1.

From left to right we show the degree of quantization from fine to coarse. The vertical scale is the degree of complexity. The figure is cut into three plates; the back one is for small, the middle one for medium, and the front one is for large systems. To develop a general perspective I shall review briefly the cybernetic technologies and cybernetic models shown in Fig. 1. Then I shall go into more detail on the particular ones that we can make practical use of in the immediate future.



• Fig. 1A - Cybernetic Technologies

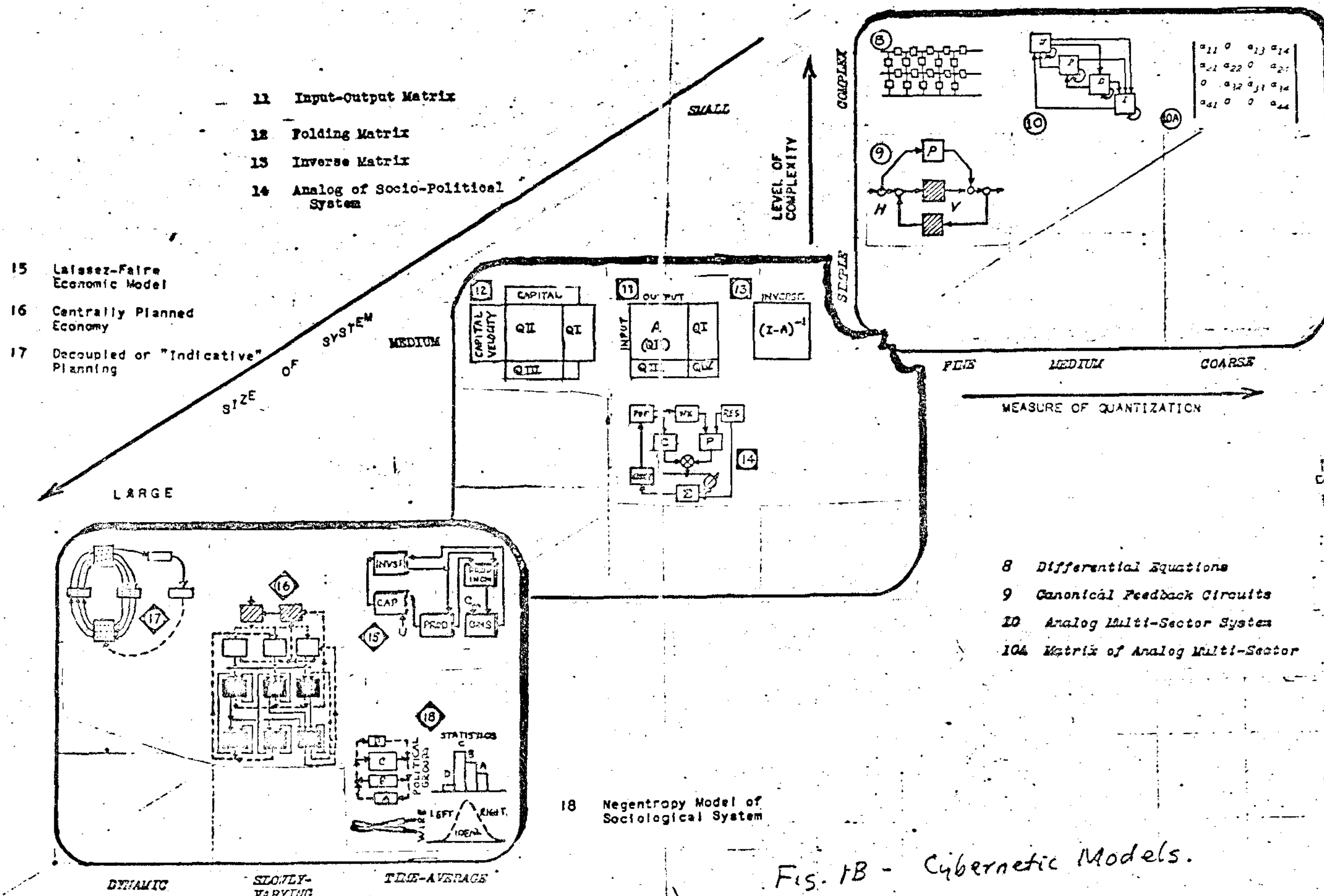


Fig. 1B - Cybernetic Models.

First I shall review the cybernetic technologies shown in Fig. 1A, and then review the cybernetic models shown in the ~~same~~ Figure 1B.

(1) Negative Feedback Circuits

The feedback amplifiers of electronic engineering have analogous counterparts in mechanical and thermal systems and also in biological and social systems. A block diagram representing a negative feedback amplifier is shown as section 1 in the small system plane in Fig. 1. Consider the amplifier represented by the block which amplifies a small input voltage to produce a large output voltage. If we take part of the output voltage and feed it back to the input as indicated by the lower line, the behavior of the circuit will be changed. If the output voltage adds to the input voltage (positive feedback), the amplifier produces a still larger output voltage. This results in the circuit going into oscillation in which the output voltage increases on each cycle, making an unstable system unless some limiting controls are introduced. If we design the feedback loop so that part of the output signal is coupled back to the input so that it subtracts from the input voltage (negative feedback), the amount of amplification is reduced but the amplifier is made stable. An example of electronic amplifiers and feedback amplifiers is given by Sluckin.[6]

The example discussed so far is drawn from the field of electrical engineering. There are negative feedback circuits in mechanical and heating systems having the same functions.

The governor on a steam engine has a set of weights which are pulled away from the center of a rotating shaft as the speed increases. These weights operate levers which close the steam valve as the steam engine goes faster so that the engine will be slowed down to the desired speed. Illustrations of heating systems and steam governors are illustrated in the Scientific American Books.[7]

(2) Complex Servomechanisms

Here we have a block diagram showing an equivalent circuit of a mechanism and the control circuits that control the movement of the access arm in a magnetic disk file. Starting from the left the desired angle is set by the control logic by setting the desired tap on a potentiometer. This results in an error voltage into the amplifier, the first block (A). This applies a voltage to the clutch, second block (C), which develops a torque which rotates the capstan (L) through an angle toward the desired position. Of the two elements in the feedback loop one represents the tachometer (T) which indicates how fast the arm is moving, and the second represents the potentiometer (P) which shows how close the arm is to the desired position.[8]

(3) Homeostat

The homeostat is a combination of feedback loops, adding circuits, read-only memory, and switching circuits which have the property of being ultrastable.

An electromechanical homeostat has been designed and demonstrated by W. Ross Ashby.[9] Similarly an electronic homeostat has been built by Earl J. Kletsky,[10] and homeostats can be simulated by computer programs. Ashby's model shown in Section 3 has four magnetic coil meters in which a signal proportional to the pointer position of each is connected to the other coils. A desired range of meter pointer position is defined as the range of stability. The switching circuits sample the meters every few seconds. When any meters are outside the desired range, the switching circuits take the next random numbers from the read-only memory to change the coupling between the meters, and repeat until all meter pointers are within the stable range.

I have mentioned the homeostat because the elementary feedback loops are purely deterministic mechanisms. They keep a system moving toward an externally determined goal when negative feedback is employed, and lead to an unstable system going dangerously out of control when positive feedback alone is employed. The added feature of the homeostat is that there are a number of alternative states satisfying the condition of stability. This has implication for more complex application to social and economic systems, in that it suggests that freedom of choice between a number of alternatives is possible under fixed goals for the system.

(4) Computer Logic and Computer Programs

Section 4 of Fig. 1 represents the flow diagram of a computer program. We refer to the program or instructions as "software", while we call the physical switching circuits, logical elements, adders, shift registers, and memory units "hardware." The software, or program, consists of a set of logical instructions specifying at each step in the calculation how the different sets of logical elements are to be connected and when to go to the next step in the program. Elementary paperback books on computers have been written by Irving Adler, by Stanley Englebardt, and by D.S. Halacy.[11]

Computers give us an example of one of the objectives of general systems research - the search for simplification of our understanding of nature and machines through the finding of forms that are isomorphic between different phenomena and levels of organization. The basic negative feedback circuit of Section 1 appears in the computer hardware as cathode follower circuits and error checking routines built into the logic and also on the next level in the software as feedback paths in the program logic flow diagram.

(5) RADAR and Prediction Theory

Switching our attention to medium-size systems in Fig. 1, we examine the role of RADAR and Prediction Theory shown in Section 5. Radar equipment may be used to detect where an aircraft is. By coupling a small computer to the radar and employing prediction theory one may compute the projected path of the aircraft and in turn the anticipated direction in which anti-aircraft guns should be fired to shoot down the aircraft. This combination of radar, the computer, and anti-aircraft guns is an example of a set of negative feedback loops to accomplish a specific purpose. This process of linear prediction is explained briefly by J.R. Pierce in his chapter on cybernetics.[12] The early history of radar development is described by Dr. Page of the Naval Research Laboratory, and the development of microwave radar in World War II is summarized in Vol. I of the M.I.T. Radiation Laboratory Series.[13]

(6) Computing Systems

The diagram in Section 6 represents a modern electronic digital computer. The oval-shaped units represent input and output devices such as card readers, keyboard, card punches, and printers. The square boxes represent the logic switching circuits and working memory; the rectangular box represents the multi-plexing units, and the circles represent magnietic tape units. When given an appropriate program or set of instructions, these computers can solve problems involving methematical calculations and logical tests in a few minutes' time. These problems would take hundreds of hours to solve on the early relay computer of World War II, and would take many man-years to hand calculate.

To keep up with the current developments in computing, any one of the following journals is very helpful: Computers and Automation, Datamation, and Data Processing Magazine.

(7) National Telephone Switching Network

The diagram in Section 7 represents the U.S. telephone network. The square blocks represent switching centers; the lines between them represent telephone cables and microwave lines, and the circles marked represent individual subscriber telephones. The national telephone network in the U.S. is one of the largest man-made systems in the world. There are 72 million telephones in the system. Any one telephone in the system can be connected to any one of the other 72 million telephones. Over half of the telephones can be switched automatically through direct distance dialing. One can keep up-to-date with new developments in the telephone network by following the Bell Laboratories Record.

We shall now go over the chart of Fig. 1B ~~again~~, this time focusing on the cybernetic models which are analogous to the circuits, systems, and programs of cybernetic technology. These models are classed as "cybernetic" in the sense defined by Norbert Wiener, in that the structure of sociological systems is composed of a complex set of feedback loops analogous to the more elementary feedback loops of the electrical and mechanical systems. They are also "cybernetic" in a second sense, in that the parameters of the sociological systems which we are able to analyse are either calculated or are simulated by use of the analog circuits, or digital computers, and in more elaborate cases the data is collected over the telephone switching network.

(8) Differential Equations

The diagram in Section 8 of Fig. 1 illustrates a more complicated situation than in Sections 1, 2 or 3. This more general system in which there are n variables, with n x n relationships between these n variables may become too complicated to show clearly by simple feedback loops. We will have made substantial progress in understanding the complex system if we can specify a set of differential equations representing the system. Even if we do not have solutions to the differential equations, we can learn something about the conditions for stability by using Liapunov's second or direct method.[14]

(9) Canonical Feedback Circuits

Section 9 of Fig. 1B represents the special case where the set of differential equations representing a multivariable system can be grouped into related sets of equations which are separable into matrix relationships which look like more elementary feedback circuits. Mihajo Mesarovic has defined a set of structures for three categories of linear systems.[15] The block diagram of Section 9 represents an H-canonical structure or mixed system in which the upper block is a P-canonical structure in which the output is dependent only on the input, and the lower two blocks together constitute a V-canonical structure in which each output is dependent upon one input plus feedback from all the other outputs. This V-canonical feedback matrix system has the advantage of being separable into parts which are symmetric and skewsymmetric such as the components of an electromagnetic field, or a hydraulic system separable into compressible and incompressible fluid matrix components. For a small number of multiple loops it may be simpler to use the direct methods outlined by Professor O.J.M. Smith.[16]

(10) Analog Multi-SectorSystem

The feedback circuits of Section 10 of Fig. 1 represent an analog multi-sector system such as an elementary model of an economic system in which the four elements going diagonally down are (1) wage-earner, (2) production of goods, (3) distributio of goods, and (4) investment. This set of multiple feedback loops corresponds to a cybernetic model of the economy described by D.A. Bell,[17] rearranged to show more simply the relationships between different cybernetic models. Some more sophisticated models can be found in <u>Microanalysis of Socio-economic System</u> by Orcutt and by others.[18]

This economic analog multi-sector system is a slowly varying system. We may be able to reduce it to a static model by integrating the flow in each path for a fixed period like a year. If we do this simplification, the results can be represented as a matrix of sixteen numbers, arranged as shown in Section 10A of Fig. 1. The coefficients a_{ij} in the matrix of Section 10A correspond to the positive and negative feedback loops between the different parts of the network in Section 10. This illustrates the transition from a feedback loop representation used in simple cases to the mathematical matrix representation used in more complicated problems. If we increase the number of elements from four to 86 (the sectors used by the U.S. Dept.of Commerce) and add six more elements for final demand, we have a multi-sector model which would be too complicated to represent by an equivalent circuit, but is easy to represent by a matrix of 92 by 92 elements.[19] We have now arrived at the Leontief matrix, which was developed independently long before the development of cybernetics. This path of development through the perspective of cybernetic models and technologies gives us a better idea of how different elements of cybernetic theory are related.

(11) Leontief Input-Output Matrix

Professor Leontief of Harvard developed over a number of years a system of studying the interrelationship between the different sectors of the economy.[20] The square marked A in Section 11 for the 1958 U.S. data would be a matrix of 86 columns and 86 rows. The values of the element of this part of the matrix represent the value of the goods produced in given industries in the row and purchased by the industries in the columns. For example, the coefficient a_{2074} in row 20 represents the products from industrial sector 20 (lumber) supplied to sector 74 (research).

The cross-hatched section of the matrix on the right represents the "final demand" part of the economy representing consumption, capital formation, exports, and government purchases. The lower cross-hatched section of the matrix represents the added value in manufacturing from labor (wages), profits, taxes, and imports. The details of the sectors will be shown later in Fig. 4. Leontief's matrix representation of the interdependence of the different industries in a country makes it possible to explore the interaction throughout the economy of proposed changes in one sector. Leontief has also developed methods of relating capital and labor requirements to the coefficients in the input-output matrix.

(12) Folding Matrix

The Russians have added a feature to the Leontief matrix, which they call a folding matrix.[21] They have converted some of Leontief's mathematical extensions into a simple display table. The black sectors added in Section 12 represent additional matrixes showing in the upper part the capital goods required to support the different sections of the economy, and on the left the amount per sector and the rate at which this capital is used to enable the sector to function properly.

The total picture of the Russian folding matrix helps one get a perspective of the whole picture of the interindustry relationships and requirements for a specified rate of economic growth.

(13) Inverse Matrix

The Leontief matrix of Section 11 can be used to trace the effect throughout the economy of any proposed change in one sector. The inverse matrix of Section 13 of Fig. 1 represents a method also developed by Leontief for simplifying the use of the data in studying the economy. By use of a high speed electronic computer, the identity matrix minus the Leontief technological matrix (a_{ij}) is inverted, giving the inverse matrix (b_{ij}). A row in the inverse matrix gives the contribution from each industry identified at the top of the column, required for one dollar final demand in the industry named at the left of the row.

(14) Analog Socio-Political Systems

It is possible to represent the relationship between different parts of an economic and political system by analog computing systems. N.D. Howard, some years ago, set up an analog computer for the development of an undeveloped country.[22] For national behavior Howard set up the differential equation on the basis of Rashevsky's work in mathematical biophysics.[23] Then he connected an analog computer as shown in Section 14 of Fig. 1 to explore how the various factors interacted in the development of industrial production within a colonial socio-economic system. References to the growing volume of computer simulation studies, most of which are now digital computer simulation, can be found in the journal Behavioral Science.

Karl W. Deutsch has summarized the state of progress in applying concepts of cybernetics to a theory of national and international politics in his book, The Nerves of Government.[24]

(15) Laissez-Faire Economic Model (Kalecki Model of Capitalist Production)

The block diagram in Section 15 of Fig. 1 shows the relation between production and the investor collecting his profits and reinvesting to make more profits. This model of the capitalist economic system is based on Kalecki's mathematical model of a natural feedback system. It has now grown more complex as the time delay between production and distribution of profits is such that additional feedback loops are needed so that corrections can be applied to keep the system stable.

In 1951 O.J.M. Smith built an electronic analog of the capitalist production system following Kalecki's model, so that the amplifiers were scaled for the interest rates and production time lags of the American economy. He found the circuit went into oscillation corresponding to a period of about 10 years, which roughly corresponds to the period between different depressions and recessions in our economic system.[25] Since then with adjustment of the interest rate by the Federal Reserve Board and the increase and decrease of defense spending and other government projects, the system is partly compensated, so that we no longer need to have depressions. However, there is a prospect that the Russians may challenge us on the economic front if they are successful in their computer-communication system and simulation of their economy to make their socialist economy more efficient.[26]

(16). Centrally Planned Economy

The diagram of Section 16 represents a model developed by the Polish Academy of Sciences for illustrating how a socialist planned economy could substitute a plan and information-collecting network in place of the market and employ government controls to direct the economy.[27]

In the diagram in Section 16 the top cross-hatched blocks represent the economic plan and the reports on what has happened for comparison. The left column represents the producer goods industry, the center consumer goods, and the right column the consumers and labor force. The bottom row (solid black) represents production, the next row up exchange, and the upper rows (white) represent information collection.

(17) Decoupled or "Indicative" Planning

The diagram of Section 17 represents a combination of central planning and planning by individual sectors of industrial enterprises. The arrows which go through the four blocks on the left represent a series of iterations. Either a government planning agency or the central office of a corporation requests the individual sectors or divisions to make plans which they send in to the central office, which then checks them for consistency and sends them back for further revision. When they are compatible, this results in a national plan without the central government interfering with the details of the individual industries. This is called indicative planning, because the plan "indicates" how a certain objective might be obtained. This process is related to the "decomposition principle" developed by George B. Dantzig of RAND Corporation in operations research.[28]

(18) Negentropy Models of Sociological Systems

Section 18 of Fig. 1 illustrates a method of analysing certain properties of a sociological system for which social scientists have not yet succeeded in defining a detailed feedback loop model. Therefore the feedback loops here are shown as dotted lines on account of the uncertainty. To the right of this feedback model a probability distribution of political ideas of a hypothetical country is plotted. The rectangular blocks represent the membership or participation in the political groups. The labels A through D range from the conservative right to the radical left. The dotted bell-shaped curve below represents a theoretically ideal distribution curve for a country with an ideal balance between freedom and stability appropriate to its particular stage of industrial development.

The telegraph wires in the lower left indicate that where numerical data such as party membership statistics are available, we can use an analogy from electrical communication theory. We use the continuous channel model of information theory and consider the probabilities that people belong to or believe in different political parties as analogous to the set of probabilities that a set of messages will be sent over a telegraph line. Computing the average negative entropy of the telegraph messages gives us a relative measure of the efficiency of the coding of the telegraph messages. Applying the same formula by analogy to the probabilities of membership in political parties gives a value of negentropy to compare with an ideal value computed from the ideal distribution.

Now that we have examined the range of cybernetic models, let us consider in greater detail a model which can be adjusted to represent various economic systems. Then we shall examine how we can integrate the effect of the complex feedback loops over a period of years to reduce the level of quantization to the level of accessible data on the economic system to obtain Leontief Input-Output Matrices for use in understanding economic systems, whether they be free-enterprise, indicative-planned, or centrally-planned.

To make a bridge between the broad brush view of the full range of the cybernetic models and technologies applicable to social and economic problems, I have selected two oversimplified models, one a model representing a capitalist economic system, and the second representing a socialist centrally planned economy.

Modelling Economic Systems

Fig. 2 is a macrodynamic production analog representing the more significant features of the laissez-faire economic model of Section 15 of Fig. 1. This diagram represents an electronic analogue that was built and demonstrated in 1951 by O.J.M. Smith and H.F. Erdley.[30] Here the elements have been shifted for easier comparison with other systems. It is based upon the mathematical model of M. Kalecki.[31] Although this model is too oversimplified to be used to aid in policy making, its demonstration of business cycles is a useful educational tool.

In this model the "investor maximizes profit," block I in Fig. 2, receives information on the national income (B) and the total industrial equipment (K). The investor is assumed to increase his investment in production facilities with increasing

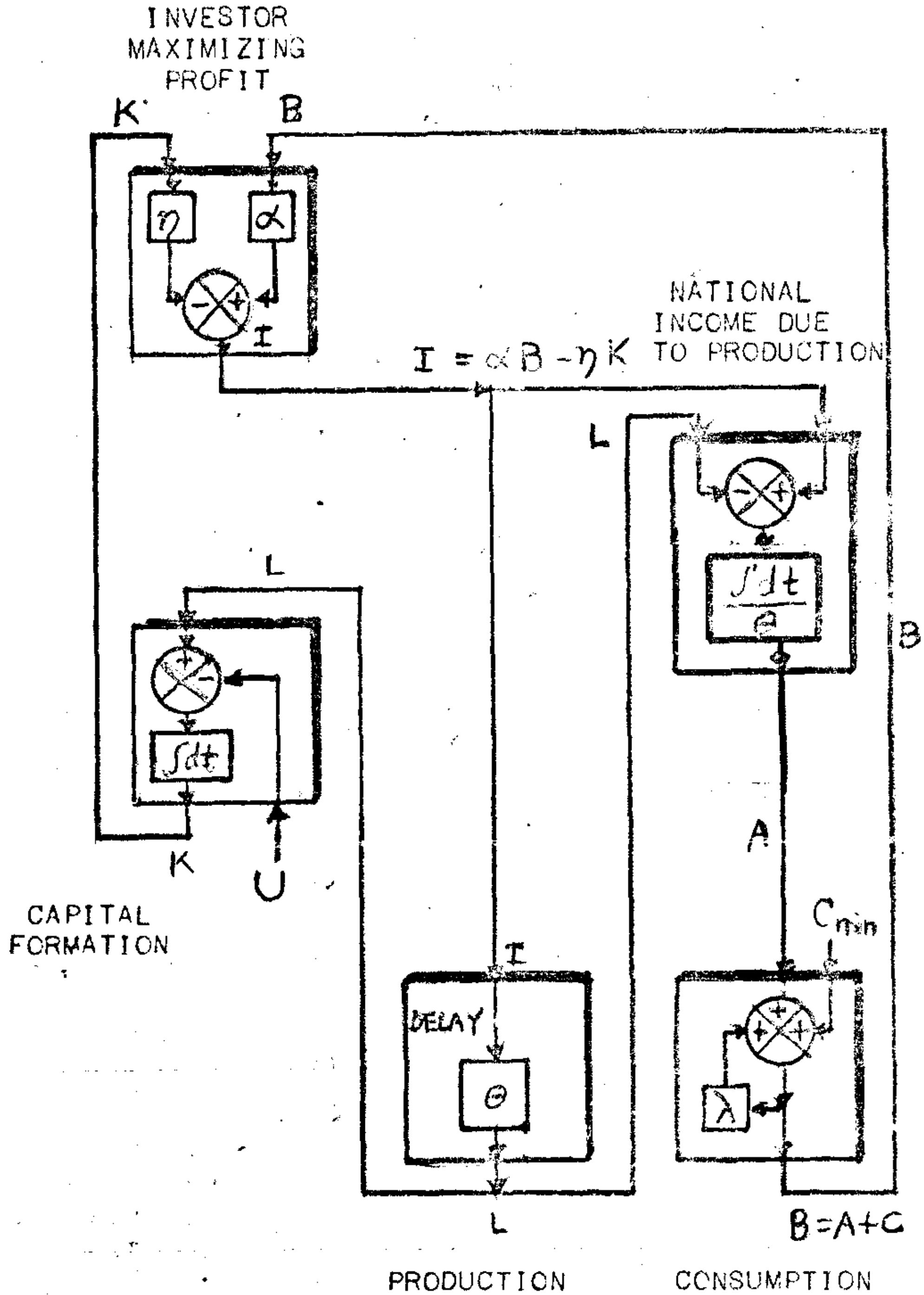


Figure 2. A Model of a Capitalist Economic System Based upon Kalecki's Model.

national income and decrease his investment orders as he sees the total industrial equipment increase toward a capability of overproduction. In this oversimplified model the stock market does not appear, because the model has been reduced to one industry. A more detailed study would be needed to show the operation of the stock market which is organized to arrange the distribution of investment among the different industries and firms within the industries.

The invested funds influence two parts of the systems: first the funds pay wages and add to the national income (A) before any products (L) are delivered; and second after a time delay (θ) producer goods or tools (L) are delivered to industrial equipment (K). In this model the money invested minus the tools produced is the contribution of national income. If the production rate exceeds the depreciation and obsolescence rate (V), the total capital goods or industrial equipment, the integral of $dK = (L-V)\,dt$ increases, having a negative feedback effect $(-\eta K)$ on future investment. The national income due to production (A) is the integral of

$$dA = \left(\frac{I - L}{\theta} \right) dt \qquad \text{as shown in Section A of Fig. 2.}$$

In the section "consumption" we show another postulate of Kalecki's, namely that consumption is a sum of an irreducible minimum (C_m) plus a component proportional to national income (B). This is illustrated by the internal positive feedback loop (λ

Smith and Erdley built an electric analog representing this model. They designed the circuit so that 0.0002 seconds of operation of the analog circuit represented one year of time in a real economic system. When they set the gain of the amplifiers so that the constants η, α, and λ and the time delay θ represented typical average values for the U.S. economy, the analog circuit went into oscillation at a frequency of 500 cycles per second which corresponded to a cycle of 10 years between depressions.

One can learn from this simple model that the stability of the economic system is sensitive to the adjustment of λ and α, and that the frequency of the business cycles is strongly influenced by the constant η. It can be seen that changes in consumer credit influence λ, and that changes in Security and Exchange Commission rules influence α. Thus the Federal Reserve Board or the S.E.C. have the opportunity of adjusting the stability of the economic system by changing their rules, thus effectively changing these constants of the system.

The famous economist J.M. Keynes in 1936 published a theory of employment which can be interpreted as an extension of Kalecki's model to the two industry case, namely producer's goods and consumers goods.[32] The mathematics of Keynes' theory has been summarized and explained by L.R. Klein.[33] Arnold Tustin, an electrical engineering professor at University of Birmingham, shows an equivalent network for the economic system based on Keynsian principles.[34] Keynes showed on the macrodynamic level that a comparatively small increase in the flow of money around the capital-goods loop is amplified via the comsumers-goods loop *into a much larger change in total income.*

Thus Keynesian theory gives us an overall picture of the economic system dealing in total investment, production, consumption and interest rates. When it becomes necessary due to strong military or economic or ideological competition to know the effect of further investment in particular industries, one must use a more detailed system of analysis to compute the multipliers for each sector of industry. This can be done with the Leontief input-output matrices which we will discuss in more detail later.

Fig. 3 is a model of a centrally planned economy developed by the Polish Academy of Sciences Econometric Commission.[35] *It also is an oversimplified model for teaching purposes, i.e., it does not have sufficient detail for real economic decision-making. This model shown in Fig. 3 is an expansion of the model shown in Section 16 of Fib. 1. In row I the "investor maximizing profit" of Fig. 2 is replaced by a planning system* ABC^{I}*. The "consumption" section of the capitalist system is recognizable as* C^{IV} *in the lower right hand corner. The production system is split into four parts* A^{IV}_{0}, A^{IV}_{1}, B^{IV}_{0}, B^{IV}_{1} *. The A's represent producer goods, and the B's consumer goods. The subscript "0" represents perishable goods, and the subscript "1" represents durable goods.*

The second row constitutes an information system providing budgets for each sector of industry plus a sum of family budgets. The third row represents a transaction system in which A^{III} *and* B^{III} *represent the exchange of goods, and* C^{III} *represents the manpower market. In the top row on the right* ABC^{I} *represents a central information system that collects information from all*

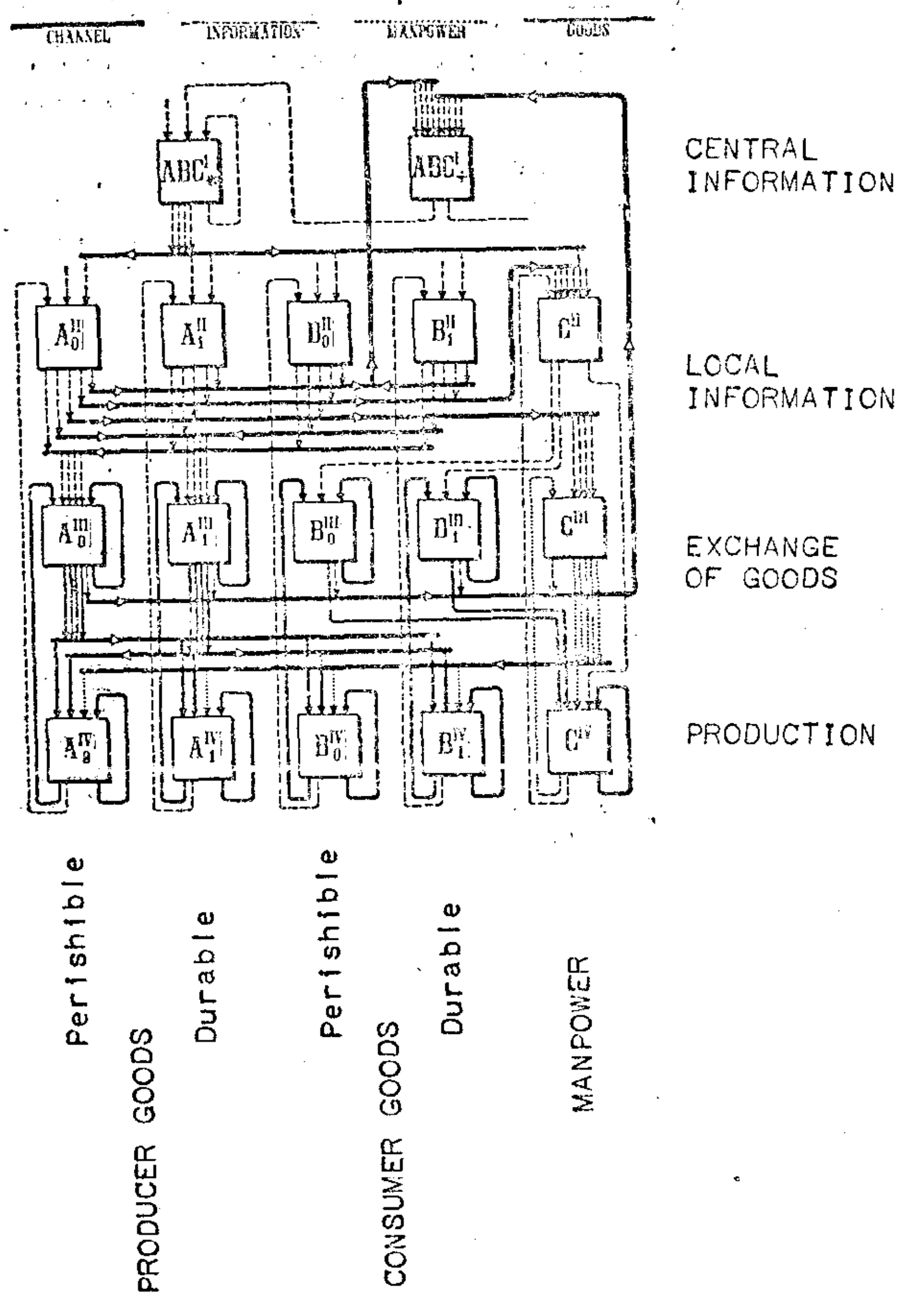


Fig. 3. Model of a Centrally Planned National Economy. *

*Adapted from H. Greniewski, <u>Cybernetics Without Mathematics</u>, Pergamon Press.

industrial sectors for comparison with the plan.

In this model we have three kinds of circuits, i.e., the flow of information, the flow of manpower, and the flow of goods. These are represented in Fig. 3 by dashed lines, dotted lines, and solid lines respectively. In this model consumption is considered as the production of man-power.

If we examine this example of socialist planning to see if there is anything of value to our capitalist system, we note that information systems , apart from politically imposed controls, might help our government follow the state of the economy and also might help our individual businesses in their market studies; provided individual firms still have freedom of action. In the next section we shall examine a method analyzing any kind of economic system - capitalist or socialist.

We have already had an introduction to the Leontief input-output matrix in Section 11 of our perspective of cybernetic models and technologies. The Leontief matrix of Section 11 of Fig. 1 is shown in more detail in Fig. 4. The corresponding sections in both figures are crosshatched. There is a long history to the development of input-output matrices, which precedes the recent history of cybernetics.

From an historical point of view, the first step toward a form of general equilibrium analysis, from which the input-output method stems, is customarily traced to the famous Tableau Économique of the French physiocrat Francois Quesnay, published in 1758. Later, in 1877, the French economist Leon Walras provided an abstract mathematical model based on the interdependencies of the productive sectors of the economy, but it was not until the mid-1930's that Professor Wassily Leontief,

		Purchasing Sectors		
		Intermediate Use	Final Use (Net Output)	Gross Output
		Sector 1 · · · · j · · · · n	Investment, Consumption, Government, Exports, Total Final Use	Production
Producing Sector	1	$X_{11} \cdots X_{1j} \cdots X_{1n}$	I_1 C_1 G_1 E_1 Y_1	X_1
	2	(Quadrant II)	(Quadrant I)	
	i	X_{i1} X_{ij} X_{in}	I_i C_i G_i E_i Y_i	X_i
	n	X_{n1} X_{nj} X_{nn}	I_n C_n G_n E_n Y_n	X_n
Primary Inputs (Value Added)	Depreciation	J_1 J_j J_n		J
	Wages (Households)	D_1 D_j D_n		D
	Taxes	H_1 H_j H_m		H
	Imports	F_1 F_j F_m		F
	Sub-Total	V_1 V_j V_n (Quadrant III)	V_I V_C V_G V_E (Quadrant IV)	V
Total Production		X_1 X_j X_n	I C G E Y	X

Fig. 4. Leontief Input-Output Matrix (Adapted from Lofting and McGauhey)

of Harvard University, developed the first applied model of this type on the basis of the empirical data available for the economy of the United States.[37]

Research in input-output economics has grown rapidly since the 1930's, and statistical analyses of interindustry relations have now been undertaken in more than twenty countries to complement the more traditional forms of economic studies.[38] Such interindustry studies can be valuable in guiding both private and public bodies in investment decisions and other matters related to resource allocation.

Prior to November 1964 the interindustry relations study for 1947 was the last officially published study of this type for the United States. Formal government work of this kind was temporarily suspended in 1952. However, on November 11, 1964 the results of a study based on 1958 census data were made available by the United States Department of Commerce.

From the technical viewpoint the basis of the Leontief analytical system is the input-output table. The table is so termed since it shows the manner in which the output of each industry is distributed among other industries as inputs for further processing; it also depicts the output going into final consumption in various forms.

The normal method of preparing an input-output table is from the dollar values of all industry purchases and sales given in census data. For a particular industry, the basic assumption is that the dollar values can be taken as a quantitative measure of physical purchases in real terms and that long run relative price changes will not grossly distort the quantitative pattern of purchases per unit of output. A further underpinning for the theoretical system lies in the condition that the technology of an industrial society changes rather gradually, so that although the dollar value matrix of transactions is prepared with data from a single year, a similar pattern of transactions can be assumed to have occurred in both preceding and succeeding years. The only major difference noted is that the industry gross output to final consumption may have been greater or less.

The preparation of an input-output table for use in empirical work takes place in several stages. Decisions must be made as to the ultimate size of the table and the manner in which producing industries can be "aggregated" or cumulatively added together into representative production sectors, depending on the uses that the table will serve.

The basic business unit in an economy is the firm, and all firms producing similar goods or services are usually thought of as comprising an industry. The concept of a sector is most useful for analytical purposes, and we have input-output tables comprised of aggregates such as the agricultural sector, the manufacturing sector, and the household sector, for example. The term "sector" is also used to include government operations, foreign trade, and capital formation. Frequently, all the groups which purchase products as final purchases are aggregated together as a so-called "final demand" sector. Essentially, it must be realized that the practical problem confronting the input-output analyst in the preparation of a table is th of reducing the number of individual industries existing in the economy which may number several thousands, to a more manageable number (preferably under 100).

Once the size and sectoral composition of the table is settled, the matrix of interindustry transactions in dollar values is prepared. This transactions matrix is then converted into an input coefficient table showing direct industry purchases per unit of output. The table of direct coefficients is then converted into a special "inverse matrix," known as the Leontief "inverse," which shows direct plus indirect industry purchases necessary for a unit increase in industry output to final purchasing sectors.

The application of the completed table to problems of economic analysis generally falls into three major categories. These are the analysis of the existing economic structure, the formulation of sectoral programs on the basis of present structure, and the prediction of sectoral capacity needs by projecting the requirements of the final purchasing, or demand, sector into the future.

To go into more detail let us examine Fig. 4. Quadrant II consists of element X_{ij} which give the amount of goods produced by the i-th industrial sector for intermediate use of the j-th industrial sector. The total value of the production of the j-th industrial sector is the vertical sum of the elements in the j-th column of quadrants II and III. The total value consists of the value of materials, semi-finished parts, and sub-assemblies purchased from other industries in quadrant II, plus the wages, taxes, cost of imported materials, and depreciation from quadrant

The sales or use of products from a given industrial sector is analyzed by reading the corresponding row across quadrants II and I. In quadrant II the elements represent the sale of sub-assemblies and parts to other industries. In quadrant I the distribution of output to final use is shown. The totals of the corresponding columns and rows must add up to the same values. However, the total of the whole table is not the same as the Gross National Product (GNP). On the average most products get counted twice, once as raw material, a part, or sub-assembly, and then it is included in the value of the product in the final use quadrant. There is an excellent introductory pamphlet on input-output economics by Miernyk.[39]

To explore some real data we have the 1947 technological matrix for the State of California aggregated into seven sectors for simplicity in Fig. 5, courtesy of E.M. Lofting and P.H. McGauh of the University of California. In Fig. 5, if we examine the fourth row, "utilities," we find that the utility service produced for other industries accounts for 53% of its gross output (bottom of column 4). In comparison by examining row 2, we find that 80% of mineral extraction goes to intermediate use. If this table is prepared in terms of finer subdivision such as the 86 x 86 matrix used for the U.S. 1958 table, the row for a given sector gives a picture of the market for products of that sector. This table can be used to estimate the effect of proposed economic changes such as the impact of expanding a given industry.

INTERINDUSTRY FLOW OF GOODS AND SERVICES, CALIFORNIA, 1947
(Millions of Dollars)

	1	2	3	4	5	6	7	(Quadrant I) Final Demand	Gross Output
1. Agriculture & Fishing	583.93	0.	1103.39	0.82	0.	81.98	8.52	1240.02	3018.66
2. Mineral Extraction	1.27	8.41	546.22	37.34	1.73	14.34	11.08	147.80	768.19
3. Manufacturing	330.95	34.46	2946.08	158.66	113.43	854.99	896.03	5514.89	10849.49
4. Utilities	67.62	6.88	346.79	173.07	94.08	339.17	120.40	952.36	2100.37
5. Trade	107.65	1.88	154.07	20.52	19.59	216.84	228.09	2525.87	3275.26
6. Services	181.47	15.52	247.68	79.31	381.63	647.09	139.44	5519.80	7211.94
7. New & Maintenance Construction	15.28	1.03	25.36	116.34	14.75	270.39	0.07	2296.47	2739.69
Value Added (Quadrant III)	1730.49	700.01	5479.90	1514.31	2650.04	4987.14	1336.06		
Gross Outlays	3018.66	768.19	10849.49	2100.37	3275.26	7211.94	2739.69		

Fig. 5. Example of Quadrant II of Leontief Input-Output Matrix Aggregated into Seven Sectors with Totals from Quadrants I and III. (Adapted from Lofting and McGauhey)

INTERINDUSTRY TRANSACTIONS, CALIFORNIA, 1947, 7-SECTOR MODEL
(Direct and Indirect Requirements per Dollar of Final Demand)

(Each Entry Shows, per Dollar of Deliveries to Final Demand by Industry at Left, Total Dollar Production Directly and Indirectly Required from Industry at Top)

	1	2	3	4	5	6	7
1. Agriculture & Fishing	1.2692202	0.0129213	0.2213421	0.0462234	0.0533165	0.0991609	0.0134827
2. Mineral Extraction	0.0094050	1.0150519	0.0714799	0.0143150	0.0050800	0.0263905	0.0033812
3. Manufacturing	0.1806195	0.0738791	1.4256292	0.0590899	0.0301373	0.0561854	0.0098635
4. Utilities	0.0215824	0.0282947	0.1584878	1.1028236	0.0210594	0.0580497	0.0638818
5. Trade	0.0123486	0.0058205	0.0822875	0.0424587	1.0131849	0.1351504	0.0122483
6. Services	0.0436893	0.0149249	0.2197757	0.0697782	0.0431746	1.1183350	0.0467465
7. New & Maintenance Construction	0.0672605	0.0308005	0.4922581	0.0750855	0.0975240	0.0895202	1.0095141

Fig. 6. Example of the Inverse of the Technological Matrix.*

When using the inverse matrix check the

*Reproduced with permission from Lofting and McGuhey

If we are interested in expanding consumption or final demand, the inverse matrix gives us a simpler method of analyzing the situation. Fig. 6 is an example of the inverse matrix for California in 1947. If we wish to increase the final demand for manufacturing, we see from row 3 in Fig. 6 that a one dollar increase in final demand requires a $1.42 increase in manufacturing, 18¢ from agriculture, 7¢ from minerals, 6¢ from utilities, 3¢ from trade, 6¢ from services, and 1¢ in construction. If a number of sectors are expanding, the required expansion of public utilities can be determined by multiplying the increases in final demand for each sector by the coefficient in the utility column.

The benefits of keeping up-to-date input-output tables are:

(1) Data collection for tables enforces consistent data so that businesses will have accurate consistent data.

(2) Tables show industry where significant investment opportunities exist.

(3) Tables can be translated to give employment picture.

(4) Tables can be used to test economic change proposals.

The experiences of different countries of the world in using Input-Output Tables are reviewed in the proceedings of a series of international conferences: (1) Driebergen, Holland, September 1950; (2) Varenna, Lake Como, Italy, June 27-July 10, 1954; (3) Geneva, Switzerland, September 1961; and (4) a special conference emphasising socialist use of input-output tables was held at Budapest, Hungary, June 1961.[40]

The countries reporting the use of Input-Output Tables and the years for which they existed in 1961 are listed in Table 1.

Table 1: Countries Having Input-Output Tables

Country	Years for which Tables Exist
Argentina	1950
Australia	1947, 1954, 1956
Belgium	1953
Bulgaria	1960
Canada	1949
Columbia	1953, 1956
Denmark	1930-39, 1947, 1949, 1953
Finland	1956
France	Updates last year, estimates current year, and estimates next year.
German Dem. R.	1950
German Fed. R.	1950, 1953
Hungary	1957, 1959
India	1951, 1952, 1954
Israel	1958
Italy	1950 used to plan 1951-1956 development program.
Japan	1950, 1951, 1954, 1955
Jugoslavia	1955
Mexico	1959
Netherlands	1938
New Zealand	1958
Norway	1938, 1947, 1948, 1950, 1954
Peru	1955
Poland	1957
Soviet Union	1959
Spain	1954
United Kingdom	1935, 1948, 1950, 1954
United States	1919, 1929, 1939, 1947, 1958

Economic Planning

At the Geneva 1961 Conference on Input-Output, Georges Delange reported on the collection and organization of data for interindustry study in France.[41] The input-output tables are prepared by the Department of Economic and Financial Research, Ministry of Finance, in a form best suited to utilize French statistical data coordinated by the Institut National de la Statistique et des Études Économiques (INSEE). In France short-term forecasts are made twice a year -- in May, when the National Accounts Commission meets, and in October when the appropriation bill is being drafted. These forecasts are based on figures for the prior year and relate to the current year and the next year. They are worked out primarily on the basis of the input-output table, which therefore is calculated twice a year for three years, i.e., four times as a forecast and two times for studying the past.

The French input-output table is similar to Leontief's 1939 United States table, except that foreign trade is not treated separately, but is accounted for within each industry sector. French experience with changes in technical coefficients is that with the exception of agriculture, the changes in technical coefficients have been due to specific technological changes in production.

Professors Mann and Pillogé have a short article on French Regional Planning which explains "indicative" planning.[42] French national planning is considered a "middle way" compared to American and Russian approaches. This kind of planning seeks to "indicate" ways that public and private groups can improve national productive efficiency and social welfare without dictating just what each private firm or individual must do. The technical economic planners develop proposals in consultation with private and public interests. Two main methods are used. The first is a promotional stimulus, raising incentives to invest or adapt production in new directions by providing information on the market capabilities of different sectors of the economy. The second is by obtaining group agreement on objectives and targets by consultation among governmental agencies and private interests. Private firm market analysis experts can start with better estimates of the markets the firm is interested in from the technical coefficients in the input-output tables. Bankers check the forecasts based on the tables, before approving loans for expansion of business.

Commissaire Géneral au Plan Massé presently considers French planning slightly more than "indicative," namely "active." Jacques H. Drèze in a recent survey says that the idea behind <u>active</u> planning is to associate many decision makers with the preparation and revisions of projections.[43] The French Commissariat Genéral du Plan is a small administrative body with 100 employees and no official authority. It relies upon other departments such as the Institut National de la Statistique et des Études Économique (INSEE) and the Service des Études et Financieres (SEEF) for data and studies. The Commissariat is assisted by 25 Commissions de Modernisation. Each commission consists of 30 to 50 appointed members belonging to three categories: public servants, business, and labor. Technicians, university professors, and representatives of other social groups join study groups into which the commissions divide to concentrate on particular problems. Altogether some 3500 people participate in the activities of the commissions and groups. Twenty of the twenty-five commissions are vertical commissions responsible for particular sectors of industry such as iron, non-ferrous metals, or chemicals. The other five commissions are "horizontal," i.e., they deal respectively with labor, finances and general equilibrium, regional development, research, and productivity.

Massé maintains three points in regard to the future of French planning:

(1) French planning should remain "indicative."

(2) Plans should become more an instrument of conscious social choice.

(3) Theoretical models leading to alternative plans should be included.

A more formal analysis linkingFrench planning to the decomposition theorem of linear programming[44] has been presented in an unpublished monograph by Malinvaud.[45]

The Russian Folding Matrix

It is of interest to note that these relatively new forms of applied analysis are also being carried forward in the Soviet Union as well as in other eastern European countries - the Russians having recently published inter-industry relations studies in varying stages of refinement for the Soviet economy.[46] Dr. Levine points out that Western economic theory for the most part has ignored the problem of intermediary flows while concentrating upon final products and primary factors. By traditional Western theory the events of the intermediate sector are decided automatically by the price and profit system. In a socialist system where the autonomous feedback loops of the price and profit system are disabled, the planners must establish a replacement decision process. Soviet planners have been using the material balances method, which has often resulted in the plan for a given year not being ready until after the year has started. Since Krushchev's attack on Stalinism in 1956, Soviet planners have been applying mathematical techniques developed in the U.S.A., such as input-output tables. They have found that input-output tables are useful for checking the consistency of plans prepared by their older material balances method, and offer the prospect of making, checking, and revising economic plans much more easily and quickly, especially when coupled with electronic computing services.

The Soviet planners have developed additional applications and interesting displays of secondary features originally developed by Leontief at Harvard. The Russians have developed a "folding matrix," which makes it simpler to obtain an overall perspective of the economy.[47] A sample folding matrix is shown in Fig. 7. The central matrix (C_{ij}) is the same as quadrant II of the Leontief matrix.

Folding Matrix in Symbols

			1	Φ_{11}	Φ_{12}	Φ_{1j}	.. Φ_{1n}	Φ_{1vs}			
			2	Φ_{21}	Φ_{22}	Φ_{2j}	.. Φ_{2n}	Φ_{2vs}			
			i	Φ_{i1}	Φ_{i2}	Φ_{ij}	.. Φ_{in}	Φ_{ivs}			
			..	..	..	..	.. ..	..			
			n	Φ_{n1}	Φ_{n2}	Φ_{nj}	.. Φ_{nn}	Φ_{nvs}			
			N	1	2	j	.. n	(V + S)			
Φ_1	ϕ_1	O_1	1	C_{11}	C_{12}	C_{1j} ..	C_{1n}	V_{1vs}	S_{1vs}	$\underline{S}_1$	P_1
Φ_2	ϕ_2	O_2	2	C_{21}	C_{22}	C_{2j} ..	C_{2n}	V_{2vs}	S_{2vs}	$\underline{S}_2$	P_2
Φ_i	ϕ_i	O_i	i	C_{i1}	C_{i2}	C_{ij} ..	C_{in}	V_{ivs}	S_{ivs}	$\underline{S}_i$	P_i
..	..	..	..	..	..	.. ..	..	..	..	..	..
Φ_n	ϕ_n	O_n	n	C_{n1}	C_{n2}	C_{nj} ..	C_{nn}	V_{nvs}	S_{nvs}	$\underline{S}_n$	P_n
			V_0	V_{01}	V_{02}	V_{0j} ..	V_{0n}	V_{0v}	V_{0s}		
			$\bar{d}_0$	$\bar{d}_{01}$	$\bar{d}_{02}$	$\bar{d}_{0j}$ ..	$\bar{d}_{0n}$	d_{0vs}			
			d_0	d_{01}	d_{02}	d_{0j} ..	d_{0n}				
			P	P_1	P_2	P_j ..	P_n	VS	M_{vs}		

Numerical Folding Matrix

			1	29·4	4·2	9·6	65·10	21·70	140			
			2	4·2	0·6	2·8	9·30	3·10	20			
			2	4·2	0·6	2·8	9·30	3·10	20			
			4	3·15	0·45	2·1	6·975	2·325	15			
			5	1·05	0·15	0·7	2·325	0·775	5			
			N	1	2	3	4	5	(V + S)			
280	0·05	14	1	1·47	0·21	0·98	3·255	1·085	4	3	28	42
40	0·05	2	2	0·21	0·03	0·14	0·465	0·155	1	0	4	6
40	0·60	24	3	2·52	0·36	1·68	5·580	1·860	10	2	4	28
30	3·00	90	4	9·45	1·35	6·30	20·925	6·975	40	5	3	93
10	3·00	30	5	3·15	0·45	2·10	6·975	2·325	15	0	1	31
			V_0	12·6	1·8	8·4	27·9	9·3	20	20		
			$\bar{d}_0$	4·2	0·6	2·8	9·3	3·1	10	—		
			d_0	8·4	1·2	5·6	18·6	6·2				
			P	42	6	28	93	31	100	30		

Fig. 7. Russian Folding Form of the Input-Output Matrix.*

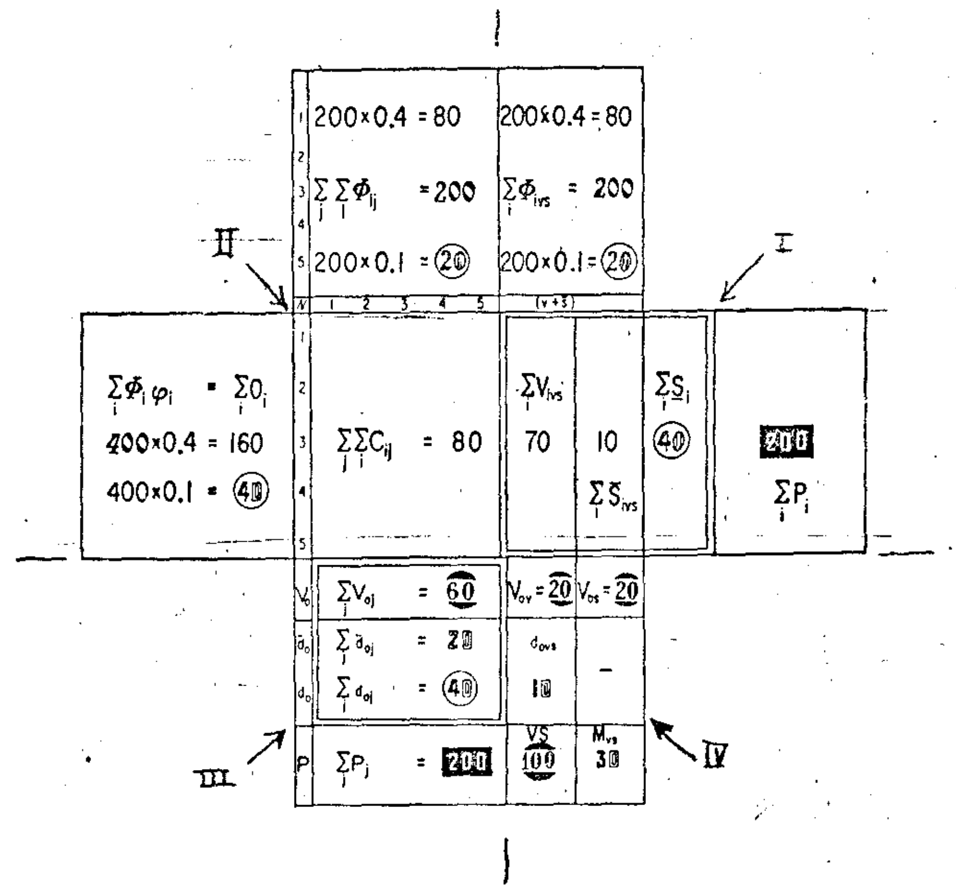


Fig. 8. Use of the Folding Matrix to Gain a Perspective of the Total Economy.*

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In Fig. 7 the costs of the j-th industry are listed in column j in quadrants II and III. The vertical cost is:

$$P_j = C_{1j} + C_{2j} \;\ldots\ldots + C_{nj} + V_{0j} + \bar{d}_{0j} + d_{0j},$$

where V_{0j} is wages, $\bar{d}_{0j}$ is taxes, and d_{0j} is profit. The subscript zero (o) means the element is a monetary transaction, distinguished from C_{ij}, terms which represent delivery of materials and products.

The horizontal production is:

$$P_i = C_{i1} + C_{i2} \;\ldots\ldots + C_{in} + V_{ivs} + \bar{S}_{ivs} + \underline{S}_i ,$$

where V_{ivs} represents consumption of goods by the population directly, $\bar{S}_{ivs}$ represents state expenditures for public buildings, highways, security, etc., and $\underline{S}_{ivs}$ is the accumulation or investment for further expansion of the economy. The numerical example in the lower part of Fig. 7 is in billions (10^9) of rubles.

The fourth quadrant is part of the non-productive sector, requiring wages V_{ov} to be paid for direct public services, and wages V_{os} for administrative services. The term D_{ovs} includes license fees, special taxes, and any profits accrued from public services.

Now we come to the added wings of the Russian folding matrix. The left wing with the rows $\Phi_i \times \phi_i = O_i$ shows the capital requirements and effectiveness for each industry. The effective capital available per year, O_i, is the total capital Φ_i times the circulation rate ϕ_i. The capital available in a given sector must be sufficient to make the effective capital equal the sum of the components purchased from other sectors plus the value of goods delivered for direct consumption plus the value of goods supplied for government construction. It is interesting to observe that a socialist government has developed a clear and simple way of tabulating capital requirements.

The wing added to the top of the matrix expands the column of capital requirements per sector into a full matrix Φ_{ij} of intersector capital requirements. The column Φ_{ivs} represents the capital required for the final processing, assembly and delivery of goods to final consumption and government service.

The use of the folding matrix to obtain a perspective of the total economy is shown in Fig. 8. The outputs $80 + 70 + 10 + 40 = 200$, added horizontally across quadrants II and I must equal the inputs $80 + 60 + 20 + 40 = 200$, added vertically in quadrants II and III. The consumption $70 + 20 + 10 = 100$, added vertically in quadrants I and II, must equal the wages $60 + 20 + 20 = 100$, added horizontally in quadrants III and IV. A balance of national income for individual lines and corresponding columns does not necessarily hold. However, the national income measured by the consumption and accumulation, $70 + 10 + 40 = 120$, added horizontally, must equal the net production, total production less the material expenditure, $200 - 80 = 120$. Accumulation (or investment) balances added vertically, $\underline{S} = 40$, must equal profits added horizontally, $d_0 = 40$. The total capital funds in the left wing, $\Phi = 400$, must equal the sum of the capital in the two upper wings, $\underline{\Phi} + \Phi_{vs} = 200 + 200 = 400$. The magnitude of funds at the beginning of the period times the velocity of circulation, $400 \times 0.4 = 160$, from the left wing, must equal the sum of the production, horizontally, 80+70+10 = 160 and vertically the intermediate production, wages, and taxes, 80+60+20 = 160. The total capital funds times the desired rate of expansion of the economy, 400 x 0.1 = 40, must equal the accumulation S = 40. Each sector can be further analysed, using its speed of circulation and rate of growth. The total production P = 200 must equal the total capital times the sum of the velocity of circulation and rate of growth, 400 (0.4+0.1) = 200. If one studies Figs. 7 and 8, other cross checks on the balancing of accounts in the economic system become apparent.

Measures of Human Values

In our efforts to make our sociological system more efficient we concentrate our attention on variables that can be expressed by numbers that can be fed into our computers. John Wilkinson, of the Center for the Study of Democratic Institutions, has expressed a concern that our quantitative society is pushing values out of the picture.[48]

At a seminar on manpower policy andprograms in Washington, D. in April 1964, Dr. Donald N. Michael said:

> One problem that is very central here is the tendency for planners and decisions makers to come to overvalue that which the computer can deal with; that is, to place most emphasis on those aspectsof the world which the computer can handle - usually the statistical - and in turn, to ignore the ineffable, the points off the curve, the unique person. Then all these individualistic attributes are dealt with by the inclusion of a ritualistic addendum which stresses the integrity and individuality of people! It will be very difficult to find a felicitous balance between the positive contributions the computer must make to society's development and the damage it can do to our respect for the individual. And this stress on the statistical will be a growing threat to our values about the sacredness of the individual. I think it is inevitable. There is a crisis ahead of us for the conventional and traditional democratic process.[49]

If we examine our perspective of cybernetic models and technologies, we will find at the intersection of large systems, simple structure, and coarse quantizations that there is a sociological model based upon analogous transmission line from electrical communication theory that can help us keep values in the system.[50]

Now I make the hypothesis that examination of this analogy can be much more than the type of "ritualistic addendum" mentioned by Dr. Michael. The concept "entropy" from physics which is briefly mentioned by Wilkinson, when examined from the viewpoint of General System Theory, can give us a valuable tool with which to help maintain respect for individual human values in a mass society.

The possibility that entropy from thermodynamics might belong both to the family of measurable quantities of science and the family of values such as beauty and melody was suggested in 1928 by Eddington.[51]

Consider the categories in Table 2. Can you group these into two classes of related categories? The first three are obviously related by their common property of being physically measurable quantities. Numbers 5 and 6 cannot be weighed or measured with a yardstick. There is something about beauty and melody which is not reduced to measurable units; these categories involve emotional feelings which are both more complex and more elementary in human development. Does entropy belong in Class I or II? Entropy is a measure of the ratio of disorder to order, a measure of something similar to beauty and melody, so it belongs in Class II. Yet at the same time,

Table 2: Classification of Categories

CATEGORY	CLASS I Measureable	CLASS II Non-Measureable
1) Distance	X	
2) Mass	X	
3) Electric Force	X	
4) Entropy	?	?
5) Beauty		X
6) Melody		X

entropy in thermodynamics (the relationship between heat and energy) is a measurable quantity defined by equations. Thus the concept of entropy becomes a link between the scientifically measurable and the emotionally meaningful.

At about the same time as Eddington's suggestion, Leo Szilard was thinking about the quantitive relationship between the entropy lost by a gas and information gained by a hypothetical "Maxwell's demon," opening and shutting the door between two compartments to separate the high and low-energy particles of a gas.[52] Dr. Szilard's paper was relatively unnoticed until the development of the mathematical theory of communication by Shannon in 1943,[53] which became known as Information Theory, and the partially overlapping concepts of Cybernetics developed by Norbert Wiener.[54]

Biological systems preserve or increase order, decreasing entropy in a limited domain, even though over a larger domain entropy is increased in accordance with the Second Law of Thermodynamics. The units of information are related to both the life process and to negative entropy in thermodynamics, as has been discussed by both Schrodinger, Brillouin, and Lindsay.

Physically entropy can be defined as:

$$S = k \ln P, \quad [1]$$

where k is the Boltzman constant, "ln" means logarithm of, and P is the number of elementary states in which the system can be.

Negentropy in Information Theory, a branch of electrical engineering and mathematics, in respect to a set of n messages is:

$$H = -(P_1 \ln P_1 + P_2 \ln P_2 \;\ldots\ldots\ldots + P_k \ln P_k + \ldots + P_n \ln P_n)$$

where P_k is the probability of occurence of message K. This gives us a measure of the efficiency of a set of telegraph messag For a basic discussion of these concepts see Colin Cherry, On Human Communication, or J.R. Pierce, Symbols, Signals and Noise.[5]

If we take the formula for information or negentropy of a set of telegraph messages or computer instructions and substitute a set of n philosophical systems (or political systems) in place of the n messages or instructions, the probabilities of occurrenc of the respective philosophies among the population of a country assumes a role analogous to the probabilities of occurrence of the n messages.

If one philosophy is required as the official philosophy by order of a dictator and the philosophy is number "k", then:

$$H = -(0x1 + 0x1 \;\ldots\ldots\; + 1x0 + \;\ldots + 0x1) = 0. \qquad [3]$$

Thus the requirement that people adhere to an official philosophy is equivalent to a zero contribution to the negative entropy of the political system or the "life process" of the evolution twoard a higher order of life. If we go back to equation 2 to see under what conditions there is a maximum contribution to the negentropy of "life process," we find when all P_i's are equal such that $P_i = 1/n$ is the condition for maximum H. Under these conditions $H = \ln n$. This corresponds to equal probability for each different philosophy, a condition approximating a democracy, provided that n is not so high that no decision can be made by the country.

What does this use of the telegraph cable analogy mean? It reminds us that we have only included data for which we can [illegible] numbers to put into our input-output tables.

By analogy with the negentropy of a set of telegraph messages, we are reminded to consider the potential of each human being or small group of humans. An individual or small group may have some important message for mankind, but it may be in the form of poetry or music which does not fit our data format for economic models.

Summary and Conclusions

Contact between engineers and social scientists has led to an examination of the problems of interdisciplinary studies based on analogies from cybernetics and information theory in an effort to convert parts of interdisciplinary studies into multidisciplinary studies via the common forms of feedback circuits in different fields of phenomena and in phenomena of varying degrees of complexity. A spectrum of cybernetic technologies and models may be positioned in a three dimensional chart using the coordinates of "size of the system," "level of complexity," and "measure of quantization."

To deal with the impact of cybernetics in public order, attention is refocussed upon cybernetic models of economic systems. Two oversimplified models are discussed, one for a capitalist economic system, the other for a centrally planned socialist system. Then a particular model, the Leontief matrix, which has more universal applicability to both capitalist and socialist systems is investigated. The perspective developed by considering the full range of cybernetic models and technologies leads to the concept that Leontief input-output matrices can be considered as alternately derivable from complex sets of positive and negative feedback loops which are simplified first by aggregating many separate loops into a few equivalent loops. Then the time average over a year results in a static model, namely the Leontief input-output table. Although static, a dynamic effect can be deduced by a series of calculations, by which matrices for different dates are compared.

In terms of application, Italy was an early beneficiary of input-output tables. The technological coefficients from the Italian 1950 table may have enables the Italian government to perceive what could be done to stabilize its dangerous politico-economic situation.

The remarkable structure of economic planning in France, their data collection and use of input-output tables, seem to exhibit economic success plus a certain amount of protection of human values through decentralization. An intriguing feature of the French decentralization is that it appears to be an example of Dantzig's decomposition theorem from linear programmin

The Soviet Union is using Leontief's input-output tables first to supplement and check their material balances method of planning. The Russians envisage more direct use of input-output matrices with a computer-communication system to run their economic planning. Soviet planners have combined the input-outpu matrix with other equations from Leontief's analysis to make a "folding matrix" which gives one a bird's-eye view of both the static equilibrium of the economy of a nation and the allocation problems involved in meeting a prescribed economic rate of growth The folding matrix simplifies the visualization of the numerous balances that must be maintained in an economic system.

The next problem considered is what human values may be lost sight of in the quantization of society. Are we forgetting the non-quantizable human values? Reviewing the classification of a set of categories, we find that the physical concept "entropy" appears to overlap the normally exclusive categories of "measureable" and "non-measureable." Exploring the possible use of "entropy" as a bridge between the quantifiable properties of physics and the aesthetic values of the arts and the humanities we find that maximizing the negative entropy of a social system is a plausible hypothesis for measuring progress.

This leads to a suggestion. Since the socialist Russians added the capital requirements wings to the Leontief matrix, why don't we capitalist Americans add a humanistic wing to keep us alert to what extent our economy is giving a chance to every human being to do something worthwhile? To account for people in this way would involve an extensive study and reorganization of some data collection procedures and census data analysis. An example of such a reorganization of data can be found in Fritz Machlup's analysis of the knowledge production industry in the U.S.[57]

To take care of the dislocation developing in our economy due to the increasing productivity of automation, the Leontief matrix could be used to estimate the practicality of proposed economic changes. Louis O. Kelso has pointed out the potential breakdown of our present distribution system due to what he calls "decreasing labor productivity and increasing capital productivity."[58] He proposes to increase the ownership of capital in our society by means of a Capital Diffusion Insurance Corporation which would promote the participation of more individuals in corporate ownership.

More recently another group, The Ad Hoc Committee on the Triple Revolution, has defined part of the problem in terms of an increasing productivity per man-hour as the "cybernation revolution," particularly since they claim their measure of productivity shows an upsurge in 1960 which has risen by more than 3.5% per year in 1961, 1962, and 1963.[59] The Ad Hoc Committee proposes that "society through its appropriate legal and governmental institutions, undertake an unqualified commitment to provide every individual and every family with an adequate income as a matter of right."

Hubert Humphrey, in September 1964, introduced in Congress a proposal for a President's Advisory Staff on Scientific Information Management to be known as Project PASSIM.[60] This would advise the government on plans for collection of the necessary data and establishing the necessary computer simulation system to aid the decision processes.

Our American economy could be substantially strengthened by the prompt data collection and preparation of input-output tables each year. Such a development could work to the mutual advantage of government, business management, and labor as follow

(1) Government could follow the basic functioning of the economy. This would enable our system to compete adequately with the projected improvement of socialist economic systems the Russians are proposing.

(2) The industry sectors could be divided so that projections of future section planning production could also be of great value to individual business men in helping them plan ahead. Professor Leontief predicts a real breakthrough in sales forecasting by business marketing analysts in individual firms cooperating in the preparation of up-to-date input-output tables.[61]

(3) The household and government sectors could be divided with supplementary wings for people and production so that information on the labor force, students, retired workers, dependents, and unemployed is available in a useful form for simulating proposed changes in policy to deal with changing job requirements due to automation.

(4) Regional and state input-output tables can be prepared to follow state and regional problems, and special problems such as California's water problems.

(5) A current input-output table would be a valuable aid in estimating the effect of shifts in the balance of our economy, such as those potentially resulting from declines in military expenditures. Preliminary studies along this line have been developed by Leontief and Hoffenberg.[62]

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"If, from the efforts of Project PASSIM, we help to solve only one perplexing problem, the need to provide a sustained economic growth commensurate with the needs of our society, this project will be extremely worthwhile... For example our economic growth must during this decade of 1960 to 1970 provide employment for 22 million workers whose jobs are expected to be replaced by automation and technology. At the same time another 12½ million new jobs must be created

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