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5TH EDITION

TECHNOLOGY FORECASTING AND ASSESSMENT: A METHODOLOGY REVIEW

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ABSTRACT

This is the fifth edition of the T/F and T/A Division's review of methodologies for technological forecasting and assessment, incorporating some of the ideas and constructive criticisms received from various government agencies, and adding certain other sections that have recently become available.

This report reviews the methodologies in technology forecasting and assessment available to a professional group such as the T/F and T/A Division. All methodologies are reviewed within the same format including comments on the specific applicability and the relative strengths and weaknesses of each technique. It can provide a reference source for establishing useful problem-solving procedures in technology forecasting and assessment giving effect to the scope of the problem, type of forecast or assessment required, resource limitations, etc.

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INTRODUCTION

1. TECHNOLOGICAL FORECASTING

During the last decade, interest in future studies has increased enormously and this is reflected in the growth of literature, conferences and associations devoted to them. Their advancement in quality, however, has been slower due to the probabilistic and even arbitrary nature of the future. Especially in a period of rapid social change such as ours, the future appears to be quite open. It is not the weakness of our forecasting methods alone, but the nature of the investigated phenomena themselves which result in forecasts dependent on various doubtful assumptions.

Forecasting differs from prediction. Though the distinction is arbitrary, it has to be established. Prediction usually deals with events and centers on decisions - who will win an election, will a country go to war, who will win a war, the specification of a new invention. Yet such predictions, while possible, cannot be formalized, i.e. made subject to rules. The prediction of events is inherently difficult. It is a function largely of the detailed inside knowledge that comes from long involvement with the situation.

Forecasting is possible where there are regularities and recurrences of phenomena (these are rare) or where there are persisting trends whose direction, if not an exact trajectory, can be plotted with statistical time-series or be formulated as historical tendencies. Necessarily therefore, one deals with probabilities, and an array of possible projections. But the limitations of forecasting are also evident. The further one reaches ahead in time with a set of forecasts, the greater the margin for error, since the fan of the projections widens. Forecasting is possible only when one can assume a high degree of rationality on the part of the men who influence events. These men must have a recognition of the costs of and constraints upon their actions and there must be a common acceptance or definition of the rules of the game.

- Social forecasting is mainly concerned with social changes. Here sociological variables are usually the independent, or exogenous, variables which affect the behaviour of the other variables. The most common variables are the social indicators: crime rates, the number who will be educated, health and mortality data, migration, and the like. A major drawback of this type of forecasting is that it is difficult to aggregate many of these indicators in a meaningful way.

- Demographic forecasting - population statistics are the foundation of most economic and social analysis. Given the number of children born, we can predict from actuarial tables, with high degree of probability, the numbers that will survive and the rate of cohort diminution over time. From this one can estimate such social needs as education, health, and so on.

- Economic forecasting - there are three kinds of economic forecasting:

1) The first is simple market survey based on income data, age distribution, household formations and anticipated needs.

2) The second, and most standardized, is the creation of time series of macrovariables, e.g., wholesale and consumer price indexes, industrial output, agricultural productivity, rate of unemployment, etc.

3) The third, and most sophisticated, is the econometric model, which by defining the actual interaction of crucial variables in the system, seeks to simulate the validity of the economic system as a whole.

- Political forecasting is the most undeterminate. Through public-opinion polling, one can make some fair forecasts about political events in the stable democracies. But the most important political issues involve conflict situations in which the players must make uncertain or risky calculations about each other. Game theory is the main tool for analysing such situations. The 1944 book by Von Neuman and Morgenstern "Theory of Games and Economic Behaviour", extended the theory of games with more than two persons and applied it to economic behaviour. The game theory idea has been widely applied in bargaining and conflict situations - sometimes as a metaphor, sometimes to specify numerical values for possible outcomes. (see Thomas C. Shelling, "The Strategy of Conflict").

- Technological forecasting deals with rates of change or permutations and combinations of factors within classes of events. Just as one cannot predict events, one cannot predict specific inventions. One can, however, forecast the necessary next steps in a succession of changes within a closed system. Thus it is possible to project speed trend curves, for which an important factor is transportation (from jets to supersonic speed); one can take computer memories, extrapolate the next level of capacities, and fit them within "envelope curves". Such projections can be made because technology has finite parameters which are defined by physical constraints.

Technological forecasting techniques can be grouped into intuitive, explorative, normative and feedback techniques. Of those broad approaches that have demonstrated the most promise, and on which the greatest amount of relevant work seems to have been done, three will be discussed here: extrapolation techniques, intuitive methods, matrices and contexts.

2. TECHNOLOGY ASSESSMENT

"Technology assessment is the systematic identification, analysis and evaluation of the real and potential impacts of technology on social, economic, environmental, and political systems and processes. It is concerned particularly with the second and third order impacts of technological developments; and with the unplanned or unintended consequences, whether beneficial or detrimental, which may result from the introduction of new technologies or from changes in the utilization of existing technologies".[1]

3. EXPLORATORY FORECASTING

Forecasting is viewed as exploratory when current capabilities, events and conditions are used as the basis for the forecast, without specific reference to future requirements. To illustrate - given the power output of (say) gas turbine engines today for any given engine weight and manufacturing cost, what will the performance of gas turbine engines in (say) twenty years be? The continued requirements for the specific item for which the forecast is being done, is assumed.

[1]Report of the Interdepartmental Committee on Technological Assessment, September 1972.

4. NORMATIVE FORECASTING

Forecasting is viewed as normative when the forecasted technology exists to fulfill a need which is not readily apparent at the present time. To illustrate - surface transportation on the moon will require the development of long-life reliable electrical batteries of a certain capability. Generally, normative forecasting assumes anything will be possible, but it can also be used deliberately to show how difficult (or impossible) to achieve something may turn out to be.

I - DELPHI

1. Description

A multi-step re-iterative survey method for the forecast and assessment of technological, political, social, medical and other significant societal events, relying on the intuitive forecasts of many experts in the given area under investigation, designed to synthesize convergent opinions. The Delphi operator chooses his respondents on the basis of knowledge and expertise with the field under investigation, and in the first round asks them to make forecasts either of what they themselves feel are likely possibilities, and what time-frame is required to accomplish it, or to make forecasts on specific questions suggested by the survey operator. In subsequent rounds, the operator rephrases his survey questions to focus group attention on certain points, and to develop a range of assessment on what time-frame is required for any given forecasted achievement. Participants with uncommon responses are requested to justify their opinions. Majority and minority rationalizations are fed back to the participants, but the anonymity of individuals is (almost always) retained. The group responses are statistically presented, usually with a median and an upper and lower quartile.

The Delphi is characterized by: anonymity; iteration with controlled feedback; and statistical group response.

2. Type

Delphi can be both exploratory and normative, depending on the specific nature of the survey questions and types of answers received. It is intuitive in the sense that the forecast is based on the respondents best guesses on the future.

3. Applications and Examples

Technology forecasting and technology assessment. An example of Delphi use might be an investigation of future urban-area characteristics: the survey could ask each respondent to list future features of urban areas (e.g. rapid transport, video-phones, etc.) and indicate what time in the future these are likely. From the generated list of ideas, certain more interesting ones (or more specific to the survey's real point) can be fed back to the respondents for sharper definition and forecast time.

A number of Delphi's have been carried out in the Canadian Federal government, generating forecasts on: Transportation for the Post Office; the East Coast Fishing Industry for Environment; Petrochemicals for MOSST; Computers for IT&C; Public Service space requirements for Public Works; etc. It is important to note that one of Delphi's strengths is its adaptability to many applications: these can be specific technologies or industries (e.g. the Petrochemicals case, above) to broad and/or general questions about the future characteristics and form of social phenomena (e.g. the location and space requirements of the Federal Public Service).

As will be noted below, the "Supervisor" or "Director" of the Delphi does not need to be a particular expert himself in the subject under review, unless the questions are directly posed by him, and/or the forecast concerns a very specific technology. This feature probably accounts for Delphi being an obvious choice for forecasters to use when starting from scratch. It is very probably true that the Delphi technique is presently the most commonly used formal forecasting method in use in the Canadian government.

4. Number of Participants/Staff

The number of participants is variable. The larger the survey population, the superior the validity (consistent with the quality of the "experts"), but a practical limit exists at about 30 actual respondents, owing to the difficulty of physically handling more replies. The staff need be only a supervisor, possibly with an assistant to aid in the statistical manipulations; if there are more than 30 respondents, computerization of analysis will be necessary. Delphi's have been tried with over 100 respondents, but computerization and a substantial staff were required.

5. Relative Skills Required by Participants

The participants are selected as "experts", i.e., possessing a significant and in-depth body of knowledge germane to the topic under investigation. They do not require formal analytical skills, e.g., growth-curve mathematics, etc.

6. Relative Skills Required by Supervisor/Staff

The Supervisor is required to present majority and minority rationalizations in succeeding rounds, requiring an effective prēcis technique. A moderate skill in statistical presentations is required. The supervisor may have to be an effective survey designer, especially in later stages.

Normally-the supervisor does not have to be an expert in the topic under consideration, although he will always have to be skillful enough to choose his participants carefully enough to ensure expertise. However, if the supervisor chooses himself the specific questions to be answered (as would probably be the case if the forecast was on a very specific technology or industry), then the supervisor must have a high degree of expertise, otherwise the forecast will be meaningless.

7. Critical Internal Processes

The participants must be chosen on the basis of degree of real knowledge. Survey questions must not be ambiguous, and participants must understand the point of successive rounds. The Supervisor must present arguments in support of particular positions, in successive rounds, but must ensure his own opinions are not injected into the feedback process.

8. Time Required to Complete

All forecasts can be adapted to fit the time available. It is conceivable that one could do a Delphi on the telephone in a day, if the number of participants were fairly small and the number of questions minimal. Generally, the time required is variable depending on number of participants and the number of survey rounds. Surveys are usually carried out by mail, but can sometimes be accommodated by telephone. (The latter, of course, is speedier.) A proper Delphi is generally one of the more time-consuming methodologies. A representative time might be 6 weeks to 6 months.

9. Advantages

The Delphi technique does not require the collection or development of statistical or narrative data. It allows the simultaneous application of many experts' knowledge to the topic under investigation. The interaction between participants, through the argument summarization of the Supervisor, allows maximum convergence (i.e. precision) of forecasts, based on consideration of the most significant variables affecting future outcomes and without distortion by polemics. The technique is applicable to forecasting and assessment, usually in the same sequence with the same set of experts - this factor makes this technique especially useful to independent research groups who would find the task of total data collection and analysis otherwise impossible, and objectivity is retained as the results are based on the complete range of relevant opinion.

Experiences with Delphi seem to show fairly good results. The technique has been tested on obscure, but readily-verifiable questions, (e.g. "how many telephones per capita are there in Africa as a whole?") and the results were accurate, but sensitive to applicable knowledge-levels of the respondents. The Canadian government Delphis that have been completed have generally been well-received, although it is too early to judge definitively. Judging by what experience is available it seems Delphi's are rarely completely wrong but reflect (as would be expected) majority views, which tend to overstate or understate existing trends. Hence the results are usually fairly accurate but, for example, optimistic in terms of time required to achieve a goal; pessimistic, about alleviating a certain problem; etc.

10. Disadvantages

The results of a Delphi sequence are based on intuitive knowledge, and hence cannot be demonstrated objectively. "Breakthroughs" (i.e. unexpected quantitative or qualitative jumps in technological capability) can be forecasted with this method, but may well show up in "minority" reports, leaving the decision maker without a clear forecast. The tendency to "convergence" may not produce accurate forecasts, or may distort the presentation by suppressing valid variances in opinion.

There have been some Delphi response in which the individual forecasts were so varied as to make statistical presentation impossible, (i.e. the individual forecasts were at random). Results like these are inconclusive, indicating it is not possible to determine a majority convergence.

II - SIMULATION GAMES

1. Description

In simulation games decisions or their consequences which involve conflicts of interests are simulated by subjects playing the roles of those decision makers, who in reality, would have to take the decisions. This technique has first been used for the investigation of political and military conflicts, using a given scenario as a basing-point.

Each participant or panel represents a given country, interest group, etc. with certain resources, goals, strategies, and constraints. The game supervisor passes messages, ensures continuity, and introduces critical variables (e.g. a novel technological breakthrough) into the game as required for investigative purposes. Simulation games bear some resemblence to Delphi as they rely on expert intuition of participants to develop results. They also usually use a given scenario (see below) to act as a basis for the game, or to act as a framework for the game's operation.

Simulation games can be played either in one session (or a series of sessions) or in "slow-motion". In the former case, all the participants are working in the simulation at the same time (e.g. for a week); in the latter, the game is played as part of the participant's ordinary activities, with individuals playing the game as their schedules permit.

2. Type

Exploratory - intuitive.

3. Applications and Examples

Technology assessment. Originally games of this nature were devised as analytical tools, to enable decision-makers greater insight into the variables affecting likely alternative futures outcomes, with the prospect of developing simulation games as a predictive tool, based on the development of particular situations from the opening scenario. However, predictions of specific outcomes are not achievable owing to the impossibility of reproducing accurately all the variables (e.g. specific personality, goals of interest groups, etc.). Simulation games have been extensively and successfully used for educational purposes in various universities, war colleges, institutions, and government offices. Several currently exist, including one based on the events leading up to the outbreak of World War I, and a Canadian one was developed by the present author at the Defence Research

Board (and later at Carleton University) on the outbreak of the recent Viet-Nam war. Other examples of applications could include political conventions, urban affairs, etc.

4. Number of Participants/Staff

The number of participants is variable, but each country, interest group, etc., should be well represented with expert participants from a variety of disciplines. For an eight-sided simulation, about 40 participants are required. Control must be well-staffed with supervisor, analysts, and general staff.

5. Relative Skills Required by Participants

As simulation games are applicable to social assessments, the participants need to be able to evaluate and give effect to social, psychological, political, and economic factors, based on knowledge of these areas.

6. Relative Skills Required by Supervisor/Staff

The simulation supervisor must ensure that all possible strategies and goals are given to participants, and that simulation is carried out within the framework of realistic behaviour. The introduction of critical variables must be effected at the correct point in the scenario. Therefore, the supervisor must be able to organize and present social, political and economic variables to the participants. The staff needs to include game analysts to assist the Director in introducing variables, and probably require some elementary statistical skills to handle the data flow and express changed conditions of sides during successive rounds. The quantitative expression of resources and activities needs to be very detailed to be effective (the more detailed the better), and this necessitates fairly sophisticated data handling and manipulation facilities.

7. Critical Internal Processes

The participants must have a clear picture of all their own goals and strategies, but it is often important to ensure their knowledge of others' goals and strategies is limited. The introduction of critical variables for controlled investigation has to be effected with due regard for timing and circumstance - this is the most critical factor in game operation. Participants have to be chosen on basis of expert knowledge and personality - the latter qualification restricts available players, and still may not adequately reflect real decision-making centers.

8. Time Required to Complete

Simulations can be carried out in a few days (provided preparation is adequate) if all the players can be gathered together to play simultaneously, otherwise, the game can be carried on by mail, or "slow-motion", played on a part-time basis. If the latter, a representative time would be 6 weeks to 3 months.

9. Advantages

Simulation games allow expert interaction, as with Delphi's, but (within controlled conditions) the experts can themselves choose exploratory avenues. The same game can be run several times with certain critical variations to develop a range of alternative futures, which eliminates convergence for its own sake, and preserves opinion variety. A simulation is often highly entertaining, helping to ensure participants will undertake their roles and responses with care, and making this technique especially useful in a training situation.

10. Disadvantages

Although the simulation is based on a real situation, and uses individuals to represent real decision-makers, personality dynamics are unique to specific individuals and circumstances, and therfore are impossible to duplicate - this makes simulation games only applicable to developing a range of alternative futures, without predicting which one will occur. Unfortunately, no guarantee exists all the possibilities will be brought to light, however, this criticism is probably valid for other methodologies as well.

III - TREND EXTRAPOLATION - GENERAL, INCLUDING ENVELOPE CURVES

1. Description

Trend extrapolation (in general) analyzes historical data to determine uni or multi-dimensional continuous change in the phenomena under investigation and extrapolates these changes into the future time-frame, relying on the change in the phenomena to continue at the same intensity, quality and duration as before. This technique is objective i.e., intuitive opinion is not an integral part of the process, and is based on stable continuity of the past into the future.

Usually trend extrapolation relies on some of the more complex statistical techniques to express itself, notably regression analysis. Sometimes trend extrapolation is used in sufficiently sophisticated a manner as to allow development of changing characteristics in the future (i.e. if expressed on a graph the phenomena would show a curve, or series of curves).

2. Type

Exploratory - objective.

3. Applications and Examples

Being objective, trend extrapolation is only applicable to quantitative variables, which implies only technological forecasting.

There is some question as to the applicability of trend extrapolation techniques to technological functions (e.g. transportation) or merely specific technical elements (e.g. jet tranport aircraft productivity). Usually, trend extrapolations are more appropriate to forecasting the progress of a given technological element, owing to the likely evolutionary character of progress in a given element, more consistent with the assumtions of trend extrapolation methodology. (See below No. 4 - Trend Extrapolations - Specific Growth Curves). Trend extrapolations can be used to forecast functions, on the assumption that an overall functional development trend can rest on the progress of several following technological elements, a new element ensuring continued overall development as the preceeding one matures. Trend extrapolations of this type are often described as Envelope Curves; this section refers to this type of functional capability trend extrapolation. Usually trend extrapolation is more accurate the shorter the time-frame projected.

4. Number of Participants/Staff

No "participants" are required. The staff requirement varies according to the complexity of extrapolations attempted, the ease of base data accumulation, and time requirement. A representative staff is 1 - 5 people.

5. Relative Skills Required by Participants

Not applicable.

6. Relative Skills Required by Supervisor/Staff

The staff will be required to carry out relatively complex mathematical and analytical techniques. If adequate base data is insufficient, the required additional data will have to be generated by the staff.

The question as to whether or not the analysis of trends should be carried out by "experts", "near-experts" in the topic area under investigation is open. While "experts" are likely to be needed to generate data, the interpretation of results may be biased if carried out by same, owing to the injection of individual views into the results. There appears to be a strong argument for non-experts to carry out the actual trend extrapolations, as they would not have any contaminating pre-conceived notions, (see for example, Kahn and Weiner, The Year 2,000, p. 35) consistent with understanding of the material.

7. Critical Internal Processes

The data base-point for the extrapolation must be definitive. If the trend-line data shows a regular or cyclical wave, then care must be taken to ensure the smoothed-out projected line is based on consistent points in the wave, or the line will be unnaturally depressed or raised. The analytical staff must ensure finite barriers of science or logic are not crossed by the extrapolation (e.g. rockets travelling faster than the speed of light or education expenditure exceeding prospective G.N.P.)

8. Time Required to Complete

The time required depends on the availability of base data and the complexity of the extrapolations. These may be particular time-limiting requirements for the results.

9. Advantages

Trend extrapolation is objective, i.e., can be shown mathematically, and hence the results and processes require minimal interpretation. This enhances their value as it reduces the effect of human bias. Overall trends in technological development are often evolutionary in nature, and hence for relatively short-range, single technological element projections, this technique is appropriate, or, with a higher degree of risk, a succession of techniques for a given function.

Trend extrapolation has been remarkably accurate on occasion. For example, the diminuation of the size of nuclear weapons has shown steady progress, even though a number of technical "breakthroughs" were required.

10. Disadvantages

There is a need for a large data-base to support the extrapolation; acquiring or generating the data is a substantial task. Trend extrapolation is inapplicable to circumstances where variables are not quantifiable (i.e., of a qualitative nature) or when base data acquisition or generation is impossible (e.g., radical new technologies). Even in the short-run, and more so in longer time-frames, external factors may alter the past conditions upon which the extrapolation is based.

IV - TREND EXTRAPOLATION - SPECIFIC GROWTH CURVES

1. Description

Trend extrapolation can be based on specific growth curves, i.e., many different technological elements showing a similar profile of progressive change over time. For any specific curve, the same factors for all trend extrapolations apply - the applicability to quantifiable variables, the need for historical base-data, etc. These curves can be expressed by a particular formula, usually appearing graphically in an "S" shape. Examples are the Pearl and Gompertz "S" curves, the former being a symmetrical curve around the half-way point in technological development, the latter being more developed (i.e. longer) in the latter half. Curves of this nature are often based on biological processes, e.g., pumpkin growth, etc., owing to a certain experienced historical simularity between the life-cycle of these natural organisms and the development of technology in a certain application.

2. Type

Exploratory - mathematical (objective). However, as the assumption has to be made that the phenomena under review can be represented by a growth curve in prospect, the choice of specific growth curves would be an intuitive decision. Hence the growth curve style of trend extrapolation is less objective in its application, as, say, compared to the "pure" trend extrapolation, or "envelope curve" extrapolation, because the latter rely on data generated by historical evidence of the technology itself, which, of course, the specific growth curves cannot.

3. Applications and Examples

Technological forecasting. Specific growth curves are almost invariably only applicable to a single technological element, based on a cyclical theory of innovation, exploitation, maturity, and obsolescence, that supports an S-shaped development growth, (e.g. power output of piston engines, as opposed to power output of aircraft engines generally, which would be an example of the above described envelope curves.) However, they may be very useful in forecasting the future of the next segment of an envelope curve, i.e., if the overall envelope curve has been established, specific growth curves may be useful to forecast the prospects of the next generation of technology required to keep up the overall functional capability.

4. Number of Participants/Staff

No participants required. Staff requirement is limited owing to the single element investigated and the relatively short time-frame. 1 - 3 analysts.

5. Relative Skills Required by Participants

Not applicable.

6. Relative Skills Required by Supervisor/Staff

The staff must be familiar with growth curve mathematics to select and apply promising curves to the data. Statistical analysis is required in fitting the data to a curve, e.g., least squares, regression analysis, etc.

7. Critical Internal Processes

Adequate base data must be available. The staff must select the most promising curve for forecasting - this choice is subjective, even if a "least squares" statistical analysis is used, deciding to use this criterion is subjective.

8. Time Required to Complete

Varies - can be done in an afternoon, if results are required immediately, but detailed/complex analysis could take much longer, possibly several weeks.

9. Advantages

There seems no rational reason why technological development should follow this type of pattern - the use of specific growth curves is based on their apparent success in practice. These curves are relatively easy to use for forecasting technological progress in a given element, and within this limitation, offer a valuable basis for forecasting if one can accept the assumption of technical development following some sort of pattern experienced in the past by other developing phenomena.

10. Disadvantages

As in trend extrapolation generally, there is no guarantee future development will be relatively "smooth", as the projection of a growth curve forecasts. Adequate historical data must be available, limiting usage.

Complete objectivity is not achievable, as the selection of which specific curve is to be used rests with the research group and cannot be decided perfectly objectively. What criterion for curve selection will be final?

These curves are almost invariably limited to a specific technological element forecast, and have no wider applicability.

V - TREND EXTRAPOLATION - TREND CORRELATION

1. Description

Trend correlation techniques extrapolate the correlation in the development of several variables observed in the past into the future. In the case of two variables, they are called simple trend correlations; if more than two, multiple trend correlations. The correlations are assumed to have a cause-and-effect nature (or occasionally to be the joint function of another variable) in which one variable is the precursor of the other.

2. Type

Exploratory - mathematical (objective).

3. Applications and Examples

Technology forecasting and (occasionally) technology assessment. An example might be the relationship between car ownership and urban spread. Trend correlation is much used in economic forecasting on the concept of "leading indicators" that show changes in economic activity which the rest of the economy usually follow (i.e. correlates).

4. <u>Number of Participants/Staff</u>

2 - 5 staff, as a very general representation. However, the complexity of the forecast can vary so much as to make meaningless any figure for staff requirements. It is probably true that trend correlation analysis requires more resources than other types of trend extrapolation.

5. <u>Relative Skills Required by Participants</u>

Not applicable.

6. <u>Relative Skills Required by Supervisor/Staff</u>

As for trend extrapolation in general, a high degree of mathematical and statistical knowledge and expertise is required.

7. <u>Critical Internal Processes</u>

The correlated variables must be adequately tested, to ensure the postulated relationship is plausible. It goes without saying that accuracy in the calculations is vital.

8. Time Required to Complete

1 - 4 weeks, as a representative estimate. Trend correlation will take somewhat longer than trend extrapolation, owing to the need to develop the facts on the variables, and the inevitable requirement of manipulating 2 or more variables.

9. Advantages

Trend correlation extrapolations have the capability, if adequate data is available, to interrelate future technological avenues, which offers a time-saving over extrapolation of all the investigated variables separately, and aids the decision-maker in integrating several (probably resource-competing) technological developments.

When sufficient experience of the correlation of certain variables is developed, trend correlation is a highly effective way of generating forecasts. Trend correlation remains the basis of much of modern economic forecasting.

10. Disadvantages

Critical comments of all trend extrapolation techniques apply to trend correlation with equal force. In addition, trend correlation is based on observed data, and is by nature a more complex projection than straight trend extrapolation. This introduces a greater chance for error into the analysis.

VI - MATHEMATICAL ANALYTICAL MODELS

1) Description

The process of technology forecasting always involves a "model" of the world, or part thereof, in which the changes are to occur. Mathematical models are models which use the abstract constructs of mathematics as the means by which the object/system is "described" or "modeled". Such mathematical descriptions are "analytic" if they are sufficiently tractable to reveal significant information about their structure that was not readily available from the description itself. A mathematical analytic model then is a mathematical description of an object/system which can be "solved" for new information concerning the model, and hopefully, the described object/system. It is important to distinguish the order of events which lead to the construction of a mathematical analytic model. They may be summarized as follows:

1) Examine the object/system
2) Choose a mathematical description for the perceived structure(s) of the object/system
3) Estimate the parameters (if any) of the description
4) Test the model for logical and/or empirical consistancy, and mathematical tractability

5) Use the model to gain information

This ordering ensures that the structural description of the object/system is logical or "makes sense", at least to those involved in constructing the model, and excludes empirically determined models based on statistical properties of non-cause/effect related quantities. This "logical" structure allows the analyst the freedom to explore situations in which past relationships no longer hold, and examine the impact of changed conditions within the model's structure.

2) Type

Exploratory - objective.

3) Applications and Examples

Analytic models, because of the freedom mentioned above, are particularly useful in forecasting. Many of the techniques described elsewhere in this review could be classified as mathematical analytic models, eg. 1) the systems dynamics models of Forrester, Meadows, et al. 2) trend extrapolation and 3) the CANDIDE model (to some extent) . Other examples, such as the Isenson-Hartman Growth Curve model based on information acquisition and dissemination theory; Floyd's Universal Growth Curve model; Mansfield's Diffusion of Innovations in Industry model; and Holton-Seaman's Exponential Growth model are referenced in the bibliography. Presented below are two examples of a type of analytic model using the theory of finite automata as its resource pool.

4) Number of Participants/Staff

Staff requirement depends upon the size and complexity of the description contemplated, but for most projects of a reasonable nature can be limited to 1-3 persons.

5) Relative Skills of Participants

In most cases N/A.

6) Relative Skills of Staff

The staff must be sufficiently well trained in the fields of mathematics being used in the description and analysis.

7) Critical Internal Processes

The usefulness of an analytic model is directly related to the accuracy of the description it provides of the object/system. Thought must be directed toward some technique for evaluating the quality of the description before a choice of model is made.

8) Time Required to Complete

Time requirement varies with the complexity of the model and the ease with which exogenous data can be obtained. For most reasonable projects 2 weeks - 3 months should suffice.

9) Advantages

The freedom to explore the effect of changed conditions on a described object/system, and to explore alternative structural assumptions is the primary advantage of analytic modeling. The improved understanding of the structure of an object/system which results from the formal model building process leaves lasting benefits, whether or not the constructed model was de med accurate enough for use.

10) Disadvantages

The bias introduced in a forecast produced by an analytic model is disguised and removed one level from the investigator. Bias introduced by the choice of mathematical technique, by the simplifications involved in the description, and in the availability of quantified data both for estimation and checkout, is difficult if not impossible to detect. It is important to recognize that an analytic model is only an abstract description of the object/system being modeled, and its results are only applicable as long as the description remains accurate. The results of any analysis based on an analytic model are, therefore, vulnerable to objections raised about the assumptions underlying the description of the object/system.

Example - Mathematical Analytical Model - Finite Automata

Finite automata applies the theory of graphs to modeling problems. A "graph" T is a set X of "points" or "nodes" and a set Γ of "edges" or relationships between nodes (i.e. $T = (X,\Gamma)$). A graph is a "directed" graph if the "edges" are ordered or have direction. This is depicted pictorially by lines with arrows indicating direction.

Consider a system Q with a finite number of possible "states" q_i ($i = 1, 2, \ldots, n$) with a finite number of "inputs" $x_i \varepsilon X(i = 1, \ldots, m)$ and "outputs" $y_i \varepsilon Y(i = 1,2,\ldots,k)$. If one imposes a structure on the system by specifying a function $\lambda : Q \times X \rightarrow Y$ and a function $\delta : Q \times X \rightarrow Q$ then the "transition" graph of the system, showing the possible paths by which the system may move from one state to another, can be constructed.

For example consider the problem associated with alternative trade decisions presented below. A country has three possible states Q:

q_1 : needs > resources

q_2 : needs = resources

q_3 : needs < resources

there are two "goals" (inputs) X:

x_1 : obtain resources

x_2 : sell resources

and three "policies" (outputs) Y:

y_1 : establish trade relations

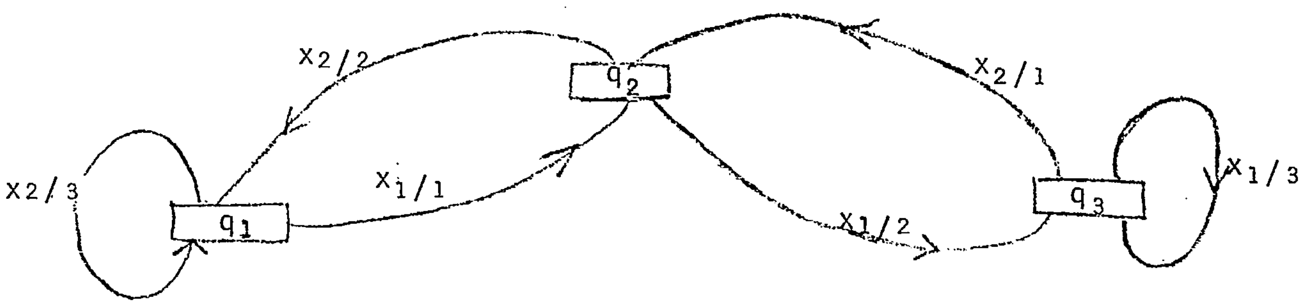
y_2 : maintain status quo

y_3 : break of trade relations

A possible "scenario" involves the specification of λ and δ ; for instance

initial: q	q_1	q_2	q_3	q_3	q_2	q_1
input: x	x_1	x_1	x_1	x_2	x_2	x_2
$\lambda(q,x) = y$	1	2	3	1	2	3
$\delta(q,x) = q$	q_2	q_3	q_3	q_2	q_1	q_1

which represents the transition graph $T = (Q,\delta)$ below:



This is an oversimplified example, but illustrates the construction of a "picture" of the problem which may give added insight. Additionally this technique allows an exhaustive search of possible transition graphs, if desired, by ordering and identifying the alternatives in a systematic fashion.

VII - CANDIDE (CANadian Disaggregated InterDepartmental Econometric) Model

1) Description

CANDIDE is a large medium term model of the Canadian economy. It was designed to forecast the Canadian economy in at least as much detail as the National Accounts (Statistics Canada) for periods of up to 20 years. It is composed of 7 sectors: Final Demand; Industry Output; Labour; Industry Wages and Prices; Incomes; Final Demand Prices; and Finance. These sectors are composed of one or more blocks, and each block is composed of one or more equations. The sectors are interconnected as illustrated in Figure 1. The equations are of two types: Identities which arise from the definitions of certain concepts; and Stochastic or Behavioural equations which capture the predictive relationships among variables. For example, an identity might look like:

$$SGOVCK = (PSPC + CQPC + CONTRV)/CPID$$

which comes from block 1 and may be interpreted as meaning total government contractual savings (SCOVCK) is assigned the sume of contributions to public pension (PSPC) plans, contributions to Canada and Quebec pension plans (CQPC), and provincial employer employee contributions to independent employed vacations (CONTRV); divided by the implicit deflator of consumer expenditure (CPID).

A behavioural equation might be:

$$SPICK = B + B*SGOVCK + (B*YD)(03-1)$$

which translates as:

$$SPICK = B_1 + B_2*SGOVCK + B_3*YD_t + B_4*YD_{t-1}$$

and means total private contractual savings (SPICK) equals a constant (B_2) plus the weighted sum of government contractual savings (SGOVCK) and disposable income in the present period (YD_t) and in the previous period (YD_{t-1}). The constants B_i $i = 1,\ldots,4$ are estimated from data, usually by ordinary least squares regression.

Figure 2 contains an outline of the model's present configuration by sector and by block. Blocks are classified as major or minor within each sector, and as belonging to one of three solution groups: prologue (P), solved independently at the start of each period; simultaneous (S), solved in each period as a system of non-linear simultaneous equations by Gauss-Seidel iteration; or epilogue (E), solved at the end of each period to provide alternate forms of the solution. Each block is annotated with the number and type of equations it contains, for example (B - 11, I - 3, U - 1) means that the block contains 11 behavioural equations, 3 identities and 1 unused location (for ease of expansion).

SECTOR COMMENTS

1) Final Demand - This sector produces figures for 170 final demand categories.

2) Industry Output - This sector converts final demand to 105 commodity requirements, which are then converted to 63 industry outputs and adjusted to agree with aggregate RDP.

3) Demography, Labour, and Employment - Labour demand is estimated using an inverted production function both in hours and in men. Supply is handled through population statistics and exogenous trends.

4) Industry Wages and Prices - Prices are represented by value added deflators (the ratio of gross to real domestic product) in 12 primary categories. Subsiduary prices are determined from aggregate

value added deflators. Wages are determined dynamically from a Phillips curve.

5) Final Demand Prices - Export/Import prices are determined exogenously. An input/output model (1961 base) is used to determine internal commodity prices.

6) Incomes - National Accounts aggregates are computed in this sector.

7) Finance - This sector is weak in the existing model. Further work is being done to find reliable predictive relationships for financial variables, and links to the rest of the model.

In summary, CANDIDE accepts a scenario of about 400 exogenous trends and produces time series for approximately 2000 variables.

Block Number Major	Minor	Solution Group	Name (Size)
			SECTOR 1 FINAL DEMAND
1		S	Savings and Macro Consumption (B-2, I-7)
2		S	Disaggregated Consumption (K$) (B-39, I-19, U-7)
	37	E	Disaggregated Consumption (C$) (I-50, U-5)
3		S	Residential Construction (B-11, I-13, U-1)
4		S	Business Investment (B-14, I-63, U-2)
	32	S	Detail (B-62, I-21, U-1)
	44	E	Capital Stocks (I-62)
	45	E	Rental Cost of Capital (I-48)
5		S	Inventory Investment (B-8, I-25)
6		S	Government Expenditures (K$) (B-22, I-18)
	38	E	Government Expenditures (C$) (I-43, U-1)
7		S	Exports (B-21, I-31)
	18	P	Exports Current $ (I-34)
	39	P	Exports & ROW Linkages (B-17, I-22)
	42	E	Current $ (I-38)
	46	P	Exports - Motor Vehicles (B-6, I-21)
8		S	Imports (B-20, I-23)
	41	S	Imports - Motor Vehicles (B-6, I-21, U-2)
	43	E	Current $ (I-41, U-1)
			SECTOR 2 INDUSTRY INPUT/OUTPUT
9/10		S	I/O Commodity Requirements (I-60), (I-45)
	25	S	I/O Value-Added (I-83)
	23	S	Real Domestic Product (B-63, I-16, U-4)
			SECTOR 3 DEMOGRAPHY, LABOUR, EMPLOYMENT
22		P	Demography (B-1, I-57, U-4)
11		S	Labour Supply and Employment (B-28, I-13, U-7
	12	E	Hours per week (I-13)

Figure 7-2

Block Number Major	Block Number Minor	Solution Group	Name (Size)
			SECTOR 4 INDUSTRY WAGES & PRICES
13		S	Wages (B-21, I-5, U-1)
14		S	Industry Prices (B-37, I-54)
			SECTOR 5 FINAL DEMAND PRICES
16		S	Export Prices (I-32, U-1)
17		S	Import Prices (I-49)
	40	S	Detailed Import Prices (B-46, I-34)
15		S	Final Demand Prices, Consumption (B-47, I-12, U-7)
	26/27	S	I/O Commodity Prices (I-60), (I-45)
	28	S	I/O Consumption Prices (I-42)
	29	S	I/O Government Prices (I-12)
	30	S	I/O M. & E. Investment Prices (I-38)
	31	S	I/O Construction Prices (I-42)
	33	S	Final Demand Prices, M. & E. Investment (B-38, I-4)
	34	S	Final Demand Prices, Structures (B-40, I-4)
	35	S	Final Demand Prices, Government (B-18, I-2)
			SECTOR 6 INCOMES
19		S	Incomes, Govt. and Private (B-31, I-58, U-2)
24		S	National Account Aggregates (B-2, I-28)
	36	E	Other Aggregates (I-16)
	47	P	Future Use for Rules and Equations for Government Transfer Payments (I-13, U-40)
			SECTOR 7 FINANCE
20		S	Financial Sector (B-9, I-3, U-2)
21		E/S	Balance-of-Payments Sector (B-7, I-7, U-4)

Figure 7-2 (cont'd)

VIII - WORLD DYNAMICS MODEL

1. Description

A notable recent model, which has achieved wide-spread publicity has been developed by Prof. Dennis Meadows, under the auspices of The Club of Rome, based on the "World Dynamics" work of Prof. Jay Forrester at the Massachusets Institute of Technology. This model is a global aggregate model intended to demonstrate "the limits of growth". It is based on five factors considered to determine and hence ultimately limit growth on this planet - population, agricultural production, natural resources, industrial production and pollution. These factors are quantified, and can each be manipulated to assess their interaction under different circumstances. The forecasts predicts all growth - economic, industrial, population, etc. - will have to be voluntarily reduced or stopped, or there will be an involuntary (and probably catastrophic) collapse before the year 2100. Reaction to these results is mixed.

Using the Continuous Systems Programming language supplied by Dr. J. Verner of Queen's University, the original programme presented by Forrester in World Dynamics was run through the computer, followed by runs with changes of parameter. The original outcome should not be taken as a prediction of the course the world is now following. The assumed structure and values in the model have not been carefully enough examined to give assurance that this model is the most likely one. Instead, it should be interpreted as one of the possible modes of behaviour of the world system.

This particular world model contains few inherent forces capable of limiting population - depletion of natural resources, rise of pollution, increase in crowding, and the decline of food. Examination was made of these forces and changes made within the model to better understand the internal behaviour of the system and to see the probable outcomes following implementation of hypothetical policies. At each stage graphs were produced to aid in studying the results and in comparing with subsequent runs. Attached is the original programme and graph, plus other runs with assumptions.

The original system (graph 1) is one in which growth is reversed by pressures arising from the declining natural resources, i.e. decline in population, lower effectiveness of capital investment, and lower material standard of living (again reducing population) - halt in exponential growth of population and capital investment. By the year 2,000 natural resources are falling steeply and if usage continues at such a rate, natural resources will disappear by the year 2,150.

To test the dependence of the model upon natural resources, a run was put through in which it was assumed that the natural resources usage rate (NRUR) was sharply reduced to 25% of its original value in 1970. This removed one layer of restraint off the growth forces and the next growth-suppressing pressure, pollution, arose. Pollution rose to more than 40 times that in 1970.
(first run - pollution maximum - 2.07×10^{10} units
second run - pollution maximum - 1.5×10^{11} units).
This was caused by the longer time of growth of both population and capital investment. This growth generated pollution (see graph 2) at a rate beyond dissipation by the environment.

With an overload of pollution, it continued to grow and climb steeply until it extinquished the pollution-creating processes. This caused a decline in population and capital investment until pollution generation again fell below the pollution absorption rate. From the corresponding graphs, it was obvious that the quality of life dropped suddenly (enough to curtail population). After 2060 quality of life turned upward due to the assumption that all capital investment is available to and usable by the remaining population. Quality of life from crowding responds to pollution (almost a reverse of the pollution trend). Food ration (amount per person) falls, capital investment-in-agriculture fraction increases.

Growing pollution affects the population in two ways - it acts directly on birth and death rates and indirectly by interfering with food production. it results in a rapid increase in death rate and fall in birth rate after 2020.

The next run was made to examine the third limit to growth by removing the natural resource and pollution effects. No resources were used after 1970 (natural-resource-usage rate normal is set to zero) and pollution rate was reduced to 10% of what it would have been. (Pollution normal set to 0.1 in 1970, originally 1.0 throughout, corresponding to graph 3).

In this case, population rose to approximately 10 billion corresponding to a greater crowding ratio (2.7 times 1970 population). This in turn caused the quality of life to fall and in turn reduced population rate.

Capital investment rose noticably, and would continue to do so following this 200 year period, with an increased capital investment ratio (CIR) over previous 1970 values. This is due only to assuming unlimited resources and suppressed pollution. CIR is only available to raise the standard of living. Increased population caused greater crowding and demand for food shifted capital investment to agriculture i.e. -- capital-investment-in-agriculture fraction continually increasing.

The graphs corresponding to this run shows the mode produced by the crowding limit i.e. effect of crowding on population. Crowding also affects the food sector - quality of life drop below previous 1970 level - a combination of rising quality from higher material standard of living and a falling quality from crowding.

The fourth run was to eliminate, along with natural resource usage and pollution, the effects of crowding on growth. The change made was to suppress the effects of crowding on the birth and death rate so that there is no effect as crwding increases. All values for crowding ratios are changed to 1. i.e. birth and death-rate-crowding-multiplier. Graphs 4a and 4b.

Population now rose further to just over 10 billion. With a steeply rising population the material standard of living is lower. There is of course, an increased demand on food - taking capital for agriculture, and capital cannot be regenerated to a higher level. In comparison to the previous run, material standard of living and the food ratio are lower. This in turn results in a lower quality of life.

Now that crowding does not limit population growth, the next limiting factor is the reduction in food ratio (40.77) - enough to halt rise of population. Population rises to a level sufficient to generate the degree of food shortage needed to suppress <u>growth</u>.

Following this sequence of runs to establish the range of limiting growth factors, the original system was tested under increased industrialization. This was done by increasing the rate of capital investment. The original value of capital investment generation normal of .05 throughout was increased by 20% in 1970 to .06 i.e. rate of capital accumulation is 20% greater than in the original model.

The result is the return of a pollution crisis. The first occurrance of this crisis appeared with decreased natural resources usage rate where population and industrialization exceeded the pollution-absorption capability. Now the pollution crisis caused by increased industrialization reaches the pollution limit for the resources are depleted.

Quality of life rises initially but falls by 2020.

2. Type

Exploratory - objective

3. Applications and Examples

"World dynamics" is an off-shoot from earlier work e.g. "Urban dynamics". So far, its classic application has been the Club of Rome's report "The limits of Growth", it has certainly had a tremendous impact on recent futures-oriented thinking, although criticised on the basis of having insufficient variables and inadequately giving effect to future technology.

4. <u>Number of Participants/Staff</u>

No participants required. Staff needs to be adequate to handle the computer program.

5. <u>Relative Skills Required by Participants</u>

Not applicable.

6. <u>Relative Skills Required by Supervisor/Staff</u>

For a "World Dynamics" computer run, the staff will have to be familiar with fairly advanced computer techniques, possibly also will have to generate new techniques depending upon equipment available, etc.

7. <u>Critical Internal Processes</u>

The world model can be dissected and separate loops controlling one item - e.g. population extracted - (1) natural resource loop (2) pollution loop (3) food loop. In each case, the interaction of population and one of the above factors only can be allowed; all other factors disregarded. This facilitates understanding of the feedback loop system, in particular, those influencing population.

Case 1 - Population and natural resources.

Begins 1900 (using same initial conditions presented before). Population increases, natural resource usage rate NRUR increases thus increasing the depletion of natural resources. This in turn lowers natural resource fraction remaining NRFR and lowers the natural resource extraction multiplier. This then reduces effective capital investment remaining and the material standard of living MSL. This MSL increases birth-rate-material-multiplier and therefore the birth-rate. It also increases death-rate-material-multiplier and death rate to eventually reduce population.

Case 2 - Population and pollution.

Increase in population increases pollution generation, increases pollution, increases pollution ratio. Through the birth and death-rate-pollution-multiplier increased pollution reduces birth-rate to reduce population, and increases death rate to reduce population.

Rising pollution reduces food-from-pollution-multiplier, reduces food ratio, and through the birth-rate-food-multiplier reduces birth-rate and population. Similarly, through the death-rate-food multiplier, falling food ratio increases death ratio to reduce population.

Case 3 - Population and food.

(inter loop) Initially population rises, capital investment ratio, CIR, decreases, capital-investment-in-agriculture decreases, food potential (per person) decreases, FR-food ratio decreases, birth rate will decrease. This implies population decrease.

(outer loop) Population rises, CIR decreases, capital investment in agriculture decreases, food potential from capital investment decreases, food ratio decreases, death-rate-from-food-multiplier increases; death rate increases. This implies population decrease.

8. Time Required to Complete

This varies according to how easily the program can be accommodated under the specific given circumstances.

9. Advantages

The model is very positive and has made a considerable impact in focussing attention onto the questions raised by ever-increasing demands on the world's support systems.

10. Disadvantages

The model is quite simple. It may not have adequate provision for all important variables. It is based on a set of assumptions (e.g. regarding natural resource reserves) that may or may not be realistic. No effect is given to Space developments, which seems rather short-sighted in view of the model's attention on long-term trends. Very little effect is given to human technology eliminating or enormously reducing certain problems.

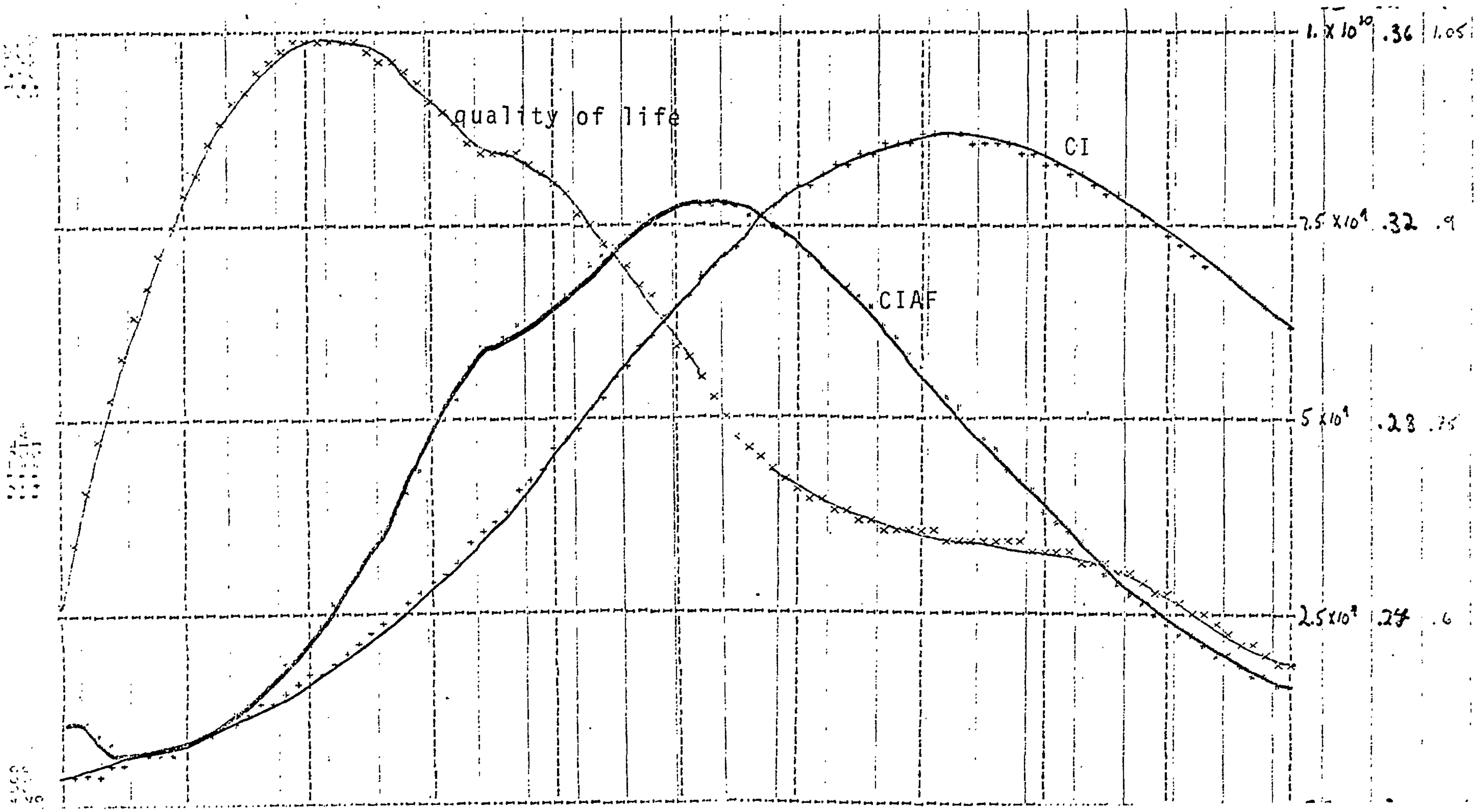

quality of life
CI
CIAF
1. X 10^10 .36 1.05
7.5 X10^9 .32 .9
5 X10^9 .28 .75
2.5X10^9 .24 .6

FIGURE 8-1A

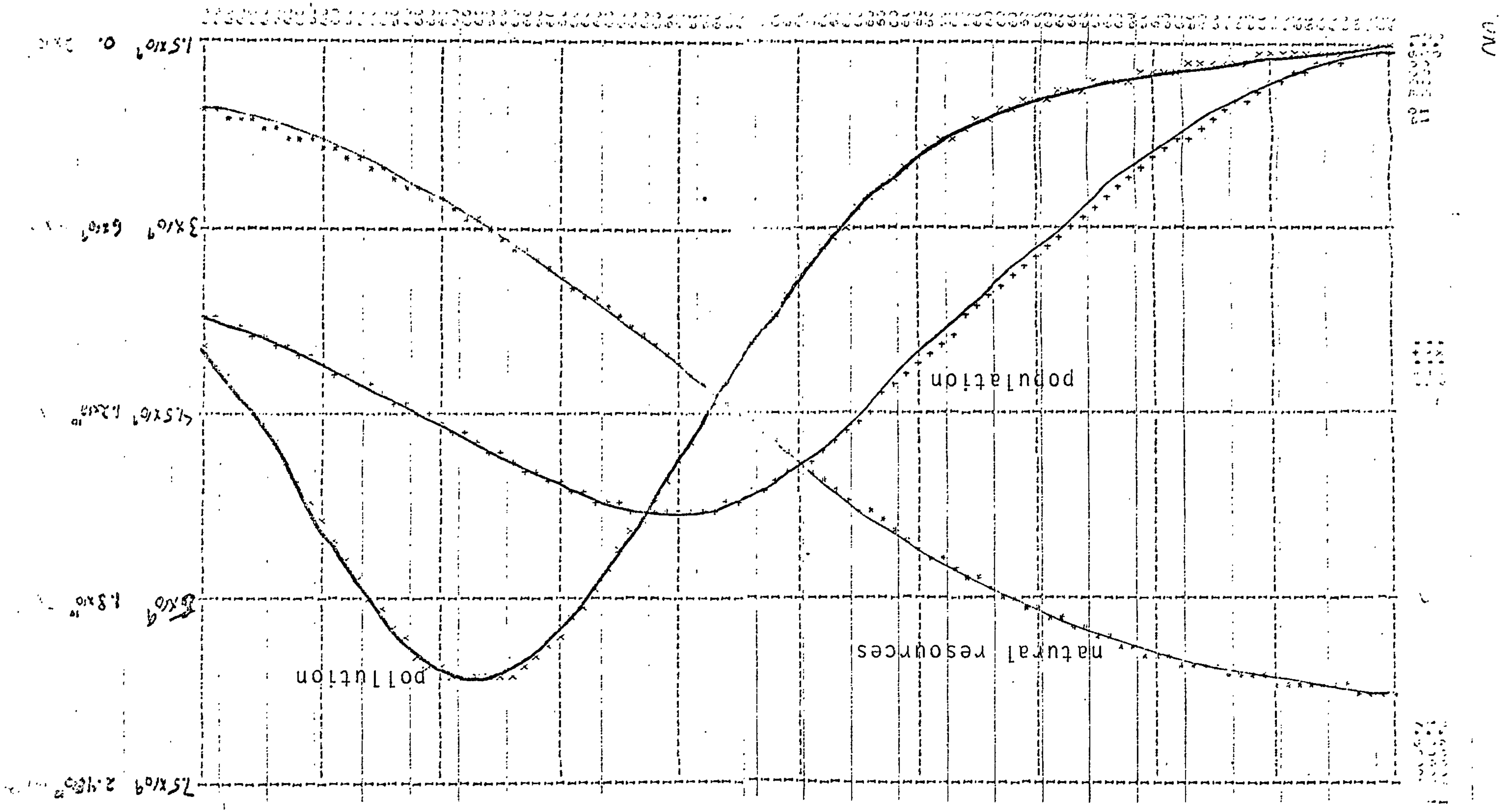


FIGURE 8.1B

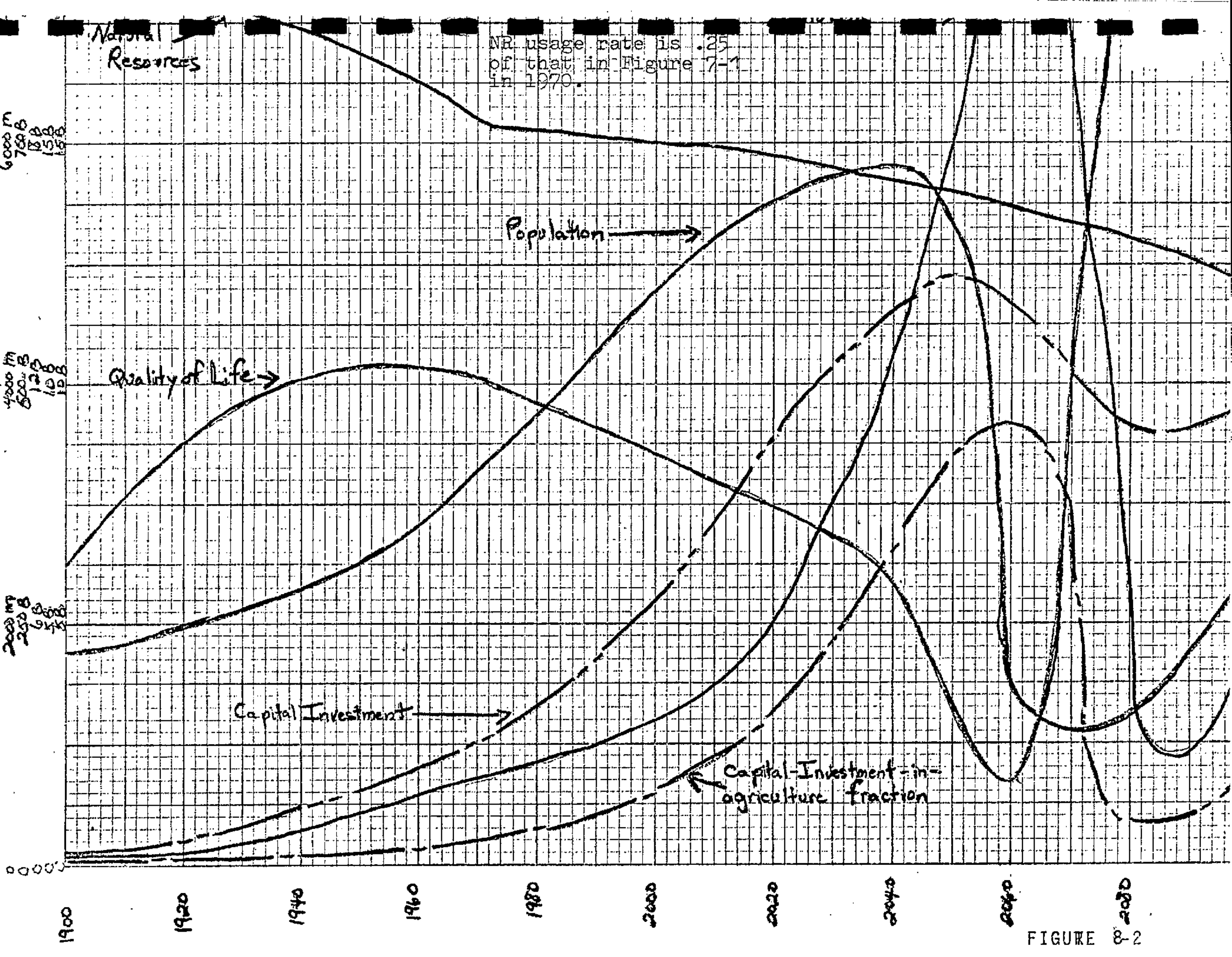
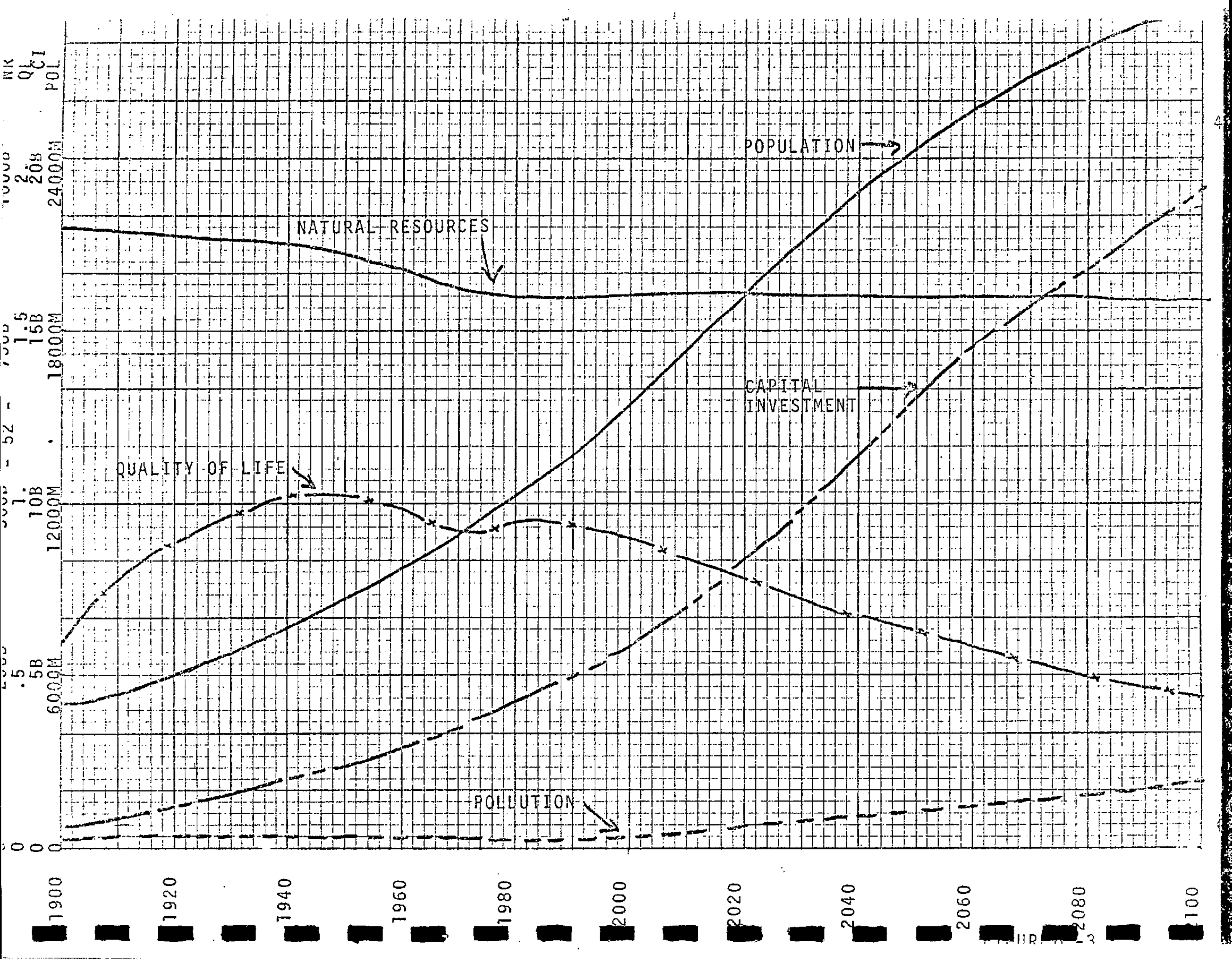
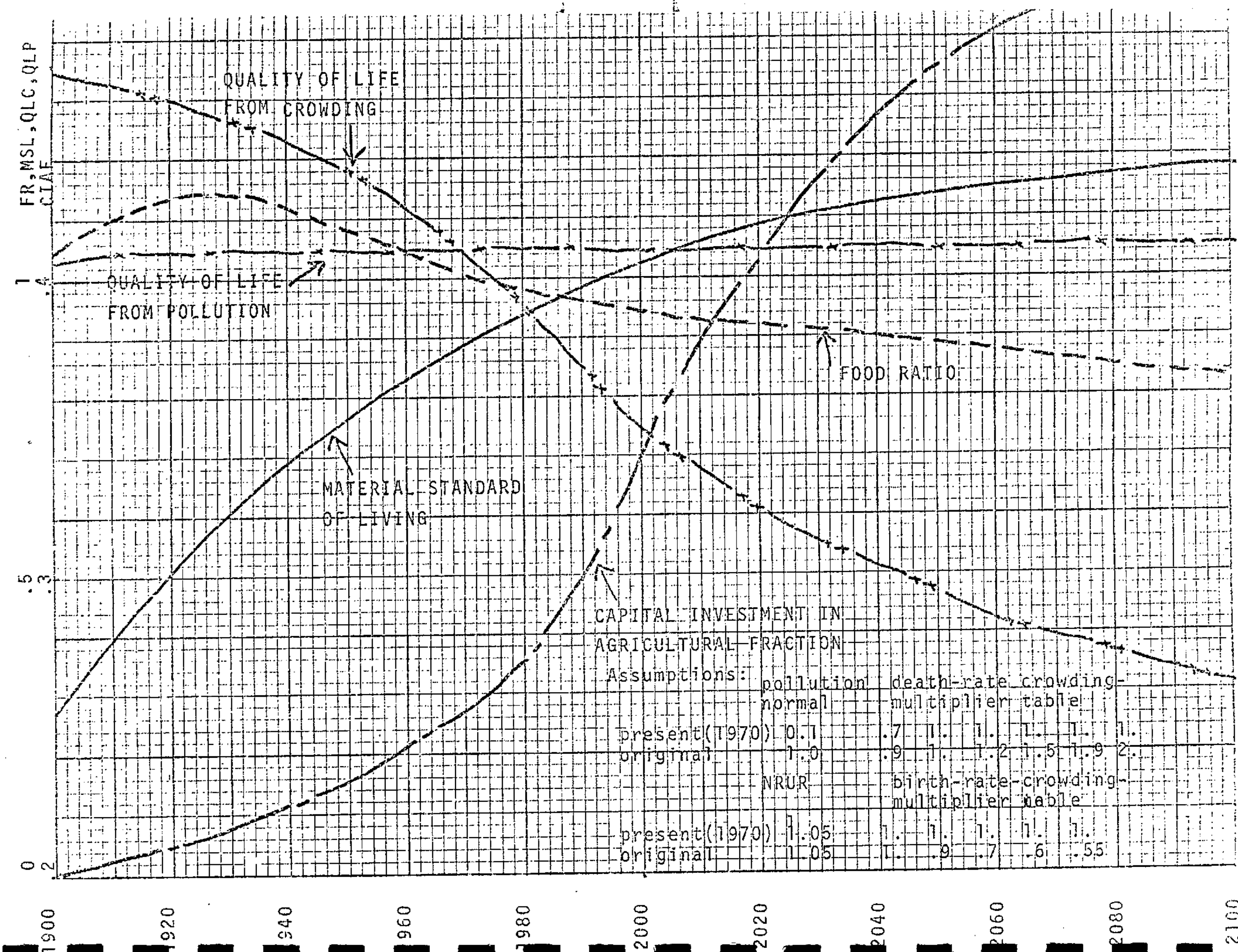

Natural Resources
NR usage rate is .25
of that in Figure 7-1
in 1970.
Population
Quality of Life
Capital Investment
Capital-Investment-in-agriculture fraction
1900
1920
1940
1960
1980
2000
2020
2040
2060
2080

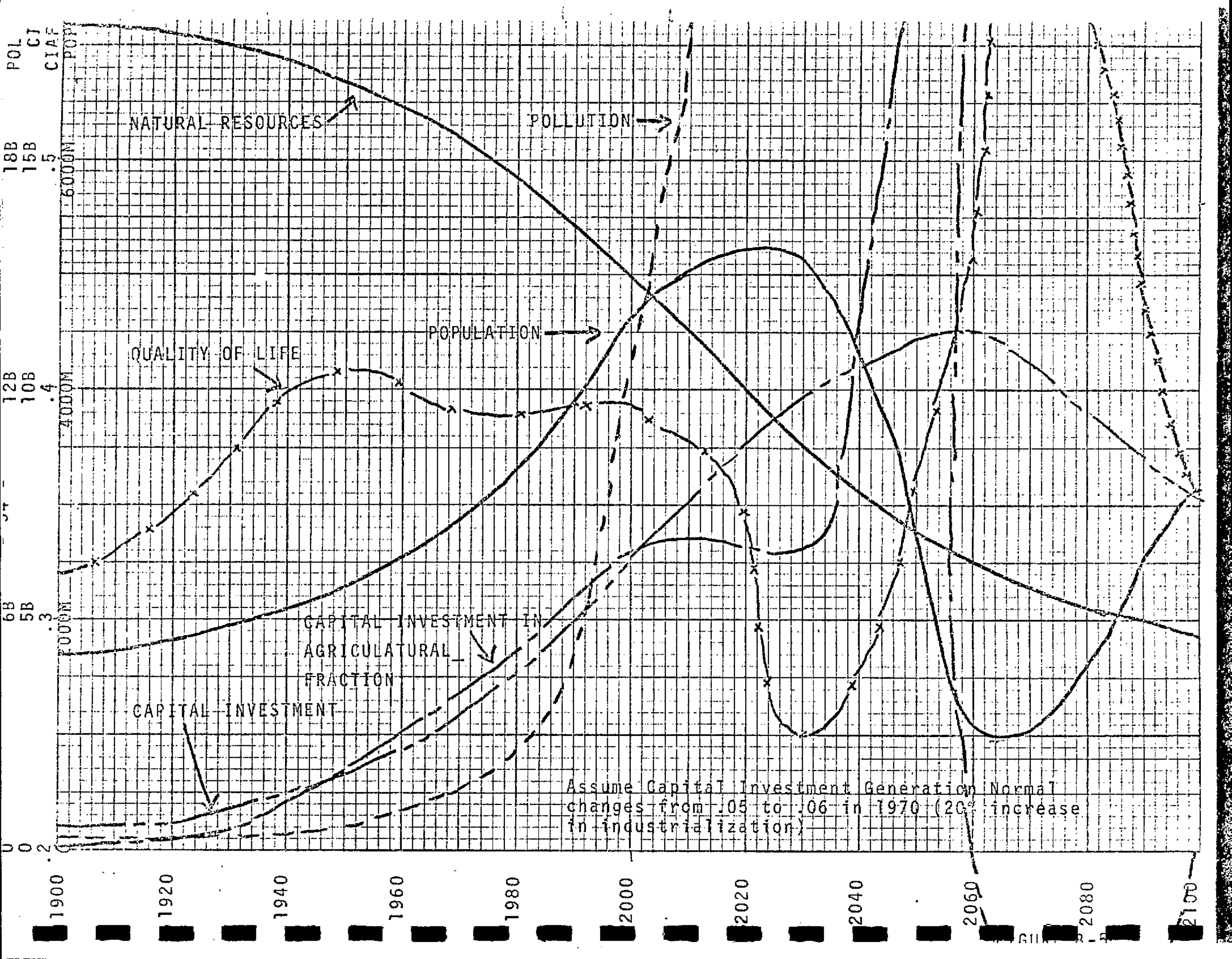
FIGURE 8-2



NR
QL
CI
POL
2
20B
24000M
1.5
15B
18000M
1.
10B
12000M
.5
5B
6000M
0
0
POPULATION
NATURAL RESOURCES
CAPITAL
INVESTMENT
QUALITY OF LIFE
POLLUTION
1900
1920
1940
1960
1980
2000
2020
2040
2060
2080
2100



FI [redacted] RE [redacted]


POL
CI
CIAF
POP
18B
15B
.5
6000M
12B
10B
.4
4000M
6B
5B
.3
2000M
0
0
.2
NATURAL RESOURCES
POLLUTION
POPULATION
QUALITY OF LIFE
CAPITAL INVESTMENT IN AGRICULATURAL FRACTION
CAPITAL INVESTMENT
Assume Capital Investment Generation Normal changes from .05 to .06 in 1970 (20% increase in industrialization)
1900
1920
1940
1960
1980
2000
2020
2040
2060
2080
2100

IX - A CANADIAN ECONOMIC MODEL

1. Description

Following along the methodology of the previous model this is one developed for the Canadian governmental department of Energy, Mines and Resources, to forecast Canadian economic development. It presents a systems dynamics model of the life cycle of national economic development. This cycle, completed in a few hundred years, can be divided into growth, transition, and equilibrium. In growth phase, population, production, and industrialization increase exponentially. In the transition stage economic growth encounters increasing negative pressure from physical and social limits to growth, and in the equilibrium stage, the forces producing and restraining growth are in balance. This model covers a 250 year period of the development life-cycle.

Economic activity is divided into 5 production sections: (i) agriculture (ii) goods (iii) services (iv) capital, and (v) resources, each with its own function and all fitting together into a structural network.

Figure 9-1 on the following page illustrates the material flows between sectors. The 5 sectors are linked through population; the

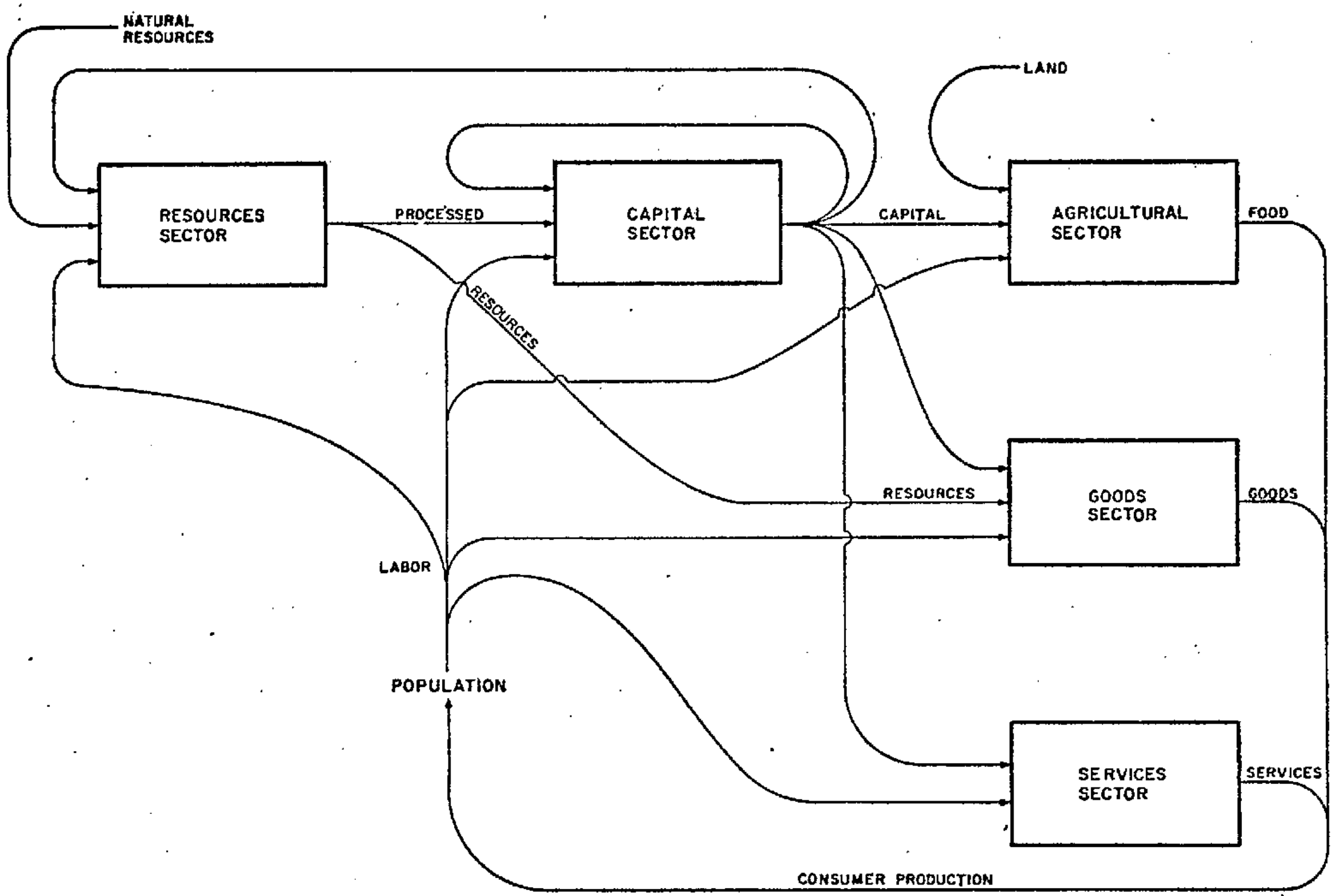


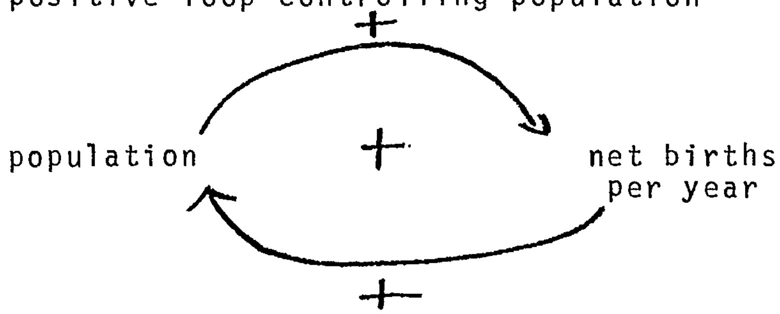
Figure 9-1 Material flows in the model.

production sectors support the flow of food, goods and services to the population. Population provides labour for all 5 sectors. The structure, as illustrated, is circular. The two secondary sectors--capital and resources--support the consumer sector. Output from the three consumer sectors--agriculture, goods, and services--support population. Labour supports all 5 sectors. The only factors of production lying outside this flow are the environmental porduction inputs--natural resources and land.

Basic Structure

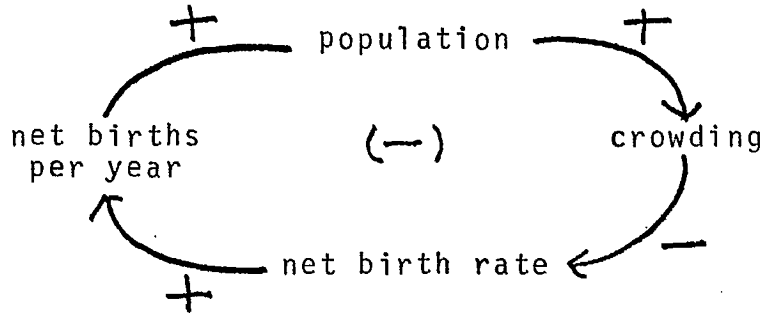
The model's over-all behaviour is determined by the interaction of numerous separate processes, each controlled by causal feedback loops. This structure consists of two or more causally related variables that close back on themselves. The relationships are either positive or negative.

eg. (i) positive loop controlling population



(net births = births - deaths)

eg. (ii) negative crowding loop
(assuming that where crowding is great enough it will reduce net births)



Methods

From the basic computer run it is possible to change particular variables to generate a number of behavioural patterns. As examples, it is possible to study three possible modes of economic development for an industrial society:

(i) transition out of the growth phase when population growth produces a food shortage,

(ii) transition when industrial growth produces a resource shortage, and

(iii) transition when population reaches a crowding limit.

In this manner it is possible to better understand the internal behaviour of the system and to see the probable outcomes following implementation of hypothetical policies.

The graphs presented correspond to the first mode of development. The model's conditions, with the exception of the assumption made to achieve this particular mode, were chosen to approximate the Canadian conditions in 1900. From the initial state behaviour is determined entirely by the internal structural relationships.

Food-limited Development Mode

Graph 3 shows population growing exponentially. Between 1900 and 2000 the capital/labour ratios rise, which causes productivity to increase. This in turn allows the material standard of living to rise while the fraction of labour non-productive increases. The increase in material standard of living allows labour to reallocate from agriculture to services.

After year 2000 many established patterns of development are reversed. In Graph 2 the capital/labour ratios in all production sectors stabilize and actually decline slightly after 2050. Also, food, goods, and services per capital fall at this time. Graph 3 shows that the fraction of labour non-productive and, after 2050, labour reallocates back into agriculture from the services and goods sector (Graph 2--decline of goods and services per capita). These reversals are caused by the assumptions illustrated in the two feedback loops on the attached sheet. Loop (a) causes the capital/labour ratios to stablize at high levels and loop (b) causes the agricultural section to expand. This is achieved by taking labour from the non-productive pool and from goods sector and services sector following the commitment of agricultural land to food production.

Graph 1 illustrates that most of the increased productive labour force after 2050 goes into the agricultural sector. Fraction of productive labour in agriculture rises from approximately 20% in 2050 to 80% in 2150. Obviously, increased technology with regards to agricultural production is not assumed within this model; for as the intensity of land use rises agricultural production efficiency falls. This decline prevents agricultural production from rising proportionately with population; thus a reduction in food per capita (Graph 2).

The expansion of the agricultural sector and related trends will continue beyond 2150 until population stops growing. Then food per capita will stop falling, causing the need for food, non-productive time, goods and services to reach a new balance. With this new balance reallocation of labour to agriculture stops. In the absence of other constraints population will grow until food per capita falls low enough to reduce the net birth rate to zero. Population growth rate by 2150 has slowed perceptibly as evidenced by the declining slope of the population curve (Graph 3).

It is interesting to note that by 2150, in many ways, the state is similar to its pre-industrial conditions: all aspects of standard of living are low, most of the labour force is in agriculture, fraction of labour time non-productive is low and the needs are high. But the differences are great in many respects; population is now thirty times as great and economic development is limited by availability of land whereas previously limited by availability of capital.

This particular mode is obtained through assuming that high technology alternatives to land-based food production have very low yields. This makes the high capital-intensity of production methods in 2150 of little use in raising the total agricultural production rate. No matter the effort expended agricultural production is therefore limited to about 215 times 1970 value. This is naturally too restrictive but facilitates in illustrating two points: (i) feedback loops, dormant during industrialization, can emerge and dominate in later stages, (ii) if population growth forces the adoption of food production methods less efficient than agriculture, the agricultural sector draws disproportionately on human and capital resources, reducing the possible standard of living.

Similarly the two other modes may be achieved by changed assumptions, allowing for further understanding and evaluation of the model.

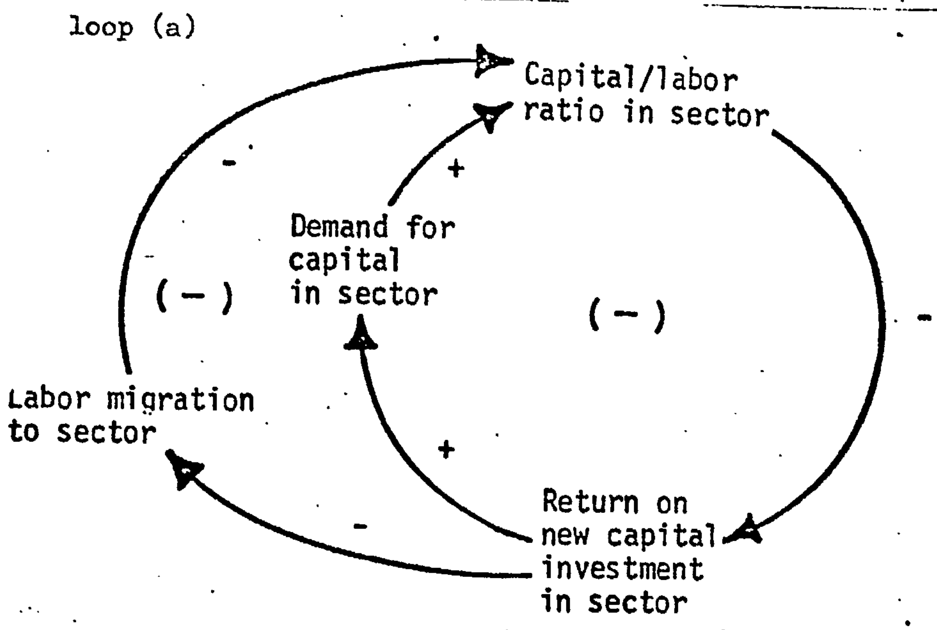


Figure 9-2 Each of the five production sectors has two negative loops limiting the capital/labor ratio.

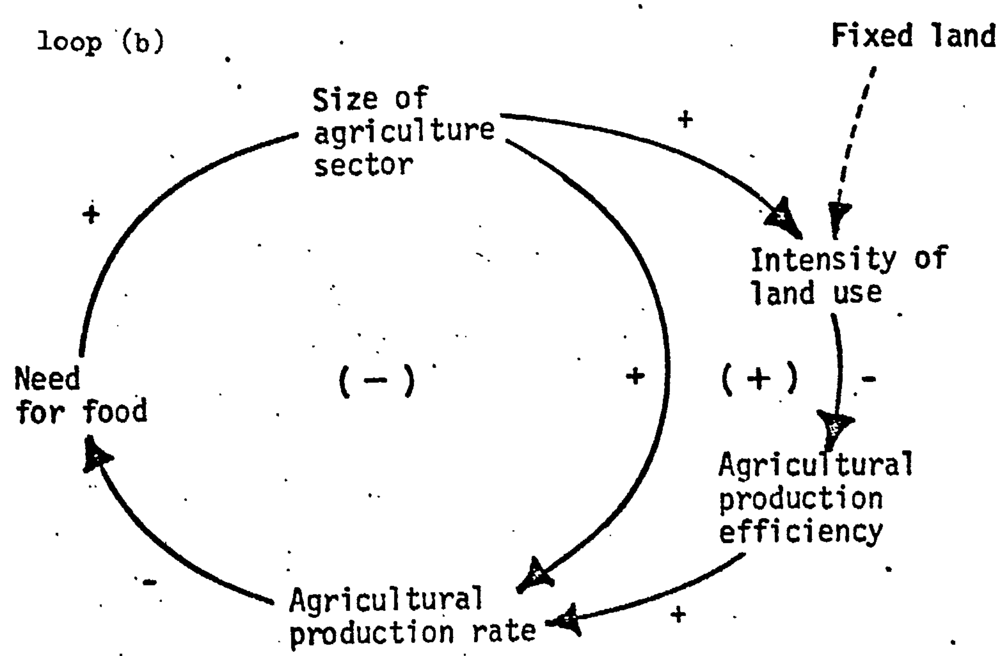


Figure 9-3 Two loops cause the agricultural sector to expand as the intensity of land use increases.

2. Type

Exploratory--objective.

3. Applications

This model is of course following along the line of work done by Forrester--the systems dynamic approach.

At present it can be used to try and further understand the Canadian economic system and its possible future alternatives. This model, too, can be criticized on the basis of insufficient representation of the real world which might lead to giving improper effect on decisions for the future.

4. Number of Participants

Once the model is set up no participants are required. Staff needs to be adequate to handle the computer programme.

5. Relative Skills Required by Participants

Not applicable.

6. Relative Skills Required by Supervisor/Staff

For an "Economic Model" computer run, the staff will have to be familiar with fairly advanced computer techniques.

7. Critical Internal Processes

As given in the description, there are a number of particular cases to further understand the composition of the model.

These facilitate in understanding the numerous influences and interactions of the system and the effect of supposed policy implementation.

8. Time Required to Complete

This varies according to how easily the programme can be accommodated under the specific given circumstances.

9. Advantages

The model makes it possible to see the effect of the interaction of numerous variables, which otherwise might remain unrealized. Initially, it is necessary to define all possible variables of the economic system and to decide on the actual dependence of each on the others--the designing of feedback loops. This requirement necessitates understanding of the system and can also further that understanding.

10. Disadvantages

The model is quite simple. It may not have adequate provision for all important variables. It is based on a set of assumptions that may or may not be realistic. Very little data is actually available, and included in this example along with the output of computer runs is some actual Canadian data for comparison. Very little effect is given to human technology eliminating or enormously reducing certain problems.

Tables

The following two tables represent the actual numerical data received from the output of (i) the original run of the economic model and (ii) the food-limited mode run. The basics for these runs have been previously described - the food-limited mode being achieved by changes in the assumptions of agricultural technology. The tables give past, present, and future information concerning fraction of labour, labour, capital, and capital/labour ratio in all of the five sectors of the economy. Attached also are graphs corresponding to the food-limited mode output.

Actual Canadian statistics are provided for comparison where possible.

TABLE 9-1: FORRESTER ECONOMIC MODEL FOR CANADA
ORIGINAL RUN

	1960	1966	1970	1976	1980
Population	15,951,000	17,629,000	18,720,000	20,349,000	21,469,000
Fraction of productive labour in goods	.11817	.10669	.10012	.092206	.088369
Labour in goods (# of men)	208,120	191,050	181,000	169,630	165,050
Fraction of prod. labour in agriculture	.20447	.19328	.1868	.17786	.17206
Labour in agriculture	360,130	346,120	337,720	327,210	321,360
Fraction of prod. labour in capital	.0804	.081003	.08163	.082385	.082345
Labour in capital	141,600	145,060	147,580	151,570	153,800
Fraction of prod. labour in resources	.13809	.13758	.13691	.13601	.13554
Labour in resources	243,210	246,370	247,510	250,230	253,160
Fraction of prod. labour in services	.45887	.48146	.49454	.51154	.52168
Labour in services	808,170	862,200	894,070	941,100	974,370
Resource extraction efficiency (dimensionless)	1.0432	1.001	.96807	.91131	.86883
Capital in agriculture (capital units)	298,700	365,660	419,930	526,460	609,780
Capital in services	1,111,700	1,665,600	2,087,100	2,771,400	3,259,300
Capital in Capital	95,254	139,750	172,140	218,110	242,000
Capital in Goods	344,350	427,870	480,040	556,040	607,700
Capital in Resources	388,350	529,410	631,880	815,720	949,940
Capital/Labour ratio in goods	1.1819	1.5997	1.8944	2.3414	2.6300
Capital/Labour ratio in agriculture	.82914	1.0565	1.2434	1.609	1.895
Capital/Labour ratio in capital	1.6817	2.4084	2.9161	3.5977	3.9337
Capital/Labour ratio in resources	.79836	1.0744	1.2765	1.63	1.8762
Capital/Labour ratio in services	.98255	1.3799	1.6674	2.1034	2.3893

in which Resource extraction efficiency is increased 20 fold

	1960	1966	1970	1976	1980
Population (pop. in labour = 65%)	15,927,000	17,557,000	18,606,000	20,160,000	21,223,00
Fraction of prod. labour in goods	.11029	.10702	.1005	.092872	.089164
Labour in goods	207,210	189,950	179,640	168,190	163,32
Fraction of prod. labour in agriculture	.20412	.1925	.18569	.17595	.16945
Labour in agriculture	357,550	341,710	331,920	318,640	310,39
Fraction of prod. labour in capital	.081401	.082717	.083998	.085692	.086843
Labour in capital	142,590	146,820	150,150	155,190	159,07
Fraction of prod. labour in resources	.13432	.13206	.12993	.12631	.12321
Labour in resources	235,280	234,410	232,250	228,740	225,70
Fraction of prod. labour in services	.46187	.48569	.49988	.51918	.53133
Labour in service	809,040	862,080	893,530	940,220	973,25
Resource extraction efficiency	1.1446	1.1424	1.1407	1.1377	1.1354
Capital in agriculture	300,000	366,500	421,550	531,160	614,63
Capital in services	115,150	174,440	220,340	298,180	354,39
Capital in capital	99,529	148,450	184,900	237,210	265,89
Capital in goods	352,380	441,360	497,620	586,900	645,65
Capital in resources	380,430	511,740	606,690	776,630	889,78
Capital/Labour ratio in goods	1.2147	1.6597	1.9786	2.4925	2.8237
Capital/Labour ratio in agriculture	.83919	1.0726	1.27	1.667	1.9802
Capital/Labour ratio in capital	1.7451	2.5278	3.0787	3.8214	4.1788
Capital/Labour ratio in resources	.80846	1.0915	1.3061	1.6976	1.9712
Capital/Labour ratio in services	1.0166	1.4453	1.7614	2.2647	2.6009

TABLE 9-3: CANADIAN STATISTICS

	1961	1965	1971
Population	18,238,000	19,644,000	21,569,000
Labour Force	6,055,000	6,862,000	8,079,000
Fraction of Productive Labour in Goods	.2398	.2385	.222
Labour in Goods (# of men)	1,452,000	1,636,000	1,795,000
Fraction of Productive Labour in Agriculture	.11247	.08656	.063102
Labour in Agriculture	681,000	594,000	510,000
Fraction of Prod. Labour in Capital	.10008	.10828	.1089
Labour in Capital	606,000	743,000	880,000
Fraction of Productive Labour in Resources	.030388	.0341008	.027603
Labour in Resources	184,000	234,000	223,000
Fraction of Productive Labour in Services	.5156	.5351	.578
Labour in Services	3,122,000	3,654,000	4,670,000

Source -

Statistics Canada:
Table of Employment by Industry and Occupation
1961, 1965, 1971.

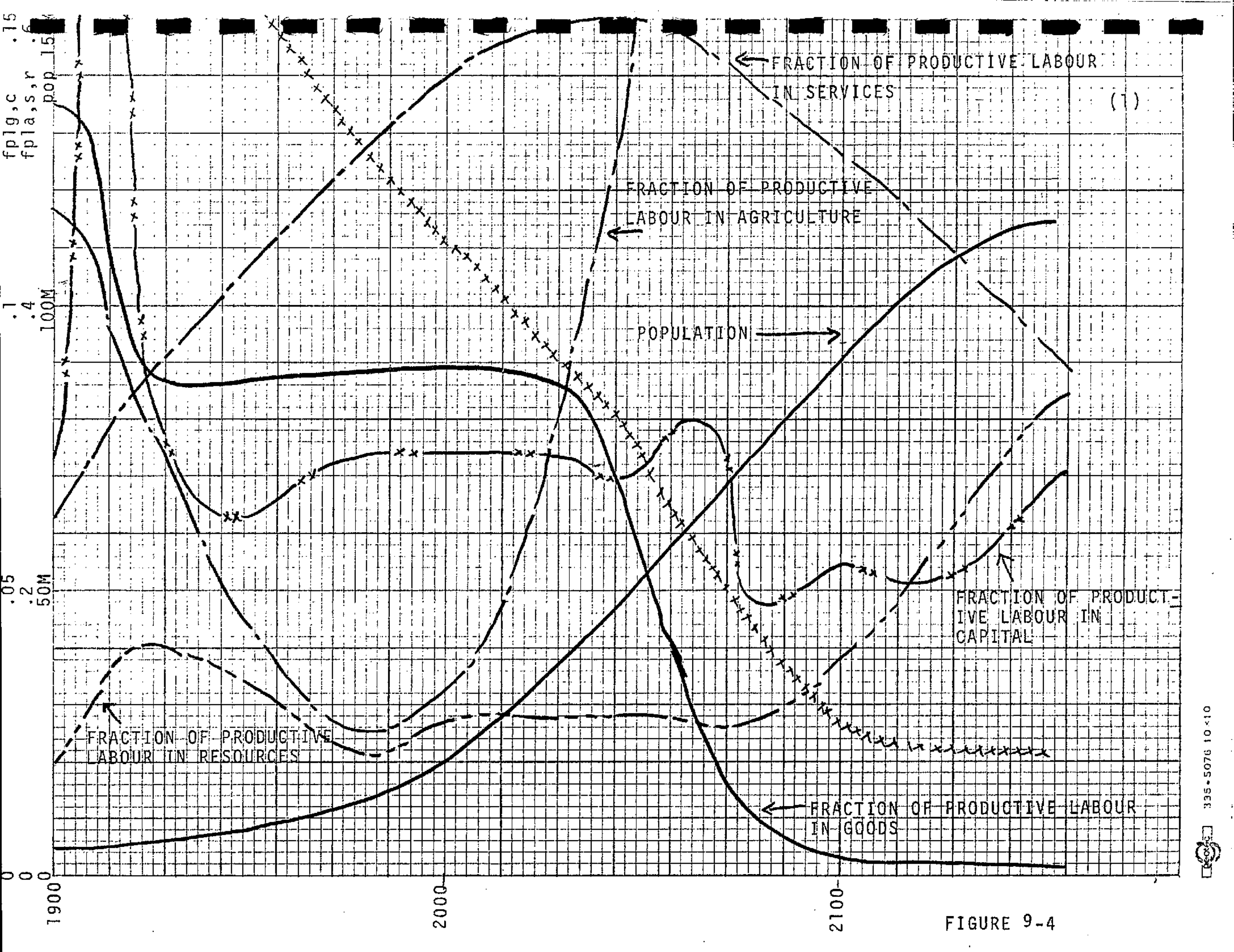
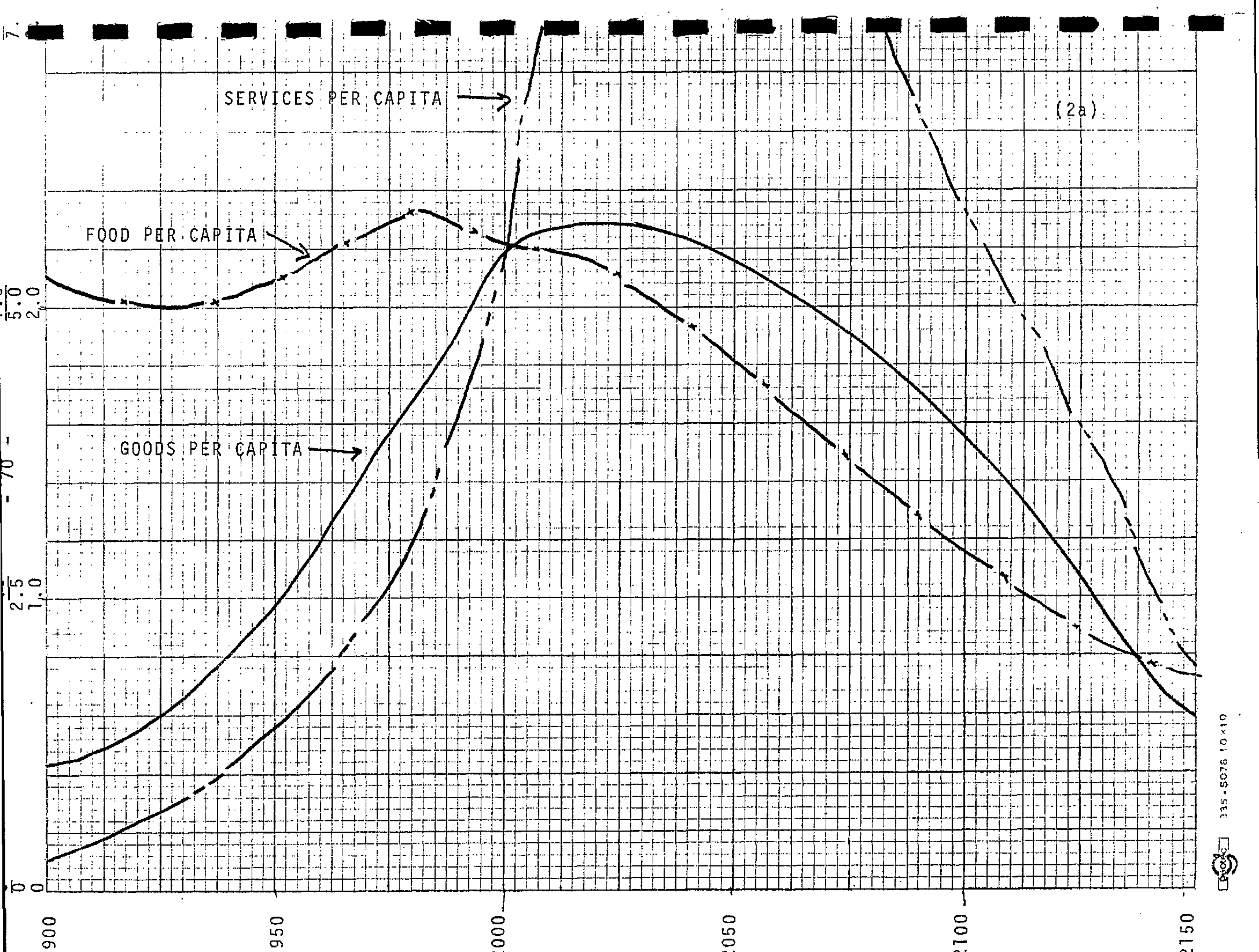
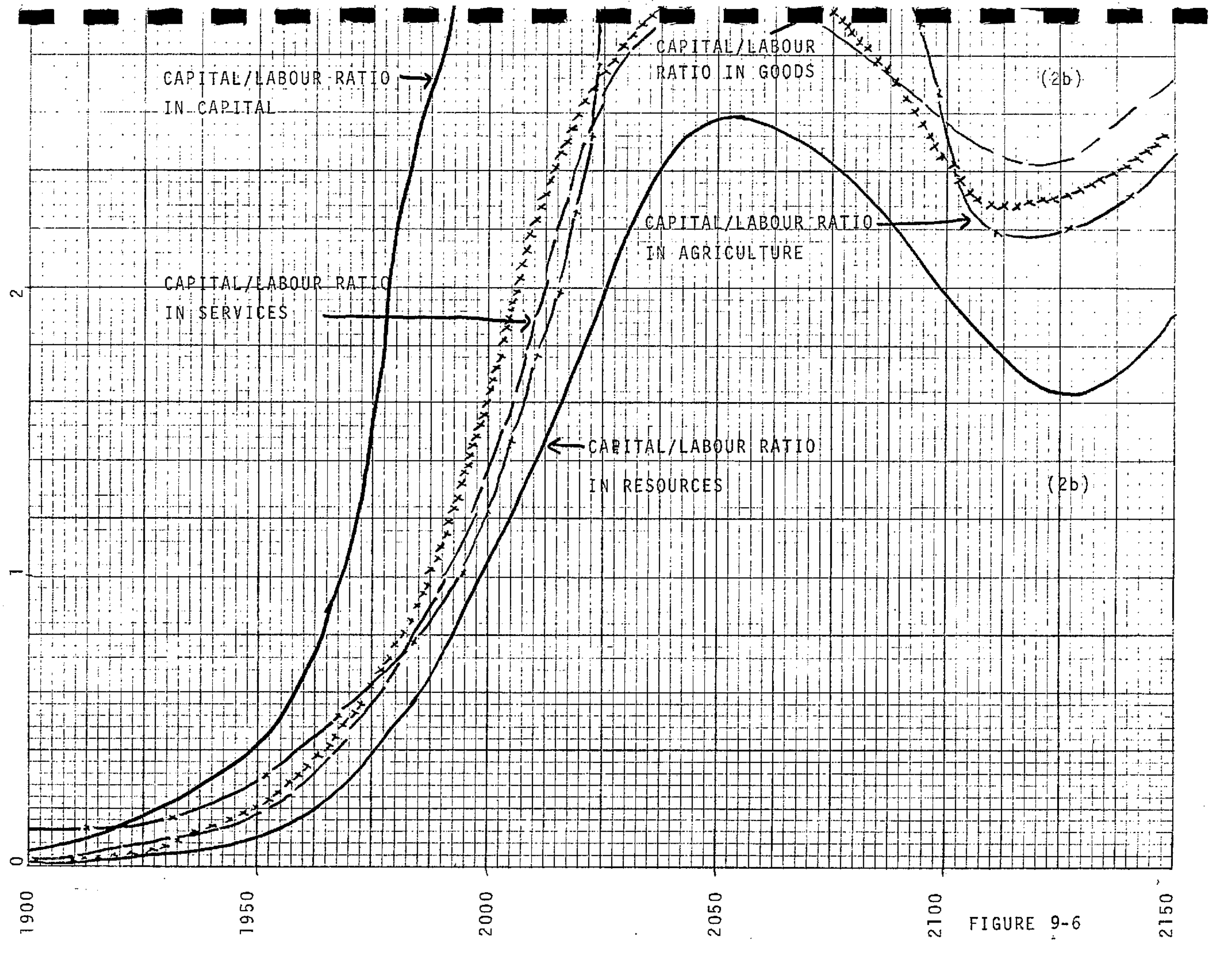

fplg,c
fpla,s,r
pop
.15
.6
15
.1
.4
100M
.05
.2
50M
0
0
0
1900
2000
2100
FRACTION OF PRODUCTIVE LABOUR IN SERVICES
(1)
FRACTION OF PRODUCTIVE LABOUR IN AGRICULTURE
POPULATION
FRACTION OF PRODUCTIVE LABOUR IN CAPITAL
FRACTION OF PRODUCTIVE LABOUR IN RESOURCES
FRACTION OF PRODUCTIVE LABOUR IN GOODS

FIGURE 9-4



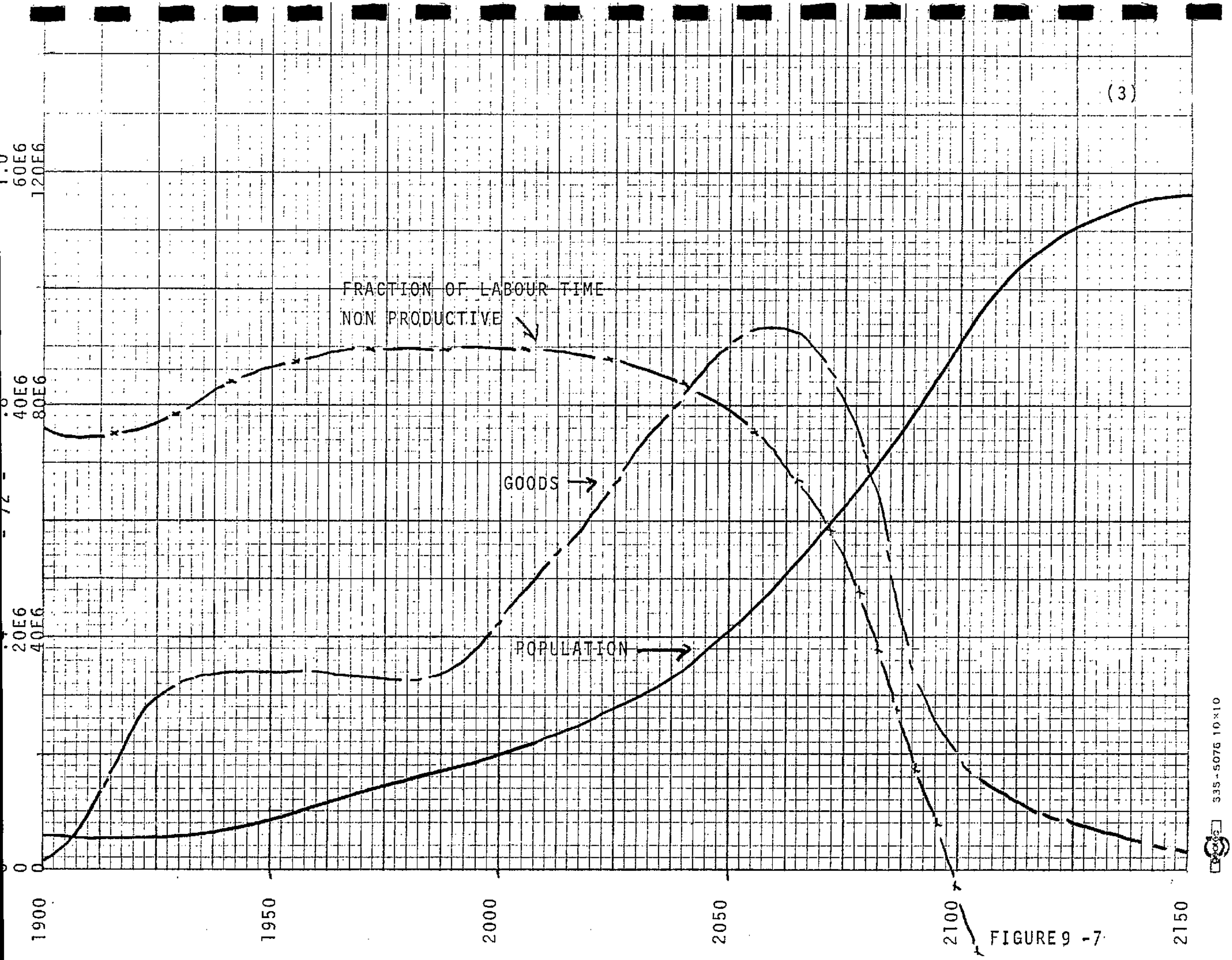
SERVICES PER CAPITA
(2a)
FOOD PER CAPITA
GOODS PER CAPITA
1900
1950
2000
2050
2100
2150
0
1.0
2.0
2.5
5.0
335-5076 10×10

FIGURE 9 -5



CAPITAL/LABOUR RATIO
IN CAPITAL
CAPITAL/LABOUR
RATIO IN GOODS
(2b)
CAPITAL/LABOUR RATIO
IN AGRICULTURE
CAPITAL/LABOUR RATIO
IN SERVICES
CAPITAL/LABOUR RATIO
IN RESOURCES
(2b)
0
1
2
1900
1950
2000
2050
2100
2150

FIGURE 9-6


(3)
FRACTION OF LABOUR TIME
NON PRODUCTIVE
GOODS
POPULATION
120E6
60E6
80E6
40E6
40E6
20E6
0
1900
1950
2000
2050
2100
2150
FIGURE 9 -7

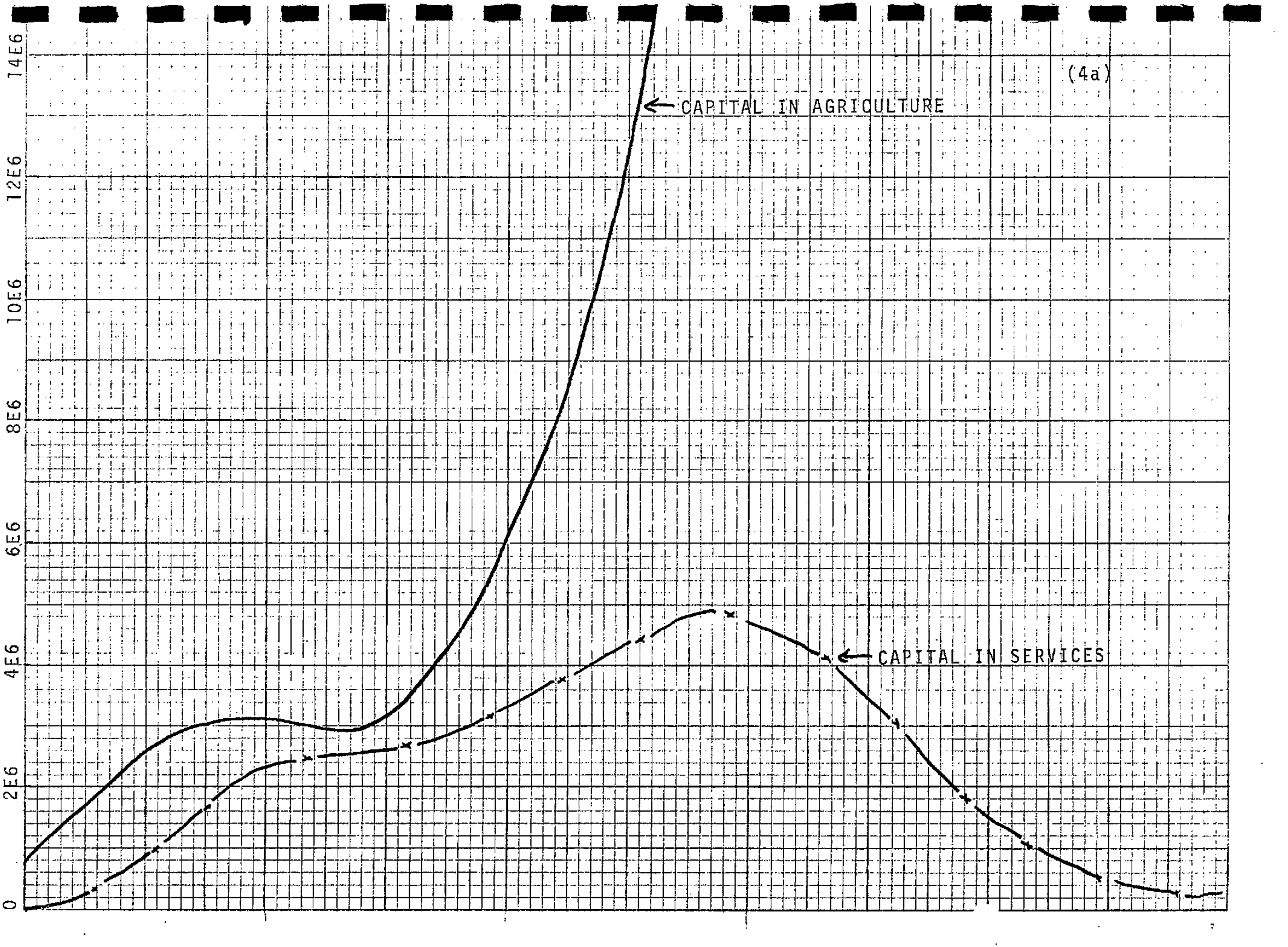
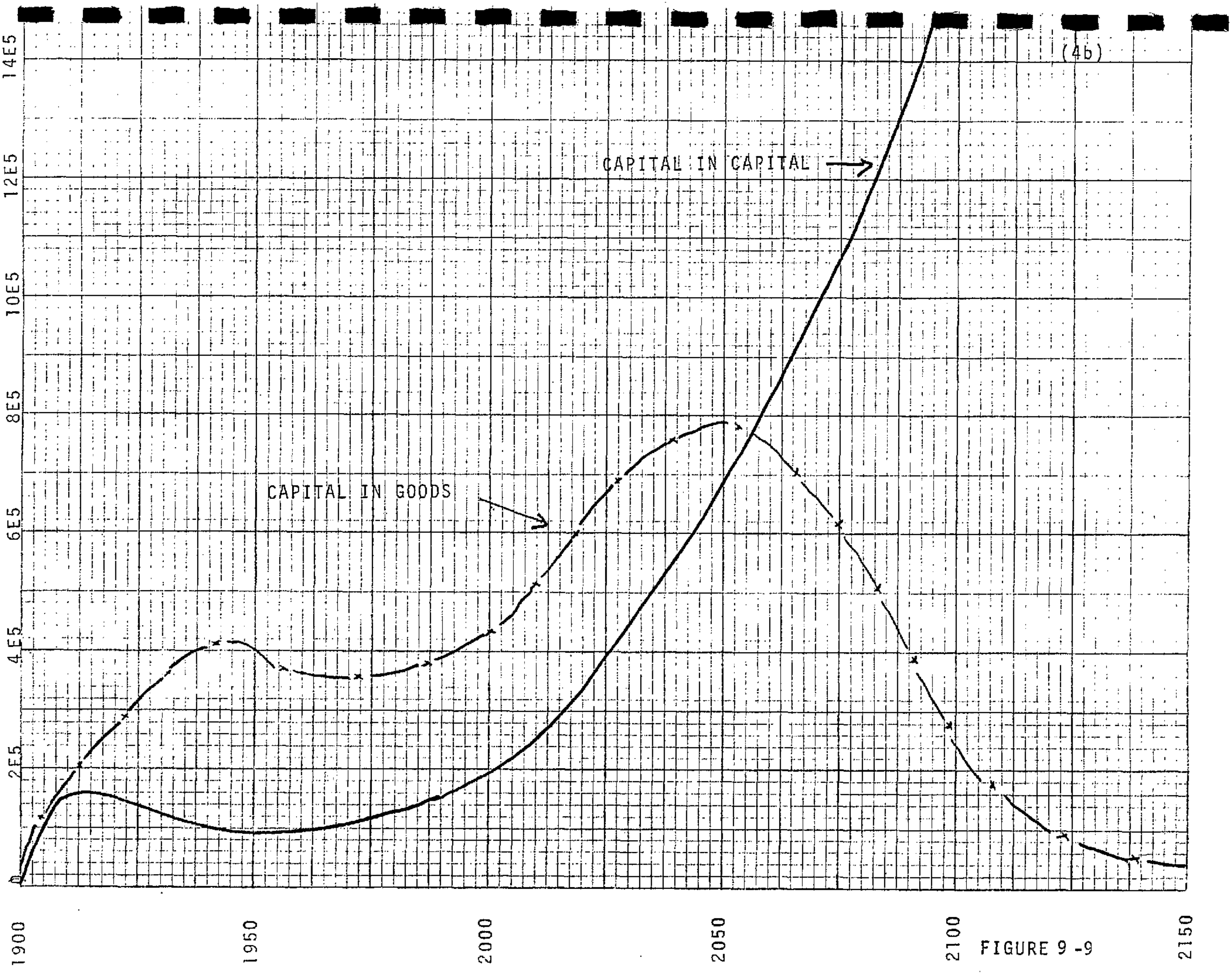

14E6
12E6
10E6
8E6
6E6
4E6
2E6
0
(4a)
CAPITAL IN AGRICULTURE
CAPITAL IN SERVICES
1900
1950
2000
2050
2150

FIGURE 9-8


(4b)
CAPITAL IN CAPITAL
CAPITAL IN GOODS
14E5
12E5
10E5
8E5
6E5
4E5
2E5
0
1900
1950
2000
2050
2100
2150
FIGURE 9 -9

X - RELEVANCE TREES

1. Description

Relevance trees analyze systems or processes in which distinct levels of complexity or hierarchy can be identified - this technique examines the relationships and dependencies between elements of some system. This technique is normative, i.e., the objective is to determine the technological capability required to carry out a certain function, based on an anticipated demand. Normative techniques are based on the principles of Systems Analysis. The relevance tree can describe the examined function in terms of levels of technological causation required to achieve it, and/or describe alternative methods along the tree's "branches". These branches can be assigned relative numerical weights, according to the importance of the factor assigned to each, and used as a quantitative guide to fixed resource allocation, as the total for each hierarchical level is "normalized" by being equal to a constant sum.

2. Type

Normative (Systems Analysis) - objective and/or intuitive.

3. Applications and Examples

Technology forecasting. An example might be determining the technology required of the forecasted automobile of the future.

4. Number of Participants/Staff

No participants required. Staff requirement variable according to complexity of investigated problem, but an exhaustive relevance tree may require several analysts, or even a "Delphi" to establish all branches or quantitative variables. A representative estimate might be 2 - 10 staff.

5. Relative Skills Required by Participants

Not normally applicable.

6. Relative Skills Required by Supervisor/Staff

Knowledge of the specific function and technological elements under investigation is desirable. Some statistical ability if branches are quantified.

7. Critical Internal Processes

All logical/possible branches must be identified. If quantification of the relative importance of branches is carried out, the basis for assigning relevance numbers must be realistic.

8. Time Required to Complete

Varies as to complexity; possibly 1 - 4 weeks.

9. Advantages

Relevance trees analyze hierarchical technological relationships; they organize and visibly structure the problem, enhancing the possibility that all technological avenues leading through successive technological elements to a specific function are identified. The quantification of the relative importance of different branches by assigning relevance numbers aids decision-makers in allocating finite resources.

10. Disadvantages

The relevance tree can be an exhaustive description of future required technology, but cannot be guaranteed. Its descriptive structure reduces its forecasting utility in favour of presenting options. Assigning numerical weights to branches is virtually always intuitive - not objective.

XI - MORPHOLOGY

1. Description

Morphology is the process of breaking a problem down into component parts, each of which can be treated independently (i.e. no hierarchical relationship). there may be several solutions to each problem-part, and the number of overall solutions is equal to the total number of possible combinations. The analysis is to assure all feasible solutions are examined before any decisions are taken.

2. Type

Normative (Systems analysis) - objective.

3. Applications and Examples

Technology forecasting. Very few examples can be found but, one might be an examination of different chemicals to be used for new fuels.

4. Number of Participants/Staff

No participants. -1 - 4 staff.

5. Relative Skills Required by Participants

Not applicable.

6. Relative Skills Required by Supervisor/Staff

Knowledge of the area under investigation desirable.

7. Critical Internal Processes

All possibilities must be included. Rejection of any overall solution(s) based on realistic assessment.

8. Time Required to Complete

Representative estimate: 1 - 2 weeks.

9. Advantages

Useful for identifying requirements for individual technologies, in order to meet overall requirements on a specific system - isolates "bottle necks" holding up novel but promising configurations.

10. Disadvantages

Has not been developed to allow quantification of any variables; tends to be static, unable to allow for spatial, temporal, or logical dynamic sequences.

XII - MISSION FLOW DIAGRAMS

1. Description

This technique involves mapping all the alternative routes or sequences by which some mission, task, or function can be accomplished. Alternatives can be identified, isolated, and if no currently available path, or flow, is feasible or cost/effective, a new alternative imagined.

2. Type

Normative (Systems Analysis) - objective.

3. Applications and Examples

Technology forecasting. An example might be urban transportation developments.

4. Number of Participants/Staff

No participants. Staff estimate: 1 - 8.

5. Relative Skills Required by Participants

Not applicable.

6. Relative Skills Required by Supervisor/Staff

Knowledge of the subject area is desirable.

7. Critical Internal Processes

The sequential steps in the mission flow diagram need to be drawn accurately and completely. All possibilities should be examined.

8. Time Required to Complete

Representative estimate: 1 - 6 weeks.

9. Advantages

Applies the normative (systems analysis) approach to technological elements that are inter-dependent sequentially (unlike morphology, which examines independent elements, and relevance trees, which examine hierarchical or causation relationships). Normative methods structure requirements and systematically present alternatives.

10. Disadvantages

Normative methods of any kind are no substitute for creativity or imagination - they are merely modernized and more sophisticated ways of making lists. Any quantification of variables will be based on intuition or one of the exploratory techniques given above.

XIII -CROSS-IMPACT MATRIX: COMBINING FORECASTS

1. Description

The cross-impact matrix is a mathematical technique for estimating the effect of one forecasted event on others. To illustrate - two forecasted events may not interact directly, but one or both may be greatly affected by a third, which is a direct interaction. Even more complex event configurations (alternative "future histories") can be projected, depending on the total product of forecasted possible interacting events. The cross-impact matrix systematizes the comparing of forecasted interactions.

The cross-impact matrix is often applicable to the results of a Delphi survey, which makes it a particularly important tool for independent research groups relying on Delphi. It is certainly not limited to that particular technology forecasting/assessment methodology, and the source of forecasts may be from several different methodologies.

An event may influence another in direction (mode), intensity (force), and timing (lag). It is often customary to list the forecasted events, in a certain order along the top and left side of the matrix, creating a blank diagonal at the square representing the intersection of an event with itself. To the right and above, the intersecting squares show the effect on each event if a previous one does occur; to the left and below, if not. Additional squares (usually on the left side) are interposed between the listed events and the matrix squares to show the given forecasted probability and year of the event occurring. A cross-impact matrix can be expanded to include permutations arising from a range of probabilities or a time-span. Larger cross-impact matrices usually require computerization.

2. Type

Usually based on exploratory - intuitive methodology.

3. Applications

Mainly technology assessment, but can be relevant to technology forecasting.

4. Number of Participants/Staff

The cross-impact matrix itself requires no participants, and the staff requirement varies. However, the generation of forecasts will require the resources as listed above, and quantification of the interaction of events will require generating new data, through a Delphi, use of "expert" staff, random number generation, etc.

5. Relative Skills Required by Participants

Not applicable except in accord with above forecast techniques if used to generate data for a cross-impact matrix.

6. Relative Skills Required by Supervisor/Staff

The staff will need some mathematical and statistical skills in constructing the matrix. The quantification of interacting variables will have to be based on expert survey techniques, staff expert knowledge, or other forecasting methods.

7. Critical Internal Processes

The assessment of the interactive impacts must be realistic.

8. Time Required to Complete

Comparing all possible permutations of interaction among many forecasted events is likely to be a time consuming task even for a large staff; 2 weeks - 2 months may be a representative estimate.

9. Advantages

The cross-impact matrix is a systematic way of relating many individual forecasted events to one another. It enables a range of alternatives and timings to be accommodated. The results of several different forecasts each relying on their own methodology can be encompassed.

10. Disadvantages

Analyzing interaction of forecasts by a cross-impact matrix adds considerable time before achieving final results, especially with the Delphi technique, and diminishing returns may obviate the effort. It is conceivable that, like all systematized forecasting techniques, the forecast is more rigid and inflexible, hence having less utility for accommodating "breakthroughs", exogenous variables change, etc.

XIV - SCENARIOS AND THE "GENIUS FORECASTER"

1. Description

Scenarios are projections of the overall social, political, technological economic and other environments in the future. They are usually presented as a sequential plot-outline of future conditions, based on present circumstances. A scenario is the intuitive framework upon which hypotheses can be developed, and are virtually invariably the basis for the projections of individuals who wish to express their own speculations about the shape of things to come. (Science fiction literature is usually written on the basis of an explicit or implicit scenario). Scenarios can have a place in professional technological forecasting and technological assessment, particularly as a focus for discussion among professional groups, e.g., the Hudson Institute's "Surprise-Free Projections" incorporate scenario techniques, (as in The Year 2000), and they can be used at seminars, addresses, and other professional group meetings. Their strictly intuitive nature reduces their value as a technological forecasting tool, but a plausible scenario at least provides a basis for discussion, speculation, or question introduction. A current on-going Hudson Institute project, The Corporate Environment to 1985, uses the scenario technique to provide a framework for more detailed investigation. This project has international group participants, including a Canadian committee of which MOSST is a member.

Individual intuition and perception will always be a vital component part of creativity. Accordingly, certain individuals have demonstrated startingly accurate (in retrospect) projections. These "genius forecasters" have relied upon their own capabilities to generate forecasts, for example, the author H.G. Wells stands out as a technology forecaster and technology assessor. He employed a scenario technique in one of his most successful works, <u>When the Sleeper Wakes</u>, which forecasted (in 1899): Nationalism; air warfare; the rise and prominence of labour unions; rapid transit; skyscraper buildings and 20th-century urbanization genrally; plastic and vinyl materials; the "new mathematics"; new coined expressions (e.g. "ecology", "escalation"); mass societies generally; radio and television (mass media); society "drop-outs" and problems of crime, alienation, etc.; the rise and prominence of advertising, public relations, etc.; rapid fashion changes; condominium housing; inumerable other ideas. H.G. Wells was among the first to recognize that technological change would bring about large scale social change, and idea widely accepted today.

A possible "most-rational" approach to scenario writing is the use of a PERT (Program Review and Evaluation Technique) chart to isolate critical "thresholds" or achievements that must be surmounted before any given end-result is reached. The PERT chart is a graphical representation of events in time, commonly used to manage very large (and often high-technology) projects, in which a number of critical sub-projects must be finished before work can proceed to a new stage. As the work progresses, it is possible to refer to the chart to determine if the project is on time, and to re-arrange the distribution of resources if one or more sub-projects are falling behind. A scenario is often based upon an explicit or implicit PERT chart, but expressed, of course, in narrative terms.

For a much more detailed review of the scenario technique, one may refer to "La Méthode des Scénarios", a report prepared for MOSST by the "Groupe de la Recherche sur le Futur" from the University of Quebec. This report is expected to be available in the near future.

2. Type

Exploratory and Normative - intuitive.

3. Applications and Examples

Technology assessment. All of the famous science-fiction works are based on scenarios. Scenarios are best used when a small group wishes to make as dramatic an impact as possible with any given forecast. Scenario writing is less a real forecasting technique per se, as it is method of presentation.

4. Number of Participants/Staff

Often a scenario is generated by one person's creative thinking. Professional research groups may synthesize a scenario among themselves as a basis for projections.

5. Relative Skills Required by Participants

If "participants" are brought in to assist in scenario development, they will need to have imagination.

6. Relative Skills Required by Supervisor/Staff

Imagination.

7. Critical Internal Processes

A scenario obviously cannot be "proved" right or wrong (nor) can any forecast) but it is extremely difficult to argue convincingly that a scenario hypothesis is unrealistic. Scenario writing requires imagination.

8. Time Required to Complete

This varies as to the scope of the scenario: up to 1 year, but can be finished in half-an-hour.

9. Advantages

A scenario formalizes and presents the cognitive steps undergone that lead to a certain projection or speculation. It can focus attention onto the variables being investigated by large groups.

As has been pointed out, the "most surprising thing about the future would be for it to have no surprises", and herein is the place for the genius forecaster and his scenario - Trend Extrapolations, Delphi's, etc., are based on the reasonableness of the projections, and only the genius forecaster with his scenario is relatively free to make unreasonable predictions, exactly what is required in the face of seemingly inevitable and unreasonable surprises.

10. Disadvantages

Absolutely no rational way of judging the forecast's validity.

Example - An Optimistic Scenario 1975 - 1985

This is a normative scenario, and is designed to illustrate critical paths that bring about an optimistic conclusion to the development of science policy. It is obviously not predictive, but is meant to be taken seriously from the standpoint of the general and specific goals it postulates.

1. A successful attempt is made to become less tied to U.S. economy, and hence less affected by U.S. economy fluctuations. This is accomplished by:
   - increased negotiated, _ad hoc_, bi-lateral trade with W. Europe and Japan, e.g., possible version of a Canada-Europe or Canada-Japan Auto pact; Concorde traded for deHavilland DHC-7 STOL airlines; Canada is, or comes close to being, an associate Member of EEC.
   - increased trade with "Third World" and Communist countries. Canada develops readily-marketable all-terrain and off-road vehicles, relatively unsophisticated but with minimum maintenace demands and cheap price. Particularly, Canada develops a "Barter" system of trade with individual countries (much like the French "Mirage" jet plane marketing tactic).
   - changing Canadian taxation to allow (say) total non-taxation of dividend income for residents, and/or a new tax system which taxes Capital Gains at normal (Progressive) rates, but permits legitimate "investments" (held for more than 1 year) to be income-tax deductible (to a greater or lesser extent); the objective is to increase

the flow of domestic-origin capital for Canadian investment. Japanese, West European investment encouraged for new projects, but some new restrictions on proportion of equity held by non-residents.

2. A concurrent and desired benefit of less inter-dependence on the U. S. economy is less U. S. control:
   - The Canadian government's Science Policy is developed into an overall industrial development Plan (as in the French case) in certain identified key areas of Canadian requirements (these are not developed because of export potential). This includes: Transportation--either on roads governed by Canadian climate or off-road entirely, e.g., in the North, high speed/capacity railways, and STOL, then VTOL aircraft; Communications--micro-wave (long distance) and in Arctic environments; Construction and housing--new insulations, building techniques, etc.; Clothing--electrically heating "Parka's" from nickel-cadmium batteries, etc. These developments are financed by the Canadian government through CDC, DREE grants, or the Defense Budget (a particularly useful way of developing high-technology under government control); through cooperative Science and Technology Programs with the U. S., Japan or Western Europe; or multi-lateral (IMF, NATO, under-developed

countries with similar urgent needs, etc.). This effects a clear-cut overriding set of priorities for Canadian development which dilutes head-office Multi-National Corporation (MNC) control of Canadian technological development. Canadian government purchasing can be assigned to high-priority items. Although this requires considerably more public assistance for technology/industry than previously considered optimum, Canadian domestic capital becomes more and more available as confidence rises in the future of Canadian manufacturing/high technology industry.

3. Major visible transportation innovations:
   - hovercraft
   - off-road vehicles
   - miniaturized nuclear power-plants for giant transport/ freight vehicles (trains, hovercraft, ships, submarines) especially in the North.
   - tilt-wing, compound-engined VTOL aircraft
   - novel air traffic control including developing of ultra-high resolution radars and long-range communication under adverse atmospheric conditions.

4. Dynamic management--"the world is our Oyster":
   The success of Canadian Sciency Policy and Industrial/ Technology plan fosters Canadian managerial expertise.

Particularly well-developed is Canadian management of MNC--government interface. The Canadian skill in this area, coupled with Canada's moderate and well-regarded image in the world, makes Canada a world-renowned leader in technological/industrial development, which encourages student/executive exchanges with other countries, etc. The new services--the growth industries of the future--are encouraged: computer software; managerial consultants, etc.

5. Substantial investment abroad--operating bases:

   Canada becomes well-regarded by "Third World" countries owing to its skill in technological development in the shadow of its great neighbor. Canadian investment in many underdeveloped countries is encouraged and even sought out. This does not lead to bad relations between Canadian investment and the host country as the Canadian objective is to develop the host country's capabilities as Canada itself is doing (new technology is available to Canada, and new markets for Canadian products created); this also further dilutes the impact of the American economy on Canada. This Canadian foreign investment also generates markets for Canadian raw materials as developing countries' industries grow, and develops Canadian capital markets in the long run.

6. Greater Resources for CBC, NFB, Arts subsidization, the "Great Canadian Novel":
   - development of a government-sponsored arts Council to which all successful Canadian talent belongs. Systematic attempt to discover new Canadian talent.
   - Canadian artists commissioned to develop patriotic-themed work after personal appeal by Prime Minister.
   - some foreign artists offered incentives to come to Canada to teach, talent scout, or express their art in Canadian themes.

7. A New Internationally-Acclaimed "Maple-flavoured soft drink":
   - Consumer products encouraged to find "Canadian-theme" trademarks.

8. Universities Booming with R&D Grants and Job-training:
   - research--engineering
   - planning--government/national
   - social science--"what is a Canadian?"
   - planning--corporate/marketing
   - climatology and weather control
   - physics for energy and energy distribution
   - environment and ecology, (especially North)

9. Develop Sophisticated International Managerial Community:
   - see "dynamic management--World is our Oyster"

- "Third World" assistance, e.g., CESO
- market research and technology forecasting to allow specialization in dynamic growth areas with long-term future.

10. Heightened National Pride:
    - awareness of "where we are going"
    - belonging to a dynamic, growing society
    - managing the climate through technology--"conquering nature, but without destruction."
    - looked to for leadership/management techniques by many U.D.C.
    - uniquely Canadian products
    - uniquely Canadian technology
    - idealistic--"helping the Third World."
    - independent of U. S.
    - playing significant role in keeping good relations between U. S. - Japan, Japan - Europe, U. S. - Russia, U. S. - W. Europe, etc., "friend to all."
    - world renowned success in development without social strains or environment destruction .
    - organization and development of multi-racial, cultural, national, state.

11. Increased opportunities for International "Service":
    - Peacekeeping
    - CUSO

- CESO
- foreign aid--CIDA
- "honest broker"
- Increased prestige
- Increased national pride
- world-wide trade
- world-wide visibility, but without rancor.

12. View of the North:

- novel ground transport (hovercraft, new-"roads").
- local, highly efficient miniaturized nuclear power-plants
- electrical grid between power-plants
- submarine transport in the Arctic
- development of natural resources
- weather control or very accurate forecasting
- efficient, reliable, even personalized, long-range communications
- special clothing
- special batteries, efficient in low temperatures
- novel housing/construction techniques
- novel agriculture, either in short summer, or artificial c climate
- eventually domed cities, artificial climate, all amenities of modern existence.

13. Oceans:

- "Mariculture"
- new ship/submarine designs
- under-sea resource development
- sonars and other acoustic under-sea detection/communication devices.

14. PaTIA--Pacific Trade and Investment Area:

- Free Trade with Australia (similar product profiles, good for competition)
- selective Free Trade with Indian sub-continent (a trade-off of markets for aid).
- Canada-Japan bilateral Free Trade and Investment in selected areas
- Tourism development--low Trans-Pacific charter fares.

15. Government:

- the optimistic Canadian scenario is based on identification of Canadian and world-wide social, technical and economic needs, and a government-led (i.e.: Science Policy) exploitation of them. The skills required most strongly in such an approach will be market research, technology forecasting, and social flexibility particularly the ability to make rapid transfers of resources from one sector or industry into another. The last is the only way dynamic specialization can be achieved: as one specialization becomes obsolete another must be found to take its place. This implies a very high ratio of Research and Development to G.N.P., and a very strong Science Policy.

BIBLIOGRAPHY

Ackoff, R.L., "Operational Research and National Science Policy", Decision Making in National Science Policy, a CIBA Foundation and Science of Science Foundation Symposium, edited by A. de Reuck, M. Goldsmith, J. Knight and A. Churchil Ltd., London.

Ansoff, H. Igor, A Quasi-Analytic Method for Long Range Planning, Prentice Hall Inc., Englewood Cliffes, New Jersey, N. Alexis and Charles Z. Wilson ed., 1967.

Ashby, W. Ross, General Systems Theory as a New Discipline, General Systems Yearbook, vol. 111, 1958.

Ashby, W. Ross, Introduction à la cybernétique, Dunod, Paris, 1956.

D'Aumale, Geoffroy, La programmation des décisions, P.U.F., Collection S.U.P., 1968.

Ayres, Robert U., Technological Forecasting and Long Range Planning, McGraw Hill Co., New York, 1969.

Barney, Dr. G.O., Modelling Methodologies and the Problem of Futures Research for Policy Formulation, Center for Naval Analyses, Arlington, Virginia.

Baudot, J., Analyse des méthodes permettant de saisir les aspects qualitatifs du développement économique et social à long terme, Nations-Unies, Commission Economique pour l'Europe, mars 1969, 7e réunion des conseillers économiques principaux des pays membres de la C.E.E.

Baudrillard, J., Le Système des objets, Gallimard, NRF, 1968.

Berr, Stafford, Decision and Control, John Wiley and Sons, London, New York, 1966, 3rd. ed., 1970.

Berger, G., Phénoménologie du temps et prospective, P.U.F., 1964.

Bertalanffy, L. Von, General System Theory, Foundations, Development, Applications, New York, George Braziller, 1968.

Bertalanffy, L. Von, "General Theory of Systems, Application to Psychology" in Les Sciences Sociales, Problèmes et Orientations, Mouton, La Haye, UNESCO, 1968.

Bertherat, Dubois, Gauron, Tiano, Berthet, Sur Les Approches et Les Instruments de l'Exploration du Long Terme, I.N.S.E.E., ronéotype, juillet, 1969.

Bestoujev-Lada, I.V., "La Prévision, Une Des Méthodes d'Exploration de l'Avenir" in La Futurologie, Numéro Spécial de la Revue Internationale des Sciences Sociales, vol. XXI, no. 4, 1969, UNESCO.

Bestoujev-Lada, I.V., "Les Etudes sur l'Avenir en U.R.S.S." in Analyse et Prévision, V, 2, février 1968.

Bieber, Alain, "Planification des Transports et Analyse de Systèmes" in Analyse et Prévision, T. VIII, octobre, 1969, no. 4.

Bright, Prof. J.R., "Technology Forecasting - New Tools for an Old Responsibility", Research Management, July 1972.

Buckley, Walter, Sociology and Modern Systems Theory, Prentice Hall Inc., Englewood Cliffs, New Jersey, 1967.

Catanese, J. and Steiss, A.W., Systemic Planning for Very Complex Systems.

Cazes, B., "Bien User de la Prospective", Informations sur Les Sciences Sociales, vol. 9, no. 2.

Churchman, C. West, The Systems Approach, Delta book, Dell Publishing co., New York, 1968.

Coenen, R., "The Use of Technological Forecasts in Government Planning" Research Policy, Vol. 1, (1971-72).

Commission Nationale de la Technologie, de l'Automation et du Progrès Economique (USA), "La Technologie et l'Economie Américaine", Notes et Etudes Documentaires, no. 3573, 18 mars 1969, La Documentation Française.

Delors, J., "La Planification Française et la Prospective Sociale", Analyse et Prévision, VI, 5, novembre 1968.

Delors, J., Le Rôle et l'Utilité des Etudes et Programmes à Long Terme, Commission Economique pour l'Europe des Nations-Unies, polycopié, mars 1969.

Deutsch, Karl W., The Nerves of Government, Models of Political Communication and Control, New York, The Free Press, McMillan, 1963.

Direction de la Prévision, "L'Analyse de Système et la Rationalisation des Choix Budgétaires", Statistiques et Etudes Financières, no. 251, novembre 1969.

Divers, Cost-Effectiveness Analysis, Washington Operations Research Council, edited by Thomas A. Goldman, Praeger Special Studies on U.S. Economic and Social Development, Frederick A. Praeger, New York, 1967.

Divers, Etapes de la Prospective, PUF, 1967.

Divers, Les Utopies à la Renaissance, PUF, 1963.

Divers, (Mesarovic, ed), Views on General Systems Theory, John Wiley and Sons, 1964, New York, London.

Divers, Modern Systems Research for the Behavioral Scientist, a source book, W. Buckley (ed.), Aldine Publishing Co., Chicago, 1968, 2nd ed., 1969, voir notamment les contributions de Rapoport, Boulding, Bertalanffy, Churchman et Ackoff, Buckley.

Divers, <u>Perspectives of Planning</u>, O.C.D.E., 1965. Une traduction française par B. Cazes est en cours.

Divers, <u>Social Indicators</u>, édité par Raymond A. Bauer, MIT Press, Cambridge, Mass., 1966. Voir notamment les contributions de Bauer, Biderman et Bertram Gross.

Divers, <u>Toward the Year 2000: Work in Progress</u>, Daedalus, été 1967 (voir en particulier les contributions de D. Bell, Leontiev, Schon, Iklé). La contribution d'Iklé a été traduite par B. Cazes et publiée dans Analyse et Prévision, juillet-août 1967 sous le titre De l'Epistémologie des Prédictions Sociales.

Domenach, J.M., "Note sur le Bon Usage de l'Avenir", <u>Esprit</u>, No. 2, 1966.

Dror, Y., <u>A General Systems Approach to Uses of Behavioral Sciences for Better Policymaking</u>, Rand Corporation, P-4091, mai 1969.

Dror, Y., <u>Systems Analysis for Development Decisions: Applicability, Feasibility, Effectiveness and Efficiency</u>, Rand Corporation, P-4159, août 1969.

Dubois, Claude-Gilbert, <u>Problèmes de l'Utopie</u>, Archives des Lettres Modernes, 1968 (1) (IV), No. 85.

Dubos, R., <u>Future Oriented Sciences</u>, Perspectives of Planning, O.C.D.E., Paris, 1965.

Ducrocq, A., <u>Logique Générale des Systèmes et des Effets</u>, Dunrod, Paris, 1960.

Duveau, G., <u>Sociologie de l'Utopie</u>, PUF, 1961.

Easton, D., <u>A System Analysis of Political Life</u>, John Wiley and Sons, Inc., New York, 1965.

Emery, F.E. ed., <u>Systems Thinking</u>, Penguin Modern Management Readings, Penguin Books, 2nd. ed., 1970. Voir en particulier les contributions de A. Angyal et G. Sommerhoff.

Enthoven, Dr. Alain C., <u>Operations Research and the Design of the Defense Program</u>, Actes de la 3e Conférence Internationale de Recherche Opérationnelle d'Oslo, 1963, Dunod, 1964.

Etzioni, Amitai, <u>Modern Organizations</u>, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1964.

Forrester, Jay W., <u>Industrial Dynamics</u>, Cambridge, Mass., MIT Press, 1961.

Forrester, Jay W., <u>Principles of Systems</u>, Cambridge, Mass., Wright-Allen Press 1968.

Forrester, Jay W., <u>Urban Dynamics</u>, Cambridge, Mass., MIT Press, 1969.

Forrester, Jay W., <u>World Dynamics</u>, Cambridge, Mass., Wright-Allen Press, 1971.

Forrester, Jay W., "Planning under the Dynamic Influences of Complex Social Systems" and "A New Corporate Design" in Perspectives of Planning, O.C.D.E., Paris, 1969.

Fortet, R. and Le Boulanger, H., "Eléments pour une synthèse sur les systèmes à auto-organisation", METRA, No. 12, 1967.

Fraisse, R., "Sur la Planification à Long Terme en Union Soviétique", Analyse et Prévision, VI, 4, avril 1968.

Gibson, R.E., "A Systems Approach to Research Management" in Research, Development and Technological Innovation, edited by James R. Bright, Richard D. Irwin Inc., 1964, Homewood.

Goodman, Richard A., "Un Diagramme du Système Constitué par des Fonctions de Direction", Direction et Gestion, No. 2, mars-avril 1969.

Greniewski, H. "La Cybernétique et la Planification", Revue Française de Recherche Opérationnelle, No. 23, 2e trimestre 1962.

Gross, Bertram M., "L'Avenir de l'Analyse Systématique des Modèles Sociaux", Analyse et Prévision, I, 2, février 1967.

Groupe de Travail sur la Prospective de la Sante, Réflexions sur l'Avenir du Système de Santé, La Documentation Française.

Haas, M., "Types of Asymmetry in Social and Political Systems", General Systems Yearbook, Vol. XII, 1967.

Helmer, Olaf, Social Technology, Basic Books Inc., New York, London, 1966.

Hetman, F., "Le Langage de la Précision", Futuribles, SEDEIS, 1969.

Hill, Brookes, Hunt, "How Much Basic Research is Enough?", Long Range Planning, Vol. 1, No. 3, mars 1969.

Hitch, Charles J. and McKean, Roland N., The Economics of Defense in the Nuclear Age, Harvard University Press, Cambridge, 1961.

Horovitz, Irving Louis, "Le Rôle des Techniciens et des Sociologues dans le Développement: Contraintes Interdisciplinaires de la Prospective Sociale" in La Futurologie, Numéro Spécial de la Revue Internationale des Sciences Sociales, Vol. XXI, No. 4, 1969, UNESCO.

Howland, Daniel, "A Model for Hospital System-Planning" in Actes de la 3e Conférence Internationale de Recherche Opérationnelle, Oslo, 1963, Dunod, Paris, 1964.

Jantsch, E., Technological Forecasting in Perspective, OECD, Paris 1967.

Jantsch, E. "Adaptive Institutions for Shaping the Future", Perspectives of Planning, O.C.D.E., Paris, 1969.

Jantsch, E., "Integrative Planning of Technology", Perspectives of Planning, O.C.D.E., Paris, 1969.

Jantsch, E., "New Organizational Forms for Forecasting", Technological Forecasting, Vol. 1, No. 2, Fall 1969.

Jantsch, E., "Technological Forecasting in Corporate Planning", Long Range Planning, Vol. 1, No. 1, Sept. 1968.

Jantsch, E., "Toward a Methodology for Systemic Forecasting", Technological Forecasting, Vol. 1, No. 4, Spring 1970.

Jantsch, E., "Vers l'Interdisciplinarité et la Transdisciplinarité dans l'Enseignement et l'Innovation, Séminaire de l'O.C.D.E., Nice, septembre 1970, ronéotypé.

Johnson, Kast, Rosenzweig, Théorie, Conception et Gestion des Systèmes, Dunod, Paris, 1970.

Jouvenel, Bertrand de, L'Art de la Conjecture, Paris, SEDEIS, 1964.

Kahn, H., and Weiner, A.J., The Year 2000, McMillan Co., New York, 1967.

Kahn, H., and Bruce-Briggs, B., Things to Come, McMillan Co., New York, 1972.

Lakhtin, George A., "Operational Research Methods in the Management of Scientific Research", Minerva, Vol. VI, No. 4, Summer 1968.

Lefebvre, H., "La Révolution Urbaine", Idées, NRF, Gallimard, 1970.

Lefebvre, H., "Le Manifeste Différentialiste", Idées, NRF, Gallimard, 1970.

Lisitchkin, V.A., "Prévisions et Pronostics", Analyse et Prévision, VI, 3, septembre 1968.

Lisitchkin, V.A., "The Process of Making Forecasts", Technological Forecasting, Vol. 1, No. 1, June 1969.

Lobstein, Jacques, "Structure: de la Fonction au Système", Management France, juillet 1969.

Lods, Adolphe, Les Prophètes d'Israel et les Débuts du Judaisme, Albin Michel, 1969.

Mannheim, K., Ideology and Utopia, Routledge and Kegan, 7th ed., 1954.

Margalef, D. Ramon, "Information Theory in Ecology", General Systems Yearbook, Vol. III, 1958.

Marney, M.C. and Smith, N.M., "The Domain of Adaptive Systems: A Rudimentary Taxonomy", General Systems Yearbook, Vol. IX, 1964, p. 107 and ss.

Marschak, Thomas A., "Strategy and Organization in a System Development Project", in The Rate and Direction of Inventive Activity, Economic and Social Factors, a Report of the National Bureau of Economic Research, New York, Princeton University Press, 1962.

Martino, Dr. J.P., Technological Forecasting for Decision-Making, Elsevier, New York, 1972.

McCracken, M.C., National Forecast Service Model Book, Informetrica Ltd., 1974.

McCracken, M.C., An Overview of CANDIDE Model 1.0, CANDIDE Project Paper #1, ECC, Cat. #22-19-1-0, 1973.

Masse, P. et Lesourne, J., "Le Problème de la Ville et l'Analyse de Systèmes", Analyse et Prévision, VII, 5, mai 1969.

McCrory, R.J., "The Design Method - A Scientific Approach to Valid Design" in Research Development and Technological Innovation, edited by James R. Bright, Richard D. Irwin, Inc., 1964, Homewood, Illinois.

McKean, Roland N., Efficiency in Government Through System Analysis, New York, John Wiley and SOns, a Rand Corporation Research Study, 5th ed., 1966, (1st ed., 1958).

Meadow, D.H. et al, Toward Global Equilibrium, Wright-Allen Press Inc., Cambridge, Massachusets, 1973.

Meleze, (J.), "La gestion par les systèmes", Hommes et Techniques, 1968.

Metayer, (G.), Cybernétique et organisation, les Ed. d'organisation, Paris, 1970.

Michael, Donald N., The Unprepared Society: Planning for a Precarious Future, Basic Books Inc. publishers, 1968.

Monod, J., Les frontières de la biologie, La recherche, n° 5, oct. 1970.

Monod, J., Le hasard et la nécessité, éd. du Seuil, 1970.

Morton, A.L., L'utopie anglaise, Maspero, 1964.

Morton, Jack A., "Le processus d'innovation" in Recherche et activité économique, ouvrage collectif publié sous la direction de F. Perroux, Collection U, A. Colin, Paris, 1969.

Olson, Jr. M., Rapport social, indicateurs sociaux et comptes sociaux, Analyse et Prévision, T. VII, n° 2, février 1969.

Optner, S.L., L'analyse des systèmes et les problèmes de gestion, Dunod, 1968.

Ozbekhan, Hasan, Toward a General Theory of Planning, Perspectives of Planning, O.C.D.E., Paris, 1969.

Ozbehkan, Hasan, On Some of the Fundamental Problems in Planning, Technological Forecasting, Vol. 1, n° 3, mars 1970.

Parsons, T., An Outline of the Social System, introduction à Theories of Society, New York, The Free Press, 1961.

Parsons, T. & Smelser, N.J., Economy and Society, The Free Press, New York, 1965 (1re édition 1956).

Perret, Analyse de systèmes et théorie des organisations, Direction de la Prévision, section de recherche et d'informatique, document ronéotypé, rédaction provisoire, 11-X-68.

Piaget, J., L'épistémologie des relations interdisciplinaires, séminaire de l'O.C.D.E., Nice, sept. 1970, ronép.

Piganiol, P., "Introduction: futurologie et prospective" in La Futurologie, numéro spécial de la Revue internationale des Sciences Sociales, vol XXi, no 4, 1969, UNESCO.

Price, don K., The Scientific Estate, the Balknap Press of the Harvard University Press-Cambridge, Mass., 1965.

Quade, E.S., L'analyse des systèmes, application de ses techniques au PPBS, Analyse et Prévision, V11, 6 juin, 1969.

Raynauld, Dr. A., Technoligical Forecasting, Notes for speech given to the Conference Board, Montreal, October 26, 1972.

Rapoport, Anatol, "Mathematical Aspects of General System Analysis" in Les sciences sociales, problèmes et orientations, Mouton, La Haye, UNESCO, 1968.

Rea, Robert H., "The Design of Integrated Technological Forecasting and Planning Systems for the Allocation of Resources", in Perspectives of Planning, O.C.D.E., Paris, 1969.

Rescher, Nicholas, La dynamique des changements de valeur, Analyse et Prévision, 11, 3, septembre 1966.

Richta, R. & SULC (Ota), "La prévision de l'avenir et la révolution scientifique et technique", in La Futurologie, numéro spécial de la Revue Internationale des Sciences Sociales, vol. XX1, nº 4, 1969, UNESCO.

Roberts, Edward B., Exploratory and Normative Technological Forecasting: a Critical Appraisal, Technological Forecasting, vol. 1, nº 2, fall 1969.

Robson, William A., L'avenir de l'administration publique, Analyse et Prévision, 1, 5, novembre 1966.

Roig, Ch., Analyse de systèmes en sciences sociales: perspectives de développement théorique, rapport introductif aux journées d'études sur l'analyse systémique en science politique, Association française de Science politique, Paris, avril 1970, ronéotypé.

Rubenstein, A.H., "Organization and Research and Development Decision-Making within the Decentralized Firm" in The Rate and Direction of Inventive Activity, Princeton University Press, N-J 1962.

Rubenstein & Radnor, "Top Management's role in Research Planning in Large Decentralized Companies", in The Rate and Direction of Inventive Activity, op. cit.

Rummel, Rudolph J., A Field Theory of Social Action with Application to Conflict within Nations, General Systems Yearbook, vol. X, 1965, p. 183 et ss.

Ruyer, R., L'utopie et les utopies, PUF, 1950.

Scheffler, Israël, Anatomie de la science, Seuil, 1966.

Schwarz, stefan, Notes on Information and Epistemology in Futuristics, International Future Conference, Kyoto, 1970, ronéptypé.

Servier, J., Histoire de l'utopie, idées, Gallimard, 1967.

Shchedrovitzky, G.P., Methodological Problems of System Research, General Systems Yearbook, vol. XI, 1966.

Simondon, G., Du mode d'existence des objets techniques, Aubier-Montaigne, 1969.

Skalina, Peter, RIHA (L.), Long-term Prognosis and Policy for Steering and Controlling the Development and Growth of Science and Technology, ronéotypé, Prague, mai 1969.

Smalter, Donald J., Analytical Techniques in Planning, Long Range Planning, Vol. 1, n° 1, septembre 1968.

Solo, Robert A., Economic Organizations and Social Systems, Bobbs-Merrill Co., Inc., New-York, 1967.

Staikov, Zahari, Methodological Problems Related to the Establishment of a General System of Prognostication, International Future Conference, Kyoto 1970, ronéptypé.

Steenbergen, Bart van, Critical and Establishment Futurology, International Future Conference, Kyoto, 1970, ronéo.

Sylc, O., A Methodological Approach to the Integration of Technological and Social Forecasts, Technological Forecasting, vol. 3, no.1, juin 1969.

Taviss, I., "La futurologie et le problème des valeurs", in La Futurologie, numéro spécial de la Revue Internationale des Sciences Sociales, vol. XXI, n° 4, 1969, UNESCO.

Technological Forecasting and Social Change; An International Journal, Elsevir, New York.

Thompson, J.W., Prediction in Physics and the Social Sciences, General Systems Yearbook, vol. IX, 1964.

Tondl, L., Man and Science, Institute for the theory and methodology of science of the Czechoslovak Academy of Science, Prague, 1969.

Towers, B., Evolutionary Trends and Human Potential, International Future Conference, Kyoto, 1970, ronéotypé.

UNESCO, Manuel d'inventaire du potentiel scientifique et technique national, Etudes et Documents de Politique Scientifique, n° 15, 1969.

UNESCO, Tendances principales de la recherche dans les sciences sociales et humains, partie 1: sciences sociales, Mouton 1970. Voir notamment l'introduction de J. Piaget et, du même auteur, le chapitre V11 "problèmes généraux de la recherche interdisciplinaire et méchanismes communs", p.559 et ss.

Walliser, B., Principes de base des systèmes finalisés, Ministère des Finances, ronéotypé.

Webb, Kenneth W.,"An Operation Research Study of the National Oceanographic Program" in Actes de la 3° Conférence internationale de recherche opérationnelle, Oslo, 1963, Dunod, Paris, 1964.

Weidenbaum, Murray L., Effets à long terme de la grande technologie, Analyse et Prévision, VIII, 1-2 juillet-août 1969.

Weinberg, Alvin M., Technologie ou Engineering Social, Analyse et Prévision 11, 4, octobre 1966.

Young, O.R., A Survey of General Systems Theory, General Systems Yearbook, vol. IX, 1964.

Young, Stanley, L'entreprise considérée comme un système total, Direction et Gestion, n° 2, mars-avril 1969.

Young, Stanley, Management : a Systems Analysis, Scott, Foresman and Co., 1966.

Zadeh, L.A. & Polak, E., System Theory, McGraw Hill, inter-university Electronics series, 1969.