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SOCIAL VALUE ANALYSIS AND ECONOMIC CONSIDERATIONS RELATING TO A NATIONAL DATA NETWORK

by

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ABSTRACT

This thesis provides a new approach to both the forecasting of telecommunication development and to the assessment of its consequences; this enables a social value analysis to be undertaken, by which the significance of a new telecommunication system may be examined from several points of view.

The research centred on proposals currently being studied for a national data network designed to replace existing inadequate data transmission facilities. A computerized analysis of the future growth of both numbers of data terminals and of the cost of a data network to carry these enables a preliminary decision analysis to be made; this indicates that an early introduction of a national data network would be favoured by all affected parties.

Since the build-up of demand will be influenced by both costs and benefits, it is necessary to model benefits explicitly. By modelling general applications of a national data network, a methodology of considerable generality is developed for the quantitative assessment of benefits to the business community. Since the constraints of time, distance, and "physical being" bound the operational environment of an establishment, constraint reduction is taken to be the essential benefit of national data network usage. Considering the most valuable constraint reduction to involve time, the value of time to an establishment is quantified in various modelled situations.

Benefits are aggregated to give estimated limit lines of the total social benefit of national data network usage; the results obtained are comparable to the macro-benefit derived using a simplified form of a dynamic input-output model. A preliminary social value analysis suggests that a national data network would involve a favourable use of national resources.

A dynamic theory of demand for a national data network is also developed. Market saturation levels, particularly for the production and distribution sectors of the British economy, are first estimated. A theoretically derived general S-curve, which models the underlying value of data network usage and the possible mechanism of network build-up, is fitted to these and to current growth trend lines; a forecast of market growth over time is thus obtained. By attempting to "see into the minds" of rational decision-makers, this new approach assesses underlying demand rather than just expressed demand. The use of quantitative models throughout

this development enables sensitivity analyses to be made; thus the results obtained are considerably more useful than are point-estimate forecasts.

Since many consequences of a national data network cannot yet be quantified, a framework is provided within which social consequences may be qualitatively assessed. By analyzing interactions between various interest groups, a limited scenario of a possible future is cbtained; it is suggested that the net effect of a nation-al data network will be highly beneficial.

Although a comprehensive social value analysis of the whole future of a national data network cannot yet be made, many of the component parts of such an analysis have been provided : these should be of considerable value in decision-making.

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CHAPTER 1 : INTRODUCTION

1.1 Background to Study

In industrially developed countries there is at present only a limited amount of data transmission along telecommunication channels. But the annual growth rates of such transmission are phenomenal; the transmission of digital data will soon be one of the essential requirements to be met by a telecommunication Administration. As the amount of potential data traffic (which is growing almost exponentially) is increasing faster than any G.N.P., the capital investment and annual expenditure which will be required in data telecommunications will represent an increasing proportion of national budgets. Moreover, new facilities may require five or more years between their development and their introduction as a regular service. There is thus a readily apparent need for long-range planning and technological forecasting in this field.

In the United Kingdom, a study covering present and likely future requirements for and developments in data telecommunication is clearly within the scope of the Post Office, who should be best equipped to handle such a study. Indeed the Post Office has recently sponsored four research studies in this field. Three studies were concerned with technical and developmental aspects of a national digital data network: Standard Telecommunication Laboratories Ltd. examined the "store and forward" approach to data network design (S.T.L., 1969a and 1969b); British Telecommunication Research (Plessey) Ltd. examined the alternative "circuit switched" approach (B.T.R., 1969a and 1969b); and International Computers Ltd. carried out a study of data terminal procedures and interfaces (I.C.L., 1969a and 1969b). The fourth study, of future data transmission requirements, was carried out by Scientific Control Systems Ltd. (SCICON, 1969).

An examination of the areas covered by these studies suggested that there might be scope for an independent and rather academic study, designed to fill in certain areas of considerable economic significance. Tremendous difficulties were encountered since the uncertain future of this field of rapid technological change makes forecasting of questionable value: one is attempting to evaluate a non-existent service, of unknown characteristics, which will be used by persons unknown for purposes as yet unspecified!

The chief contribution of this thesis is taken to be its provision of a methodology which may be used to quantify some new areas of this nebulous and uncertain future. Of considerable value should be the theory of demand which is developed; an important aspect of this is the quantification of some of the benefits expected to result from data network usage. The need for this quantification is noted from the following quotes (I.C.L., 1969b, Volume 2, Annex A2, pp. 1-2):

> "The effect of the provision of a cheap, widespread and powerful communication facility matched to the long term requirements of industry, commerce and indeed the community in general for information handling and computing power is incalculable."
>
> and:
>
> "It is difficult to avoid the conclusion that a [national data] network will have a most far reaching effect on all members of the community and on the economy and technological progress of the country: it is difficult to spell out in detail the economics as they effect the user. One might equally try to assess the economics of a telephone or a car."

Thus the challenge faced in this research work was to try to calculate the incalculable, and assess the unassessable. This was achieved using mathematical models which not only enabled assessments to be made but enabled the sensitivity of results to parameter changes to be examined in some detail.

1.2 Outline of Thesis

Chapter 2 provides an overview of the thesis from the "social value analysis" point of view. Following a discussion of cost-benefit methodology, it is shown how a dynamically formulated and explicitly modelled social value analysis might be applicable to the consideration of a national data network. Difficulties encountered in the assessment of benefits are particularly noted.

A second overview, this time from the point of view of telecommunication forecasting and planning, is provided by Chapter 3. It is suggested that the build-up of demand will be influenced by two important factors which may be modelled by closed loops: costs and benefits.

In Chapter 4, the demand now forecast for data transmission facilities is indicated, and a general national data network which might carry this demand is proposed. General characteristics of

such a network are examined and cost estimates are made.

A computer program is developed in Chapter 5 to indicate the growth of both numbers of terminals and of cost for this network. Using revenues based upon suggested tariff levels, the "capital account" is examined over time. The effects upon this of various parameter changes are studied in a computer-based sensitivity analysis.

Chapter 6 gives a preliminary decision analysis based upon the results of the previous chapter. This analysis suggests that a national data network should be favoured by data users, by telephone subscribers, by the Post Office, and indeed by the country as a whole.

The general approach of this thesis to the assessment of benefits is outlined in Chapter 7, where it is noted that the constraints of time, distance, and "physical being" bound the operational environment of an establishment. Since national data network usage could reduce all of these, constraint reduction is taken to be the essence of data telecommunication.

Taking the most valuable constraint reduction to involve time, Chapter 8 uses a series of working hypotheses to model situations in which the value of time to an establishment may be quantified. It is shown how an overall time saving may be used to increase the efficiency of an operation (so that a manufacturer may increase his capacity utilization, or so that an inventory-holder may reduce his mean inventory levels), to speed up operations (so that revenues are received sooner), to improve control, and to improve competitiveness.

These benefits are aggregated in Chapter 9, giving limit lines of the total social benefit - including that received by customers as well as that received by suppliers. The results obtained are then compared with similar macro-benefits derived quite differently using a simplified form of a dynamic input-output model. A preliminary social value analysis based upon these results suggests that a national data network would involve a favourable use of national resources.

Chapter 10 develops a theory of demand for a national data network. The first half of the chapter is concerned with the estimation of market saturation levels, particularly for the production and distribution sectors of the British economy; the second half gives a general theory which may be used to forecast the build-up of demand. A theoretically derived S-curve, fitted to the saturation levels and to current growth trend lines, gives a forecast of market growth over time.

Chapter 11 provides a framework within which the social consequences of a national network can be assessed from a qualitative point of view. By analyzing the interactions between the various interest groups involved, it is possible to trace out causative chains of possible social consequences: these provide a limited scenario of a possible future, which suggests that the tremendous impact of the network upon society will be predominantly beneficial.

Finally Chapter 12 concludes the thesis with a general résumé of the methodology used. Also given is a summary of forecasts derived for a British national data network.

1.3 Summary of Conclusions

The economic considerations of this thesis suggest that a national data network will be overwhelmingly beneficial to users, to the Post Office, and to the country as a whole; the Post Office is thus encouraged to implement a suitable form of national data network as soon as possible. Since such a network will introduce a fundamental change in the infrastructure of society, great caution must be exercised to minimize the adverse social effects; it is, however, felt that the overall results of the introduction of a national data network will be highly beneficial to society.

The actual results obtained in this thesis are really only estimates and forecasts. The methodology and approaches are emphasized, since these provide a tool - social value analysis - which may be used by decision-makers in planning for the future.

CHAPTER 2 : SOCIAL VALUE ANALYSIS

2.1 Cost-Benefit Analysis

A cost-benefit analysis is used in choosing among alternative projects in cases where there may be a divergence between social and private costs and benefits. The usual application is to problems in which the output cannot be evaluated in market prices, while the inputs can be and are substitutable at exchange relationships developed in the market. As output benefits have no market prices, "shadow prices" are imputed to them in an attempt to represent the true social benefits of a project (Chase, 1968).

It is immediately obvious that the cost-benefit approach is not strictly applicable to the assessment of data network proposals since a market price can be placed upon benefits: namely tariff charges. Nevertheless, since the investment appraisal approach of this thesis owes much to the cost-benefit methodology, it is necessary to examine this in more detail.

For a policy or choice of action to be chosen on rational grounds, *objectives* must first be explicitly formulated. *Alternatives* must then be produced which give technically feasible means of attaining the objectives within the *constraints* which may be imposed by other factors (such as legal restrictions); the *costs* of each alternative, measured in terms of opportunity costs, must also be determined. The analysis then uses *models* (whether explicit or implicit) to abstract the features of the situation relevant to the question being studied and to determine the consequences of choosing an alternative; the models predict the costs that each alternative would incur and the extent to which each alternative would contribute to the attainment of the objectives. Finally a *standard* criterion is needed to provide a means for weighing costs against benefits and for ranking the alternatives in order of desirability. (A suitable method involves estimating annual net benefits, expressed in monetary terms, then discounting back to the present to obtain the net present social value: this is the total value, at the time of the decision-making, of the net addition to consumption that would result from undertaking the project.) Once the alternatives are ranked, it is a simple matter to chose the most promising one (Quade, 1967).

A more complete discussion of cost-benefit analysis is given in the excellent surveys by Prest & Turvey (1965) and by

Peters (1966). And an annotated bibliography of the field is given by Keefer (1969a).

2.2 The Assessment of Benefits

The determination of the direct costs of a project is usually fairly straightforward; the assessment of benefits is, however, vastly more difficult and must be considered in some detail. A distinction must first be made between the *enumeration* and the *evaluation* of benefits. The enumeration of benefits involves a categorization of affected persons, and a listing of the various impacts the project has on the categorized groups; the evaluation of benefits then involves attempting to place a value on each of the impacts on each of the groups. These values are then summed to give the total benefit. However, a full assessment of all benefits is generally held to be impossible; one tends to concentrate on benefits to the direct users.

Some of the limitations of the cost-benefit analysis methodology immediately become apparent as soon as an application is attempted. Any results obtained or policies suggested are seen to contain considerable uncertainty because of necessary (and possibly concealing) simplifications and approximations and because of the uncertainty of the future (Quade, 1967). Uncertainty and lack of reliability also result from several difficulties encountered in the evaluation of benefits. First, one is trying to measure surpluses, and this involves questions of the measurability of utility, the interpersonal comparability of utilities, etc. Second, benefits cannot merely be assessed in monetary terms; many effects are uncertain, intangible and incommensurable. In spite of the difficulties involved, the maximum quantification of the effects of a project is desired. The third major problem of evaluation involves the treatment of time streams; the discount rate chosen should take into account both the "social opportunity cost" of the funds used and society's "social time preference" (Feldstein, 1964). The fourth difficulty is that of allowing systematically for uncertainty: a range of possible futures must be considered and the preferred course of action should be chosen by optimizing within this band of possible futures (Prest & Turvey, 1965, p. 729). While the above discussion has referred explicitly to benefits, it is obvious that these difficulties also apply to the assessment of non-monetary costs if they are considered as "negative benefits".

2.3 Social Value Analysis

A new form of analysis is now suggested: the "social value analysis". This term is used to refer to a comprehensive cost-benefit type of analysis carried out at the national level (or at least at some macro-level), in which all possible social and economic benefits and costs are included in the analysis. While this analytic method is based upon the cost-benefit methodology discussed above, it incorporates several important improvements.

While a cost-benefit analysis includes models, these are usually only implicit; in the new form of analysis, numerous explicitly formulated models are included. For example, benefits are evaluated through fundamental models which endeavour to "see into the mind" of those affected. As its name suggests, social value analysis emphasizes the consideration of social aspects as well as the ordinary consideration of economic aspects. At present it is not really possible to consider both of these aspects simultaneously and in detail, although a new conceptual approach which would enable this to be achieved is outlined in Appendix A. The social value analytic methodology now available considers economic costs and benefits quantitatively (using money as the only realistic and available measure of utility); social consequences of a project are then separately traced out, as fully as possible, as a chain of interlinked effects (Chapter 11).

Another important characteristic of social value analysis is its dynamic nature: the interaction of costs and benefits with the development of a project is considered, as suggested in Figure 3.1. Thus the assessment of a complex project which develops over time may be undertaken. And since quantitative models are used in this assessment, it is possible to examine the sensitivity of results to parameter changes; a band of possible futures may thus be considered so that the uncertainty of the future is explicitly allowed for. In addition, various methodological considerations may also be examined by altering parameters and models; for example, the sensitivity of results to the choice of the discount rate may be assessed.

2.4 Social Value Analysis of a National Data Network

The social value analysis approach is applied to the consideration of a national data network because of the possibility that the introduction of such a network could produce enormous social benefits

which might far outweigh those direct benefits for which the recipients could be charged. For example, if the actual revenues did not quite meet the costs of providing the network while the social benefits far exceeded these costs, a case might be made for going ahead with a financially unattractive but socially overwhelmingly rewarding programme of network implementation. (A case in point is the Victoria Line, whose revenues from fares would not have made it a commercially attractive proposition were it viewed in isolation (Peters, 1968, pp. 27-30).)

Numerous alternatives face the decision-maker who is attempting to identify the preferred choice for a national data network: the Datel services could be extended; one of the three proposed national data networks of the research studies could be introduced, or a combination of proposals could be used to make a general network with elements of all three. To a first approximation, the costs and benefits of each of the proposed networks are the same. It should thus be possible to carry out a social value analysis of a general network; minor modifications would make this applicable to any specific proposed network.

The first choice will, of course, involve comparing the general network with the network of Datel services now provided to decide whether or not to go ahead with the network at all. The main economic aspects of this decision are considered in Chapter 6 following. Then, if it is decided that the network is a viable proposition, choices must be made as to the speed of build-up (or the phasing), the types of services to be offered, the spread of the network, etc.

Since the Post Office Corporation is meant to be run as a commercial concern, it will expect medium- and long-term profitability of an investment project, according to the criteria given in Section 3.4. Thus the Post Office would want to implement a new network at a rate which would give this, rather than at a rate which would give the overall social optimum. If any serious divergence were found between these rates, government intervention might be indicated to enable the Post Office to attain the social optimum without necessarily attaining its financial targets.

The estimation of the cost of a national data network, and of the cost of an individual's usage of the network, is relatively straightforward: these costs are discussed in some detail in Section 4.4 and in Chapter 5. The assessment of benefits is considerably more

difficult, whether overall benefits at the macro-level or individual benefits at the micro-level are being examined. At the macro-level, it is possible to attempt to determine a correlation between telecommunication development and historical changes in performance indicators (such as G.D.P. its rate of growth, etc.); any correlation thus determined would not, of course, indicate causation. Alternatively, one might attempt inter-country comparisons using performance indicators to compare growth, productivity, etc. It is expected that an inadequate communications structure would handicap a country, acting as a brake upon its development; conversely, an excellent communications structure should act as a stimulus to development. Unfortunately, however, these hypotheses cannot really be quantified to the extent that they might be usable in attempting to assess the overall benefit of a new form of telecommunication service.

Turning to the assessment of benefits at the micro-level, it is noted that data transmission services have had a considerable impact upon industrial and buisness efficiency. The ability to transmit data a high speeds greatly improves communication within organizations and enterprises. It makes possible (and very effective) a widespread yet centrally controlled organization, since each unit of the organization can have direct access (*via* a data terminal) to large data processors at a data centre. Increased reliability results from using data transmission for the transportation of data; moreover, data transmission improves customer service, since goods can be delivered faster as the time required to process an order is reduced. And the speed and virtual immediacy of reply of an on-line connection makes it possible to answer enquiries very rapidly (Jeppsson, 1966). While these benefits may easily be described qualitatively, it is rather more difficult to measure them in quantitative terms.

One approach to determining the value of improved telecommunication facilities involves considering the value of information received and acted upon by a decision-maker, using Shannon's concept of information as the number of bits required to resolve the uncertainty of a problem (Shannon & Weaver 1964). Using information theory, it is possible to estimate the value of a management information system when the decision problem can be viewed as a problem in decision-making under uncertainty (Richmond, 1968, pp. 550-6; Bedford & Onsi, 1966). The most comprehensive approach in this field has been made by Marschak's group studying the economic theory of information at

the Western Management Science Institute. The demand price of various informational instruments or services is taken to depend on the expected payoff they can earn for their users (Marschak, 1968a and 1968b; Marschak & Miyasawa, 1965). Unfortunately, however, the information theory approach does not give a direct evaluation of an information-handling service. This follows from the distinction between information and data: information is concerned with the use of evaluated data by a decision-maker at a certain time in considering a problem to achieve a definite goal. The value of information is thus a function of its uses, its timeliness, etc. (Hyvärinen, 1968). A problem thus arises: the information theory approach can give the cost of communicating bits of data and the value of the information derived from them, but there is no relation between the number of bits conveyed (or their cost) and the gross value of the data service. The information theory approach may certainly be useful in particular applications (Bonney, 1969); however, in attempting to assess benefits at the micro-level in such a way that they may be aggregated to the macro-level, it is obviously of little value.

The approach suggested by this thesis involves making a fundamental examination of the very essence of data telecommunication in order to see how a telecommunication system fits into, and interacts with, the general environment; such an examination could suggest what type of service should be provided to optimize benefits. This new approach is discussed in detail in Chapters 7 and 8. It is, however, noteworthy that a criticism which has been levelled against the information theory approach is still applicable: the value determined for information includes not only the value of data transmission but also the value of the various computing and deciding facilities used. It is thus necessary to exercise great care in isolating the value which may be imputed to the data transmission alone.

The above discussion suggests that a social value analysis of a national data network is possible. And it is apparent that such an analysis is of great value in considering various vital questions concerning investment policies, tariff policies and other matters. In making decisions about resource allocation at the macro-level, social value analyses are required for all sectors seeking national resources for investments if the allocation is to maximize social welfare; this thesis indicates how such an analysis may be made for a national data network.

CHAPTER 3 : NATIONAL TELECOMMUNICATION PLANNING

3.1 Introduction

One of the greatest problems facing the Post Office is the accurate assessment of future demand for its services. If predictions exceed actual demand, the Post Office would undertake too great an investment programme too early, and capital plant would remain unutilized; this constitutes a misallocation of resources. (The history of the G.P.O. suggests that fear of the consequences of over-provision of plant has been of paramount importance.) But if predictions fall short of actual demand, supply cannot keep pace with demand, especially since the long provisioning period acts as a lag. With under-supply a restricting constraint on development, a waiting list of unsatisfied potential subscribers develops. It is thus obvious that an accurate forecast of future demand is tremendously important; this thesis attempts to provide a new and useful theory of demand.

3.2 Forecasting Telephone Development

The forecasting of future demand for telephone facilities is a relatively straightforward matter, carried out by telephone Administrations throughout the world (Neilson, 1969). While modifications may be incorporated to include additional factors, the usual approach involves fitting an S-shape curve to the extensive historical data available. Densities (such as telephones per 100 population) are used so that factors such as population growth may be removed from the calculus and considered separately.

The most commonly used curve is the logistic curve, derived on the simple assumption that the value of a service increases in value proportionally with the number of subscribers connected to the service. This curve, which may be written in the exponential form

$$D = \frac{A}{1 + ke^{-ct}} \qquad \ldots(3.1)$$

where D is the density at time t,
A is is the saturation level,
k is a constant representing the initial situation, and
c is a constant representing the "dynamism of the national economy",

is found to fit time series of historical data very well (Bogaerts, 1963, pp. 190-1; Lancoud & Trachsel, 1963; Rafalowicz, 1964, pp. 305-6; Morgan, 1965, pp. 129 ff). The logistic curve is symmetrical about its point of inflection at

$$D = A/2$$
$$t = \ln k/c \qquad \ldots(3.2).$$

A simpler S-curve which has also been found to be suitable for the assessment of telephone requirements is of the negative exponential form

$$D = Ae^{-d/t} \qquad \ldots(3.3)$$

where d is chosen to fit the curve to existing statistics.

This curve is not symmetrical about its inflection point at

$$D = A/e^{2}$$
$$t = d/2 \qquad \ldots(3.4).$$

3.3 Forecasting Data Transmission Development

While the assessment of future demand for data transmission facilities is likely to be of great importance in the future, it is obvious that very few methodological tools now exist which might be applicable. Although a trend extrapolation of forecasts is used in Section 4.1, this only provides a first approximation. And curve-fitting as outlined in the above section cannot really be used, since the saturation level and indeed the form of curve to be used are unknown.

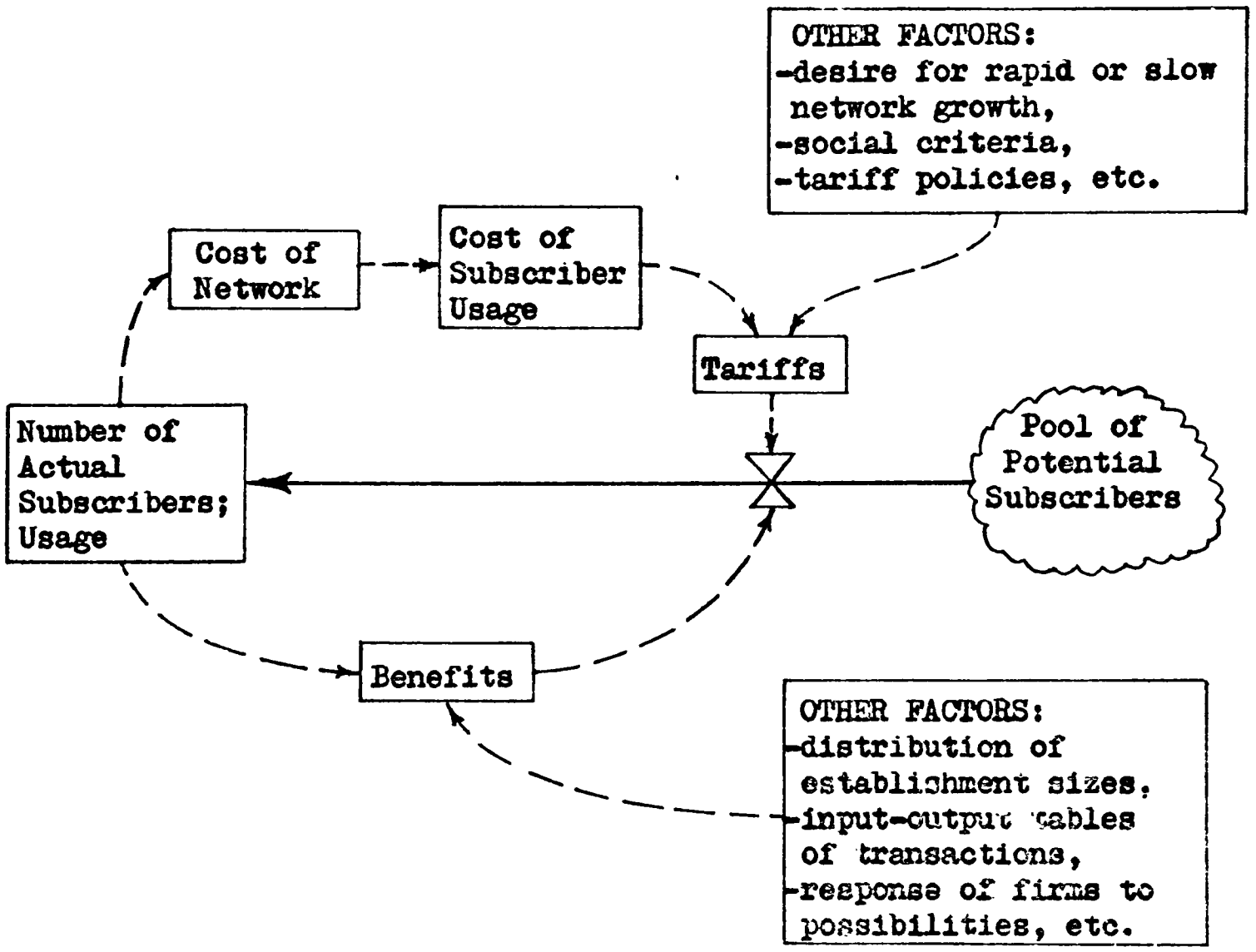
It is apparent that a new and fundamental approach is required to assess future demand. The approach used in this thesis assumes that a potential data user compares the benefits which he expects to receive from data network usage with the costs of such usage. If the present value (PV) of these direct benefits exceeds the present value of costs (which are assumed to be represented by tariff charges), then the potential user will join the data network. Thus

$$PV(\text{Direct benefits}) \geq PV(\text{Tariff charges}) \qquad \ldots(3.5).$$

Using this simple assumption, we may develop the simple model given in Figure 3.1 of some factors influencing demand for data network facilities. There are of course many additional factors: the social and economic conditions within a country and the characteristics of subscribers will obviously influence usage, since they describe

the environment within which the network is to operate. Technical factors can also have a considerable influence on traffic: a high quality of service and technical improvements to keep costs down are both important. Particularly important from the point of view of the Post Office are the controllable factors of investment policies and tariff rates: these are further discussed in the following section.

Figure 3.1: A Simple Model of Factors Influencing Demand for Data Network Facilities.



3.4 Criteria for Planning

Although Chapter 2 indicated how social effects of a data network should be included in a social value analysis, and although Chapter 11 will actually examine some of the social consequences of such a network, it will be assumed throughout the quantitative analysis of this thesis that the data network would be run as a commercial service; thus it must be convincingly justifiable on economic grounds alone.

Various economic criteria must be established as a preliminary step; several criteria are explicitly given by the Post Office.

For example, the rate of return on capital investment is 10% p.a.; this rate was increased from the old 8½% p.a. rate in July 1970 in order to make the Post Office Corporation self-financing (Daily Telegraph, 1970). This rate of return is used with a depreciation rate, based upon the service life and net salvage value of equipment (Lönnström, Marklund & Moo, 1965), in discounted cash flow calculations to determine the acceptable inclusive capital cost for projects. Unfortunately, however, depreciation rates must be estimated for data network equipment since none can yet be known; rates based upon eight, ten and twelve year payback periods are used in the computations of Section 5.7, thus providing a sensitivity analysis of results to changes in this parameter. The sensitivity of results to the choice of a rate of return is also examined.

Linked closely with these investment criteria are various tariff criteria. The usual Post Office practice has involved setting tariffs to cover average costs, although this is often condemned by economists who prefer some form of marginal cost pricing (Turvey, 1968). Taking the intention of socially-minded network planners to be to

Maximize (Total Social Benefit - Total Social Cost)
subject to relevant constraints, ...(3.6)

it may be shown from the first order maximizing condition that welfare would be maximized when price is set equal to marginal cost plus certain correction factors to include the influence of important complements and substitutes (C_1) and to satisfy the constraints (C_2). Thus

$$(\text{Price}) = (\text{Marginal Cost}) + C_1 + C_2 \quad \ldots(3.7).$$

However, the comparative statics marginal costing approach is really only applicable to services already in existence, for which a proposed investment is "marginal" with respect to existing capital plant. The non-recoverable (but still in use) fraction of capital plant is effectively "written off", then tariffs are chosen to maximize welfare in later time periods.

To consider investment properly, especially when virtually all of the investment involved lies in the future as in the case of a new national data network, a dynamic formulation is required. The approach taken involves discounting back (or, alternatively, compounding forward) time streams of costs and benefits; for the network

to justify itself on economic grounds, the following present value relationship must hold:

$$PV\ (\text{Tariff revenues}) \geq PV\ (\text{All costs}) \qquad \ldots(3.8).$$

It is apparent that, for planning purposes at least, tariffs must be chosen to meet or exceed average costs. This could be indicated using equation 3.7 if the correction factor C_2 was chosen to pay off interest and depreciation charges on the new investment. But since C_2 will be considerably greater than "marginal cost", the marginal cost approach must be stretched beyond recognition if it is to be applicable here; the average cost approach is really more appropriate.

CHAPTER 4 : PROPOSALS FOR A NATIONAL DATA NETWORK

4.1 The Demand for Data Transmission Facilities

The first problem encountered in planning a national data network concerns the size of the network: a forecast of future demand for data transmission, and for digital data transmission in particular, is required. Without adequate historical data, there are grave analytical problems in projecting potential demand, especially since there is almost certainly a fairly substantial (but unquantifiable) suppressed demand.

In commissioning its data network studies, the Post Office provided a fairly arbitrary "Data Traffic Model for 1973/74" so that these studies would design networks to carry the same traffic load. The actual form of the Model used in the network studies is far too detailed for the purposes of this thesis. A suitably aggregated and condensed form of this Model is, however, given in Table 4.1; the traffic estimates of average busy hour traffic per terminal (in erlangs-E) and of total daily traffic (in Megabits-Mb) are taken from two of the research reports (S.T.L., 1969a and B.T.R., 1969a respectively).

Table 4.1 : Summary of Post Office Data Traffic Model for 1973/74.

Service	Bit Rate (b/s)	Number of Terminals	Average Busy Hour Traffic per Terminal (E)	Total Daily Traffic (Mb)
A	1200	16,915	0.0869	75,504
B	200	17,230	0.255 †	22,405
C	160	3,800	0.0426	1,891
D	2.4K-9.6K	2,867	0.00972	6,881
E	48K	1,620	0.0331	77,762
T	200	10,114	0.112	2,622
"6"	48K	30	0.00400	144
TOTALS		52,576		187,209

Services :

A - Bank enquiry and distribution; Data collection (cf. Datel 600)
B - Bureau; Broadcast (cf. Datel 200)
C - Data collection (cf. old Datel 300)
D - Coded facsimile; Magnetic tape (cf. Datel 2400)
E - Uncoded facsimile; High speed use (cf. 48 KHz Wideband)
T - Telex (cf. Datel 100)
"6"- Inter-computer.

† This assumes digitally-based data transmission; with analogue-based transmission, this traffic would be 0.510 E.

The Model of Table 4.1 will now be recast in a convenient form. It will be assumed that the general national data network (described in Section 4.3 following) would provide four general categories of service: Service 1 (up to 600 b/s) would deal with services T, B and C of the Model; Service 2 (up to 2.4 Kb/s) would deal with A; Service 3 (up to 9.6 Kb/s) would deal with D, and Service 4 (up to 48 Kb/s) would deal with services E and "6". This recast is given in Table 4.2; the average annual traffic per terminal is calculated in Gigabits (Gb) for a year of 250 working days.

Table 4.2 : Recast Form of Post Office Data Traffic Model for 1973/74.

Service	Maximum Bit Rate (b/s)	Number of Terminals	Average Annual Traffic per Terminal (Gb)
1	600	31,444	0.214
2	2.4K	16,915	1.12
3	9.6K	2,867	0.60
4	48K	1,650	11.8

Now the Post Office Model really only gives a point estimate of future data traffic; it is also important to examine other forecasts and estimates. Table 4.3 gives various estimates of demand for (digital) data transmission facilities, both for the past and for the future. (One of these is a simple Post Office forecast for 1983, obtained as ten times the forecast of Table 4.1.) The estimates of Table 4.3 are plotted in Figure 4.1 and a smooth curve is fitted to suggest the underlying demand for data terminals. This underlying demand will be used in Chapter 5 when the cost aspects of the development of a national data network up to 1995 are studied; it is assumed that this underlying demand may be subdivided into demand for each Service as in Table 4.2: 59.3% for Service 1, 32.2% for Service 2, 5.4% for Service 3, and 3.1% for Service 4.

The curve of Figure 4.1 suggests that the demand for data transmission facilities is now growing almost exponentially over time. It is hoped that the Post Office will plan its data network investment programmes in full awareness of their future implications. Historically, the Post Office has been slow to recognize and to accommodate the growth of demand for telecommunication services; as a result,

Table 4.3 : Demand for (Digital) Data Transmission Facilities

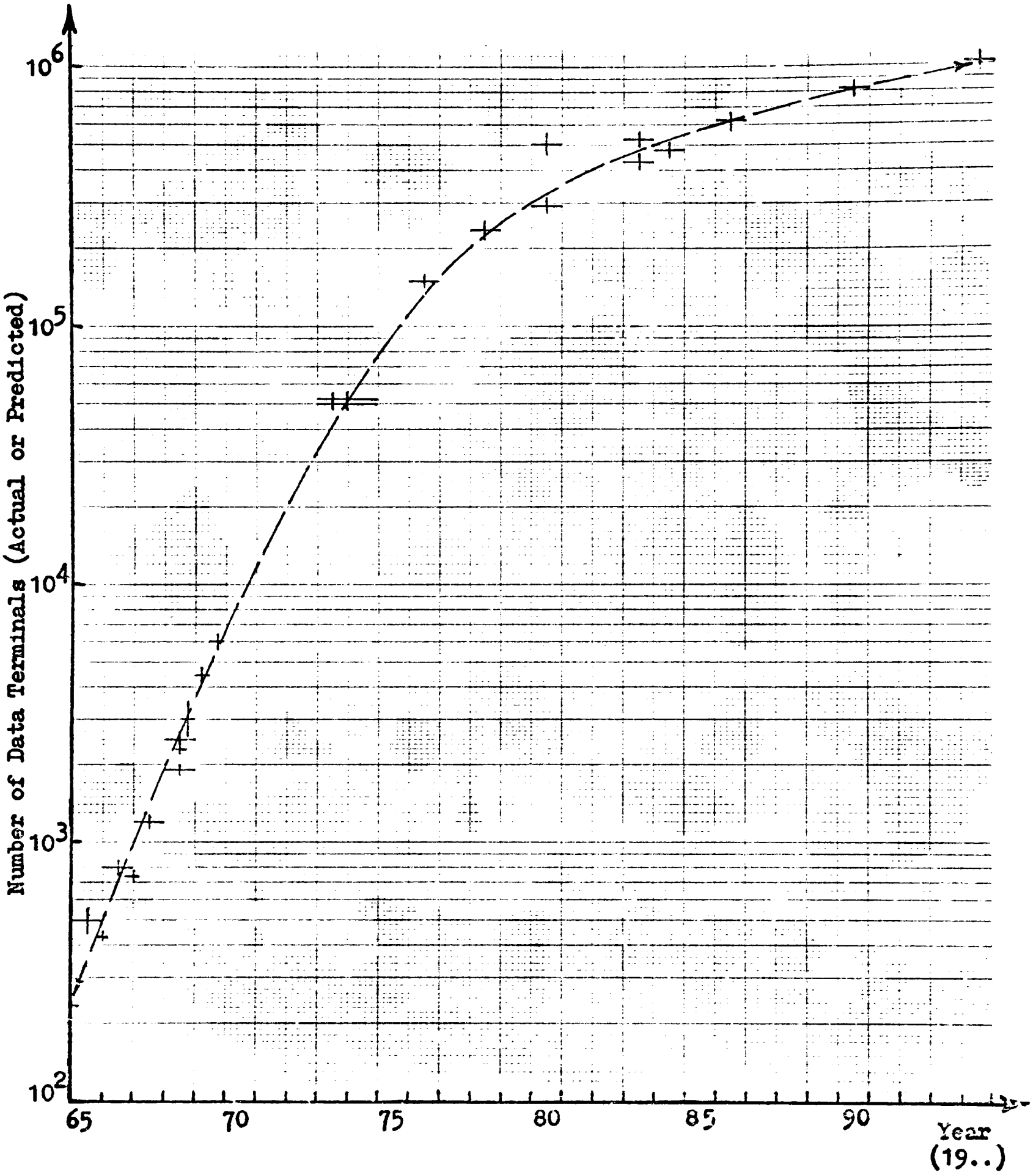
Date	Number of Data Terminals (f indicates forecast)	Source
1.1.1965	237	Westerberg, 1968
1.1.1966	435	"
1.1.1967	747	"
1965	500	Neilson, 1968
1966	800	"
1967	1,200	Post Office, 1967a
1968	1,900	Post Office, 1968a
March 1969	4,500	Post Office, 1969a
1973/74	52,576 f	Table 4.1
August 1969	3,000	SCICON, 1969
August 1969	6,000	"
1973	51,000 f	"
1978	234,000 f	"
1983	434,000 f	"
1968	2,500	I.C.L., 1969a
1973/74	50,000 f	"
1980	500,000 f	"
1983	525,760 f	Post Office (10 x Table 4.1 values)
1976	150,000 f	P.O. Telecomms H.Q., 1969a
1980	290,000 f	"
1984	480,000 f	"
1986	620,000 f	"
1990	810,000 f	"
1994	1,030,000 f	"
June 1968	2,285	P.O. Telecomms H.Q.,1969b

growth has often been supply-limited since the Post Office only attempted to meet "explicit" demands (where there was a definite and indisputable demand). Cherry (1970, p.8) explains this as the usual British approach of considering technology as something that "satisfies" demands rather than, more correctly, as something that may create† future needs and demands.

The Post Office policy of not looking for new business but just attempting to keep up with explicit demand has not led to

† This creative function of new technologies of communication is indicated by the "regenerative" nature of growth curves of demand for their use.

Figure 4.1: The Predicted Demand for Data Transmission Facilities.



really serious difficulties in the telephone field, since the net growth rate is only about 6-7% p.a. (Post Office, 1969b). Thus, although supply has lagged demand, waiting lists have not become too long. But the present rate of growth for data transmission terminals is (from Figure 4.1) about 80% p.a.! Although this rate of growth is predicted to fall (to about 50% p.a. by 1975), the compounding effects will be considerable.

In addition, there may be additional demand resulting from considerably reduced costs and from as yet unforeseen uses of a national data network.

It is apparent that the Post Office must plan far ahead so that it can meet the "implicit" demand as well as the "explicit" demand. The theory of demand given in Chapter 10, and the resulting demand forecasts derived from it, provide a methodology for this long-term forward planning.

4.2 The Datel Services

Appendix B gives a brief survey of the Datel services now available. The Datel services have been ideal for the early years of data transmission growth, since they provide a simple user interface, maximum freedom of data code and format, and simple installation and application due to the ubiquity of the already existing speech network over which data transmission is carried by Datel. However, the need for improved data transmission services is now apparent to both the user and to the Post Office. The user is restricted by the high noise level and narrow bandwidth of analogue circuits, and by the slow and noisy signalling techniques; considerable redundancy is required to maintain low error rates. The Post Office finds that the Datel services are costly to provide because of the inefficiency of sending data over the analogue network. Data often has a different traffic pattern - many terminals with few processors - from voice, which is entirely point-to-point. Since much data traffic is intermittent and of short duration, it is wasteful to restrict it to the circuit switched analogue network if it could be sent by the packet switched facility of a digital data network (I.C.L., 1969a).

One possible way of attempting to carry the data traffic predicted in the above section is to extend the Datel services. This possibility will be considered in more detail in Chapter 6; at this point it is merely noted that the Datel services provide an unsatisfactory medium for data transmission. On the other hand, a digital data network would provide many improvements - a higher data transmission rate, a greater range of services, a higher level of service, and a better network utilization; moreover, this better data network would probably be provided at a lower cost (to users and to the Post Office) than the cost of extending the Datel system! This cost reduction would be largely due to the replacement of frequency division analogue transmission by time division digital transmission.

4.3 Research Proposals for a National Data Network

The following facilities and features may be considered to be essential users' requirements of a national data network: for effective data transmission one requires an open system with a choice of speeds and with a flexible user interface (with minimal restriction on terminal equipment), an attractive cost to users, a very short response and call connection time, adequate reliability (and a fail-soft system), adequate security, unattended terminal operation, widespread and flexible geographical coverage, minimal procedural requirements, compatability with existing services and networks, full duplex working, etc. (I.C.L., 1969a). Taken with the Data Traffic Model for 1973/74, this list of requirements may be taken as a set of objectives to be met by any data network proposal.

Several technically feasible alternatives have been proposed which would provide an acceptable standard of service: in addition to the proposals resulting from the Post Office sponsored research studies (mentioned in Section 1.1), a National Physical Laboratory model has also been suggested (Davies, 1969). The particular network models which have been proposed will, however, not be examined in detail, partly for reasons of confidentiality, and partly because these proposals are in a state of flux. We thus generalize the proposals and consider (as suggested in Section 2.4) a general national digital data network† which might contain compatible elements of all of the proposed networks. The actual choice of a network, which will be made by the Post Office on technical and economic grounds, is thus not considered; it is assumed that the general reference network will describe any such actual network to a reasonable degree of accuracy.

In spite of the unspecified form of our general network, it is possible to indicate certain general characteristics and general principles relating to it. Once installed and equipped, a new telecommunication network must be capable of providing whatever services are required, for however many subscribers require them, for very many years (B.T.R., 1969b). A premium is thus placed upon versatility of future evolution, flexibility (without an undue increase in cost), and extensibility (of the digital mode to a much wider range of traffic, including

† Throughout the rest of this thesis, this is abbreviated to "national data network". Since this network will be digital, it could equally well be called a "digital data network".

P.C.M. voice) (S.T.L., 1969b). The use of synchronous digital methods of transmission is widely accepted; however, it is difficult to plan for extensive use of synchronous working and T.D.M. without excessive transitional difficulties and without causing difficulties in user's and Administration's investment patterns (S.T.L., 1969a).

The network will probably be a mixed system offering both circuit switched and packet switched (using store and forward) modes of transmission. (In fact, the network may well have a third major component - leased traffic lines - if the new network as a whole cannot be introduced for several years; this component may be considered as a sub-set of the circuit switched network with dedicated lines, time slots, etc.) The use of a mixed system provides a practical method of allowing users to obtain the benefits of either circuit switched on packet switched data transmission (S.T.L., 1969b). The circuit switched facility obviously handles a long continuous stream of traffic better than if it were packet switched, since once a route is established the address does not need to be repeated for interactive exchanges. Thus traffic may be handled with less average delay and with less probability of delay; in addition, the "false traffic" (of addressing) of the network is minimized by circuit switching (B.T.R., 1969a). The packet switched facility, on the other hand, carries data in fixed length packages which are stored and then routed by a network of message-handling computers to the required destinations (Hughes, 1969). Packet switching has an inherent speed changing facility; this mode of transmission is especially valuable for asymmetric working and for intermittent traffic, since one only requires transmission capacity for that data which is actually sent.

Several further characteristics of the general network must be specified for it to be costed; since the actual costings used in research studies are Post Office confidential, the approach used will involve making a hypothetical estimation of costs. Following Section 4.1, it is assumed that the network will offer (circuit switched) data transmission at four basic synchronous speeds: 600 b/s, 2.4 Kb/s, 9.6 Kb/s, and 48 Kb/s. These speed facilities are referred to as Services 1,2,3 and 4 respectively, and it is in terms of these Services that detailed costings per subscriber will be made. In considering these four distinct Services, circuit switching is implicitly assumed. But since similar costs will be expected for packet switched usage, this use of Services retains its generality.

4.4 Estimated Cost of a General National Data Network

To estimate a cost for the general network described above, it is necessary to assume a general network topology with various levels of transmission lines between exchanges, concentrators, etc. At this stage the network will taken to be of a size to carry the traffic forecast by the Data Traffic Model for 1973/74; thus the estimates to be made could be compared directly with the costings of the research studies. This Model forecasts some 52,500 terminals for 1973/74; about 20 Data Switching Exchange (DSE) locations would probably be required to serve these terminals (Post Office TD14, 1970). Each DSE would really be an exchange computer installation which, as a "universal switch", would carry out both packet switching and circuit switching. Each DSE would be connected to other data exchanges by high speed (possibly 1.536 Mb/s) digital links; taken together, these high speed links and the DSEs comprise the high level (H/L) network. It is assumed that this H/L network would cost about £15 million, with about £2 million being attributed to the high level transmission network, leaving some £13 million for the DSEs.

The low level network is taken to include the network terminating units (NTUs) which provide the interface between the network and users' terminals (and may indeed be part of these terminals), and the data transmission lines from the NTUs to multiplexers (MUXs) typically sited at the telephone local exchange (L/E) building; the low level network also includes the data transmission lines from these multiplexers to multiplexer and concentrator units typically situated at the telephone group switching centre (GSC) building, plus the lines from there to the DSE (Post Office TD14, 1970). It is assumed that the cost of this low level network would be about £35 million. (This cost is chosen to make the total cost of a national data network to carry the 1973/74 forecast traffic be about £50 million.) A possible breakdown of this amount might be: about £6 million for concentrators and multiplexers, about £3 million for the GSC to DSE links, and about £10 million for NTUs, leaving about £16 million for the NTU to GSC links. These estimated costs (which are of course all in 1970 pounds) are summarized in Table 4.4.

Table 4.4 : Estimated Cost of a General National Data Network to Carry Forecast 1973/74 Traffic.

Area of Expenditure	Inclusive Capital Cost (£ million)
Low Level Network:	
NTUs	10
NTU to L/E (First MUX) Transmission	(10)
L/E to GSC (Second MUX & Concentrator) Transmission	(6) } 16
Multiplexers and Concentrators	6
GSC to DSE Transmission	3
Sub-total	(35)
High Level Network:	
DSEs	13
DSE to DSE Transmission Links	2
Sub-total	(15)
Total	50

The cost dominance of the low level data transmission network is apparent; an attempt could be made to reduce this by installing the new network as an overlay network (with respect to the existing analogue system) rather than installing it as a completely separate network (as costed above). This might be achieved by using P.C.M. time slots of the telephone network to carry some data traffic . With some transmission plant shared, both telephone and data transmission costs could be reduced; in particular, the inclusive capital cost of the network costed in Table 4.4 might be reduced (Kelly, 1970). Since the amount of this reduction cannot really be determined, it will be assumed that the £50 million total stands.

It is of considerable interest to estimate what the average capital cost per terminal might be for each of the four Services. To break down the total of £50 million, the following assumption is made, based on various cost estimates (S.T.L., 1969b) for individual terminals:

$$\text{(Cost of Service 1)} = \frac{1}{1.5} \times \text{(Cost of Service 2)}$$
$$= \frac{1}{3} \times \text{(Cost of Service 3)}$$
$$= \frac{1}{4.5} \times \text{(Cost of Service 4)} \qquad \ldots(4.1).$$

Taken with Table 4.2, this equation suggests that the 1973/74 forecast

is equivalent to some 72,800 Service 1 terminals. Table 4.5 gives the correspondingly derived costs per terminal.

Table 4.5 : Estimated Average Capital Cost per Terminal for General National Data Network to Carry Forecast 1973/74 Traffic.

Service	Average Capital Cost per Terminal (£)
1	690
2	1030
3	2060
4	3100

Since demand for data transmission facilities is growing rapidly (as indicated by Figure 4.1), the above total cost estimate of about £50 million is of only limited value; it is also necessary to examine the growth of costs over time: this is the subject matter of Chapter 5. To indicate how costs rise, the cost of a general national data network to carry ten times the traffic forecast for 1973/74 (i.e. the Post Office forecast for 1983) may be estimated.

A first estimate is obviously just ten times that of Table 4.4, giving a total of about £500 million. A lower figure might, however, be more appropriate, since a lower factor than ten times would almost certainly apply to DSE costs and to the GSC to DSE and DSE to DSE transmission costs. In addition, the overlay approach suggested above might enable low level costs to be somewhat reduced. Thus a revised estimate of about £450 million is taken as the inclusive capital cost of a national data network to carry the traffic forecast for 1983.

CHAPTER 5 : PHASING-IN A NATIONAL DATA NETWORK

5.1 Introduction

This chapter gives the development of a computer program which simulates the build-up of a general national data network and the corresponding monetary flows - both investments and revenues - involved in the project. A "standard" computer program (which is given in Section C.3) is first developed; a parametric sensitivity analysis is then carried out, in which the effects of altering various parameter values are considered. The program is written in "KID", a FORTRAN-based mnemonic simulation language (described in Section C.2) which is derived from the DYNAMO language of Forrester's Industrial Dynamics (1961).

From the fitted curve of Figure 4.1, an estimate may be made of the underlying demand now forecast for data transmission facilities. From the first difference of this curve, the Change in Underlying Demand for all terminals, Rate during year I-1, CUDR(I-1) may be determined. (These values are listed in Section C.3.) Since there has been a continuing tendency in the past to underestimate the future demand for telecommunication facilities, an additional factor XUDR(I-1) (the eXtra Underlying Demand for all terminals, Rate during year I-1) can be added to include the positive feedback effects which might increase demand, giving the Sum of the change of Underlying Demand for all terminals, Rate during year I-1, SUDR(I-1):

$$SUDR(I-1) = CUDR(I-1) + XUDR(I-1) \qquad ...(5.1)$$

The extra component XUDR(I-1) is at this stage taken to be zero. The actual Underlying Demand for all terminals, Level at year I, UDL(I) is

$$UDL(I) = UDL(I-1) + SUDR(I-1) \times DT \qquad ...(5.2)$$

where DT, Delta Time, is taken to be one year so that

$$DT = 1 \qquad ...(5.3).$$

Consideration of a national data network will be made in terms of the four Services described in Section 4.1. Assuming (in the absence of more accurate information) that the same relative allocation as in Table 4.2 is made between the four Services (which are labelled by J = 1,2,3 and 4 respectively), the Underlying Demand for Individual Service J terminals, Level at year I, UDIL(I,J)

is

$$UDIL(I,1) = 0.593 \times UDL(I)$$
$$UDIL(I,2) = 0.322 \times UDL(I)$$
$$UDIL(I,3) = 0.054 \times UDL(I)$$
$$UDIL(I,4) = 0.031 \times UDL(I) \qquad ...(5.4).$$

A similar allocation is assumed to hold in subdividing CUDR(I-1), XUDR(I-1), and thus SUDR(I-1), into their component parts CUDIR(I-1,J), XUDIR(I-1,J), and SUDIR(I-1,J) respectively.

Initial values for these variables are specified from Figure 4.1 and equation 5.4, using the starting point of I = 1 at the start of the year 1964. (See Section C.3.)

5.2 Build-up of Cost of the New Network

Using the cost "benchmarks" of Section 4.4, it is assumed that the cost of providing a national data network to handle the traffic of 52,500 terminals is about £50 million in 1970 pounds; the costs per terminal of each Service are as in Table 4.5. These costs are taken to be divisible into standing costs (which must be incurred before any subscribers can be put on the full network) and connection costs (which are incurred when subscribers actually join the full network). The connection cost is assumed to relate to the NTU and to the NTU to L/E transmission link, so that each CNIC(J) (the CoNnection cost for Individual Service J terminals, Constant) is taken to be about one-quarter of the Table 4.5 cost. Thus, in pounds,

$$CNIC(1) = 172.5$$
$$CNIC(2) = 257.5$$
$$CNIC(3) = 515.0$$
$$CNIC(4) = 775.0 \qquad ...(5.5).$$

The total CoSt for CoNnecting Individual Service J terminals, Rate during year I-1, CSCNIR(I-1,J), is given by

$$CSCNIR(I-1,J) = CNIC(J) \times DNTIR(I-1,J) \qquad ...(5.6)$$

where DNTIR(I-1,J) is the Data Network Total number of Individual Service J terminals, Rate of change during year I-1.

The first standing costs to be considered are those comprising the remaining three-quarters of the £50 million mentioned above. These are included as part of CSTRSR(I-1) (the CoSt, TRanSient,

Rate during year I-1); this cost element includes the initial costs incurred in introducing a national data network. During the year 1969 (I-1 = 6), the Post Office is assumed to have spent about £500,000 on contracts and paper studies. If IC is taken to be the Year of go-ahead for starting work on the new national data network, Constant, then about £1 million will be spent on development during year IC. The remainder of CSTRSR(I-1) is the basic standing cost of £37.5 million which will be spread over the provisioning period IDIFC (the number of Years DIFference between the end of IC and the start of ISC, Constant, where ISC is the Year of Start of operation of the new national data network, Constant). It is initially assumed that

$$\begin{aligned} & IC = 7 \quad \text{(i.e. 1.1.1970)} \\ \text{and} \quad & ISC = 12 \quad \text{(i.e. 1.1.1975)} \end{aligned} \qquad \ldots(5.7)$$

so that the provisioning period is four years, and CSTRSR(I-1) = £9.4 million for each of these four years. (Values of CSTRSR(I-1) are given in Section C.3.)

We now examine the standing costs required to build up the national data network in later years; connection costs are assumed to remain as given in equation 5.5. Thus the connection costs for the 525,000 terminals forecast for 1983 are £125 million, leaving £325 million as standing costs (to give a £450 million total). It is estimated that the £37.5 million standing costs incurred in the provisioning period would actually allow the initial network to handle some 60,000 terminals; this number is taken to be the GRowth LiMit for the network before extra expenditure is required, Constant, GRLMC. It is now assumed that an additional standing cost investment is required for each further quantity of 25,000 data terminals to be added; the amount of this investment quantum is CSXTRC (the CoSt for eXtra TeRminals, Constant). It can be shown that a value of CSXTRC = £15.46 million gives the additional standing cost of £287.5 million. (This amount could conveniently be increased to include the additional expenditure required to modernize and improve the national data network once it is installed; this involves improving the service of, and handling the increased traffic of, existing subscribers, plus the "standing still" expenditure (Neilson, 1968).) The new amount of standing cost investment required in any year is CSXGR(I-1) (the CoSt for eXtra Growth, Rate during year I-1).

5.3 Tariffs and Revenues

It is first assumed that annual running and maintenance costs for the national data network would be directly recoverable from the annual revenue received from tariffs; thus our concern is with the remaining part of the annual revenue (including any connection charges made) which is used to pay off the total inclusive capital cost of the new network. This Amount raised annually for Individual Service J terminals, Constant, AIC(J) must give a rate of return equal to ROIC (the Rate Of Interest, Constant) and must pay off depreciation charges to give a payback at the end of PBC years (the PayBack period, Constant).

Section 3.4 indicates that a rate of return on capital investment of 10% is required, so

$$ROIC = 0.10 \qquad \ldots(5.8).$$

The sensitivity of results to this choice is considered in Section 5.7. The choice of a payback period is more difficult. A short payback period indicates great caution, and is useful in areas of great technological change. For example, the Post Office uses a payback period of about five or six years for modems (Hartley, 1969). A longer payback period might however be justified, since so much of the expenditure for the new network would be for transmission lines. For example, the Post Office uses a twenty year costing period for local line and plant projects in discounted cash flow (D.C.F.) calculations to determine the acceptable inclusive capital cost for projects (Lönnström *et al.*, 1965). A reasonable compromise between these two extremes is the choice of a payback period of ten years (B.T.R., 1969a). Thus

$$PBC = 10 \qquad \ldots(5.9).$$

The sensitivity of results to this choice is also considered in Section 5.7.

FDC is taken as the Fraction of the average capital cost per terminal (taken from Table 4.5) which is raised annually by tariffs to pay off Depreciation charges, Constant. It may be shown that if depreciation is provided for on a sinking fund basis, then (Merrett & Sykes, 1963)

$$FDC = \frac{ROIC}{(1 + ROIC)^{PBC} - 1} \qquad \ldots(5.10).$$

Taking FDITC as the Fraction of the average capital cost per terminal raised annually by tariffs to pay off Depreciation and Interest (Total) charges, Constant,

$$FDITC = FDC + ROIC \qquad ...(5.11).$$

Thus,from Table 4.5 and equations 5.8 to 5.11,

$$\begin{aligned} AIC(1) &= FDITC \times 690 = 112 \\ AIC(2) &= FDITC \times 1030 = 168 \\ AIC(3) &= FDITC \times 2060 = 335 \\ AIC(4) &= FDITC \times 3100 = 505 \end{aligned} \qquad ...(5.12).$$

The average REVenue, for paying off depreciation and interest charges, from Individual Service J terminals, Rate during year I-1, REVIR(I-1,J) may be obtained as

$$REVIR(I-1,J) = \frac{AIC(J)}{DT} \times \left[DNTIL(I,J) + \frac{DNTIR(I-1,J)}{2} \right] \qquad ...(5.13)$$

where DNTIL(I,J) is the Data Network Total number of Individual Service J terminals, Level at year I.

The annual charges per terminal required to pay off maintenance and running costs as well as interest and depreciation are now considered. A fraction of 10% of the inclusive capital cost is allocated to pay annual maintenance and running costs (B.T.R., 1969a); this figure may be derived from a comparison of telecommunication operating and maintenance expenses with the gross book value of telecommunication plant (Post Office, 1969a). Adding 0.10 to FDITC gives annual charges (to be raised by tariffs) for network use of

$$\begin{aligned} &\text{Service 1} : £181 \text{ p.a.} \\ &\text{Service 2} : £271 \text{ p.a.} \\ &\text{Service 3} : £541 \text{ p.a.} \\ &\text{Service 4} : £814 \text{ p.a.} \end{aligned} \qquad ...(5.14).$$

It is noteworthy that these charges may even be a little high, since the discussion of Section 5.2 suggests that the estimated costs of Table 4.5 may be higher than the eventual long run costs.

While the tariff structure *per se* will not be considered at this stage, it is interesting to note how the charges given in equation 5.14 might be raised if they were in the form of a charge per unit of traffic. Assuming that these charges would be raised entirely by usage-dependent tariff charges, and using the traffic estimates of Table 4.2, the following tariff-only charges might be

suggested:

Service 1	:	£0.845/Mb
Service 2	:	£0.242/Mb
Service 3	:	£0.903/Mb
Service 4	:	£0.069/Mb
Overall	:	£0.281/Mb ...(5.15).

The first four of these charges are based upon the assumption of separate tariffs for each Service; the final charge would be a constant usage charge, irrespective of what transmission speed was used. (The Service 3 charge is obviously somewhat out-of-line; this follows directly from the low traffic suggested by Tables 4.1 and 4.2.) Of these two possibilites, the former (different Service charges) might be used with circuit switching, while the latter (a single overall charge) might apply with packet switching.

A possible call charge may now be estimated for a unit of 110 Kb of traffic; this corresponds to about three minutes of transmission at 600 b/s, for example. From the overall tariff-only charge of equation 5.15, this unit would cost a total of about 3p. Assuming that five-sixths of this cost would be raised by an annual rental (or fixed charge), the call charge (or variable cost) for one unit might be about $\frac{1}{2}$p. (This is exactly what three minutes of public Datel 600 transmission now cost.) This call charge might even be made distance-independent throughout Britain (S.T.L., 1969b; Amos, 1969).

An interesting comparison between these suggested tariff charges and the recent American DATRAN proposal is given in Appendix D.

5.4 Build-up of Usage of the New Network

At the beginning of year ISC, the Post Office should have the new national data network ready to carry subscribers' traffic; at this time there should be UDL(ISC) terminals being served by the Datel services, assuming that the provision of such services has managed to keep pace with the rising demand. These subscribers will not immediately be transferred to the new network; indeed, some of them may be very reluctant to leave a service of known security and reliability for an unknown service. It will be assumed that the number of Datel terminals transferred to the new network will follow an S-curve over time; thus DNDIL(I,J) (Data Network, from Datel, number of Individual Service J terminals, Level at year I) is taken to give a sine curve build-up of transferred terminals, from 0 at time ISC to UDIL(ISC)

after a time NIC(Y) (the Number of years of S-curve build-up of Individual Service J terminals transferred from Datel, Constant). The average rate of transfer during period I-1 is the corresponding rate DNDIR(I-1,J) obtained from the basic equation linking a rate to levels:

$$DNDIR(I-1,J) = \frac{1}{DT} \times \left[DNDIL(I) - DNDIL(I-1)\right] \qquad ...(5.16).$$

The parameters NIC(Y) are arbitrarily assumed to have the values 4,7, 7 and 10 years respectively. (See Section C.3.)

Once the new data network is in operation, it is most unlikely that the Post Office will allow any new subscribers to join the Datel services (except in rare cases of isolation, etc.). Thus all of the increases in underlying demand from time ISC onwards, SUDIR(I-1,J), will involve terminals being added to the new data network. It is assumed that the build-up of this part of network usage also follows an S-curve: a fraction SIC(J) (the parameter describing S-type build-up of number of Individual Service J terminals from underlying demand, Constant) of the demand SUDIR(ISC,J) is assumed to be added in year ISC, SUDIR(ISC+1,J) is added in year ISC+1, and SUDIR(ISC+2,J) plus the remaining underlying demand from year ISC is added in the next year. This gives DNUDIR(I-1,J) (Data Network, from Underlying Demand, number of Individual Service J terminals, Rate of change during year I-1), which indicates the lagged build-up of usage; after year ISC+2 this parameter merely follows SUDIR(I-1,J). The parameters SIC(Y) are arbitrarily given values of 0.9, 0.8, 0.8 and 0.7 respectively.

The total number of Service J terminals in the new national data network at time I, DNTIL(I,J), may now be obtained from the re-written form of the basic equation 5.16:

$$DNTIL(I,J) = DNTIL(I-1,J) + DNTIR(I-1,J) \times DT \qquad ...(5.17)$$

where

$$DNTIR(I-1,J) = DNDIR(I-1,J) + DNUDIR(I-1,J) \qquad ...(5.18).$$

Since it is assumed that the Datel services would be phased out over time periods NIC(J) from year ISC (although in fact some Datel subscribers would probably remain on Datel long after these periods have elapsed), it is possible to examine what might be the future of Datel. DATIL(I,J) (the DATel number of Individual Service J terminals, Level at year I) is at first identical to the underlying demand UDIL(I,J), so the Datel network would grow initially (until time ISC) as indicated by Figure 4.1. (For Datel purposes, Service 3

is assumed to operate as Datel 2400, at 2.4 Kb/s (or, later, possibly at 3.6 Kb/s). Thus Services 2 and 3 are assumed to be the same here.) Thereafter, the number of Datel terminals would decrease according to a cosine function corresponding to the sine curve used to derive DNDIL(I,J). (See Section C.3.)

The build-up of usage of the new network is indicated, according to the Industrial Dynamics flow chart approach (Forrester, 1961), in Figure 5.1. DNTL(I), the Data Network Total number of all terminals, Level at year I, is obtained (as for other totals) as

$$DNTL(I) = \sum_{J=1}^{4} DNTIL(I,J) \qquad ...(5.19).$$

This is the basic equation linking a total variable with the corresponding individual Service variables.

5.5 The Capital Account Level

To examine the full financial (or accounting) aspects of a national data network investment programme, the concept of the CAPital ACcount, Level at time I, CAPACL(I) is introduced. It is supposed that the Post Office, acting as a firm, might be visualized as financing the construction of the national data network by a 10% p.a. bond issue, where these bonds would be floated as required to raise capital to pay off the costs described in Section 5.2. These costs are the negative elements of CAPACL(I); the positive element is (predominantly) provided by revenues, which pay off interest charges and which pay off the bonds through a depreciation sinking fund (Section 5.3).

Because of the incidence of interest charges, CAPACL(I) is compounded at the annual rate ROIC. With annual flows CAPACR(I-1) (the CAPital ACcount Rate of change during year I-1), this financial account is defined by

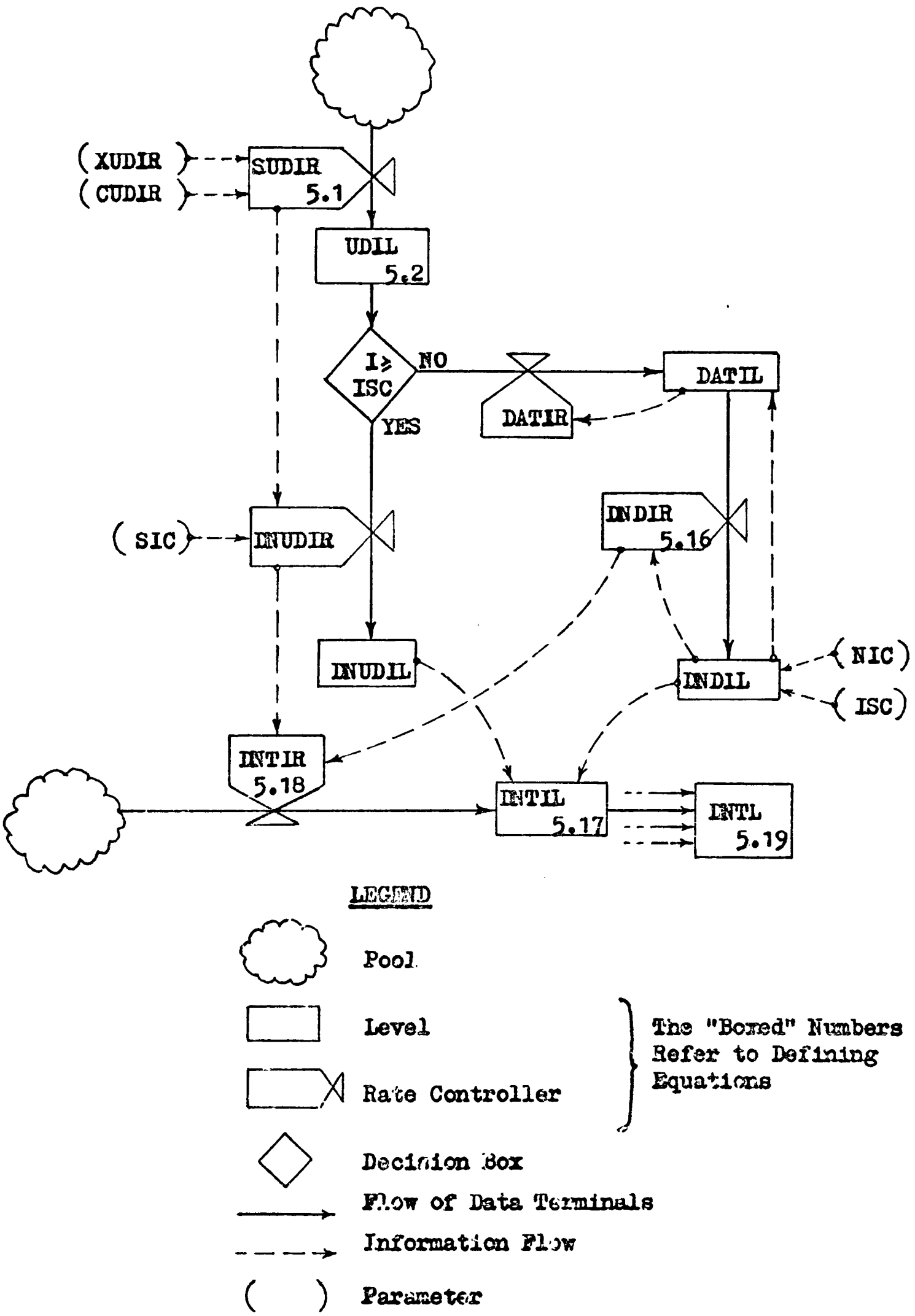
$$CAPACL(I) = (1 + ROIC) \times CAPACL(I-1) + (1 + ROIC/2) \times CAPACR(I-1) \qquad ...(5.20).$$

Including the elements mentioned above, CAPACR(I-1) is defined as

$$\begin{aligned} CAPACR(I-1) \equiv\ & REVR(I-1) - CSTRSR(I-1) \\ & - CSCNR(I-1) - CSXGR(I-1) \\ & - CSPNR(I-1) \end{aligned} \qquad ...(5.21)$$

where REVR(I-1), CSCNR(I-1) and CSPNR(I-1) are obtained, using the basic equation 5.19, as the sums of their four components: REVIR(I-1,J), CSCNIR(I-1,J), and CSPNIR(I-1,J) respectively; the cost penalty CSPNIR(I-1,J) is defined below.

Figure 5.1: Build-up of Usage of Service J Terminals in National Data Network.



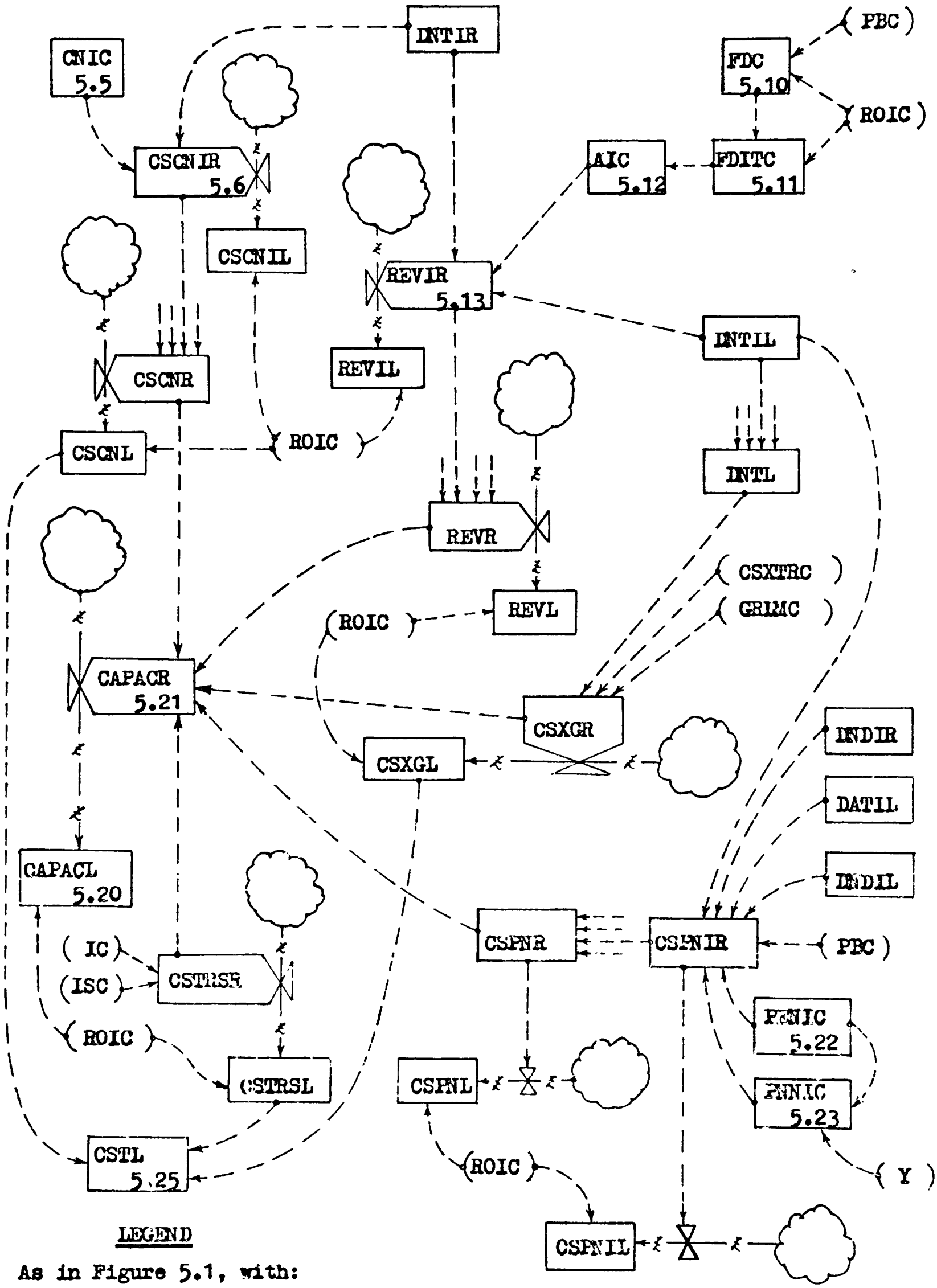
The flows (or rates) and levels involved in building up the capital account are indicated, using the Industrial Dynamics flow chart approach, in Figure 5.2.

The term CSPNIR(I-1,J) is now defined by considering the economic effects upon the capital plant of the rest of the telecommunication structure resulting from the introduction of a national data network. In particular, we are concerned with the economic consequences of transferring Datel subscribers to the new data network. Suppose that there is a capital cost, including the modem cost, of X(J) to put one Service J terminal on the Datel network; estimates of X(J) are given in Section 6.3. When this terminal is transferred to the new network, part of the equipment used by the Datel terminal, of value Y(J), may be used by subscribers on the analogue (telephone) network. Thus an amount Y(J) would be completely depreciated, first within the Datel system and later within the telephone system, regardless of when the transfer takes place. But if the terminal is transferred before the full cost of X(J) has been depreciated (i.e. within PBC years of its installation in the Datel network), there would be a loss of the undepreciated fraction of the amount X(J) - Y(J). Taking this amount to be a constant parameter PENIC(J) (the PENalty charge for Individual Service J terminals, Constant), the CoSt PeNalty for Individual Service J transfers from Datel, Rate during year I-1, CSPNIR(I-1,J) is formed as the product of PENIC(J), DNDIR(I-1,J), and the fraction giving the relative proportion that is still undepreciated by time I. The parameters PENIC(J) are assumed (fairly arbitrarily) to have the values (in pounds) of

$$\begin{aligned} PENIC(1) &= 400 \\ PENIC(2) &= PENIC(3) = 700 \\ PENIC(4) &= 6{,}000 \end{aligned} \qquad \ldots(5.22).$$

A refinement may now be added to this cost penalty model. With a provisioning period of several (IDIFC = ISC-IC-1) years, it is reasonable to assume that those starting to use data services during the period from IC+1 to ISC would not be put onto the Datel system as we now know it. Rather, they would be put onto a system which appears to be Datel but which would be composed, as much as is possible, of elements which would later become part of the new national data network. (This might, for example, involve the high-speed digital transmission network.) Until year ISC, these subscribers are considered to be part of the Datel network; after year ISC, they would be the first to be transferred to the new network. As each terminal is

Figure 5.2: Capital Account for the New Data Network.



LEGEND

As in Figure 5.1, with:

—ɛ—ɛ→ Flow of Money

transferred, the capital accounts will show a connection charge of CNIC(J); it is, however, assumed that there is no penalty since these subscribers were carried on a "quasi-digital" network.

But as indicated in Sections 4.2 and 6.3, the capital plant used by a Datel subscriber is of considerably greater value than that used by an ordinary telephone subscriber; thus the provision of Datel services imposes a heavy burden upon the analogue network. So when Datel subscribers are transferred to the new network, circuits and equipment which were overloaded would be freed: this is equivalent to an effective capital investment in capital plant of the undepreciated fraction of the amount Y(J). (Estimates of this may be made using X(J) estimates from Section 6.3 with equation 5.22, giving Y(J) values (in pounds) of 650, 400, 400 and 6,000 for the four Services respectively.) For the cases where this amount exceeds PENIC(J), the contribution to the cost penalty rate CSPNIR(I-1,J) will be negative, indicating a positive contribution to CAPACR(I-1). (In cost-benefit terminology, this direct benefit to the Post Office is a "negative cost".) This gain is incorporated through a PeNalty charge, Newly defined, for Individual Service J terminals, Constant, where

$$PNNIC(J) \equiv PENIC(J) - Y(J) \qquad \ldots(5.23).$$

Thus, in pounds,

$$\begin{aligned} PNNIC(1) &= -250 \\ PNNIC(2) &= PNNIC(3) = 300 \\ PNNIC(4) &= 0 \end{aligned} \qquad \ldots(5.24).$$

This new formulation is used for subscribers who join Datel before the present time of writing (I=7) and before time IC; if they join Datel after time IC, there is no "penalty cost" at all. But if they joined Datel between time I=7 and a later time IC, then future analogue expenditure would be required; since this cannot be considered as a former "written off" investment which could be recovered, Y(J)=0 in this case and the PENIC(J) formulation of equation 5.22 is used.

The capital account approach is considered to provide a valuable tool for investment appraisal. Among the more popularly used appraisal techniques are the 'net present value" (NPV) and "rate of return" approaches (Merrett & Sykes, 1963); these are, however, severely restricted by the fact that they only provide a one-parameter screen; the use of a single parameter for appraising complex investment projects can be very dangerous, since such an approach drastically oversimplifies the situation. A more rational approach to investment

appraisal involves using the capital account rate of change, CAPACR (to examine annual monetary flows to see if the project can be afforded), and the capital account level, CAPACL (to see how far "in the red" the project will go and when it will break even), to provide a second level of screening which can be employed in addition to a suitable first level screen such as NPV.

CAPACR and CAPACL plots give a reasonable description of future financial aspects of a project. And the use of computer-generated plots enables sensitivity analyses to be carried out to give a fairly complete picture of likely outcomes; decision-making may then proceed under conditions of far greater awareness of future consequences.

5.6 Computed Results : "Standard" Program

The first computer run made was of the "standard" program developed above (and given in Section C.3); the results obtained are shown graphically in Figures 5.3 to 5.5. Figure 5.3 shows the build-up of the data network; the S-curve transients are just noticeable.

Figure 5.3: Build-up of Usage of New Data Network.

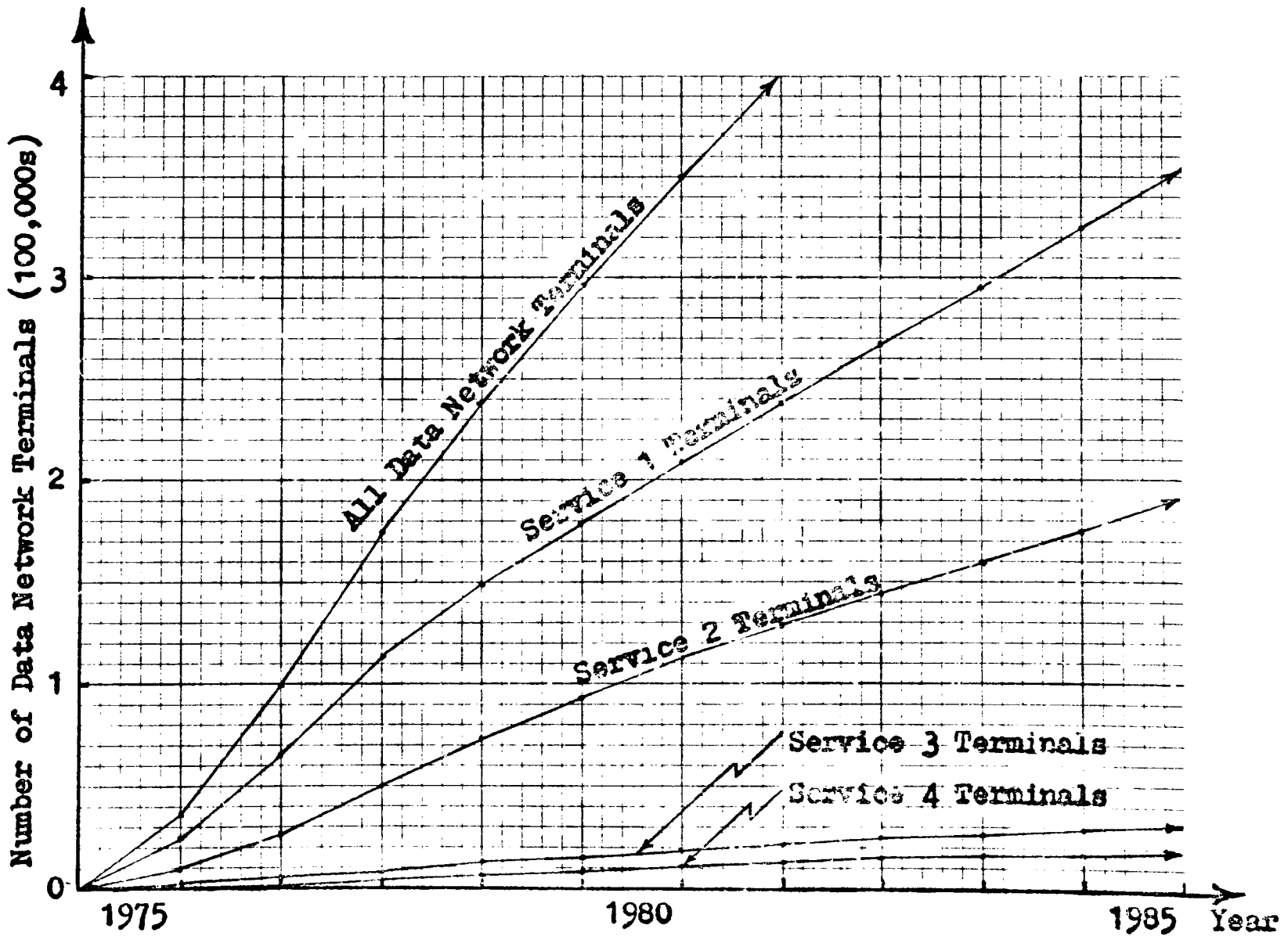
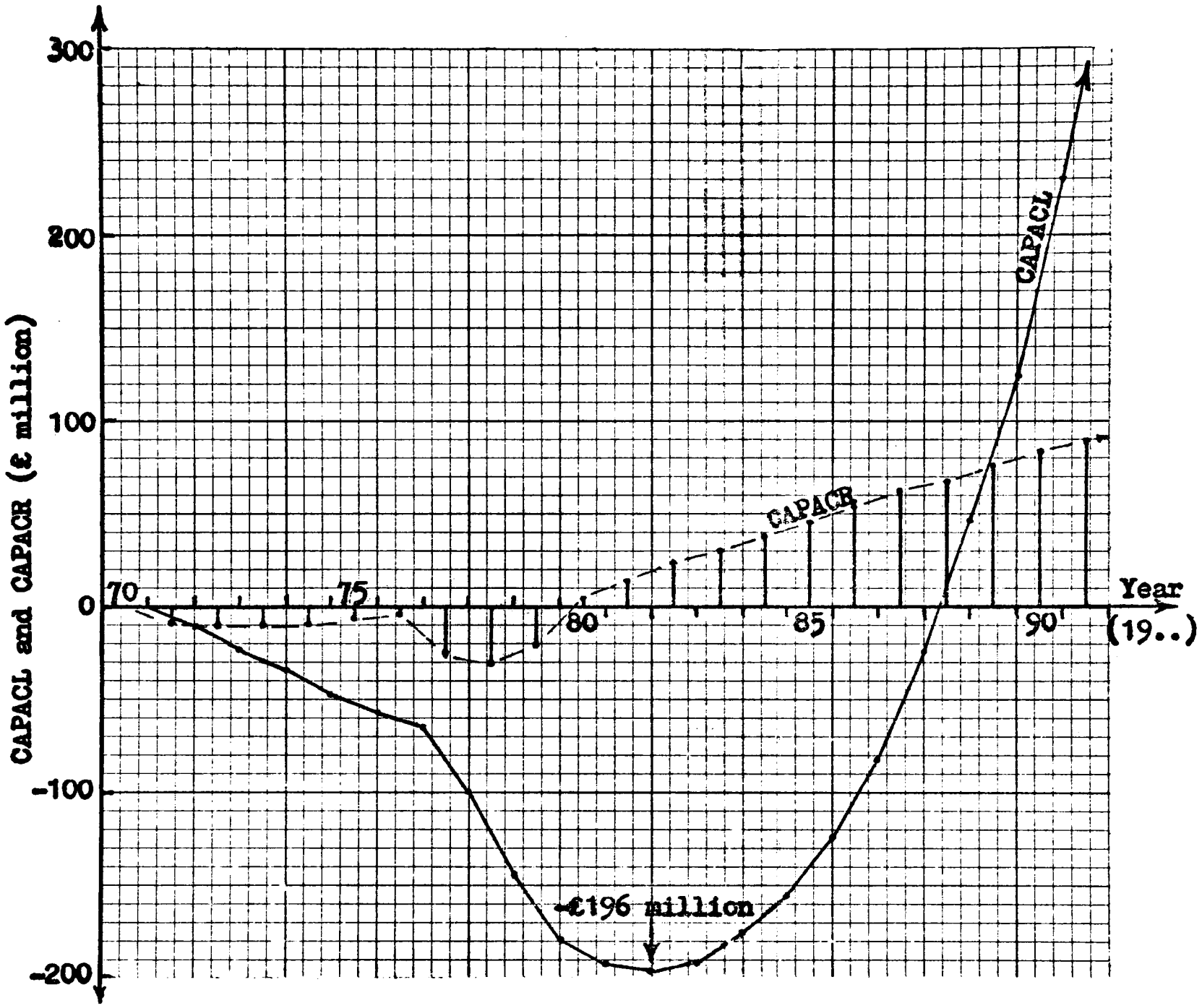


Figure 5.4 gives the growth of CAPACL; the cash flows CAPACR are indicated by vertical bars. It is noteworthy that the investment project

Figure 5.4: CAPACL and CAPACR Over Time.



goes as much as £196 million "in the red", and that it does not break even until 1988. Taken with the cost discussion of Section 4.4, these facts indicate the difficulty of saying - in any meaningful sense - just what the overall cost of the project is; the temporal element of cost must not be neglected. One possible way of including this element involves the use of net present (i.e. at 1.1.1970) values.
Since costs and revenues are compounded at 10% p.a. in calculating CAPACL (equations 5.20 and 5.21), the appropriate NPVs may be determined from the limit lines (of semi-log slope at 10% p.a.) which these elements approach. Thus a plot of the total direct cost of the investment project, CSTL(I) (CoSt, Total Level at year I), where this

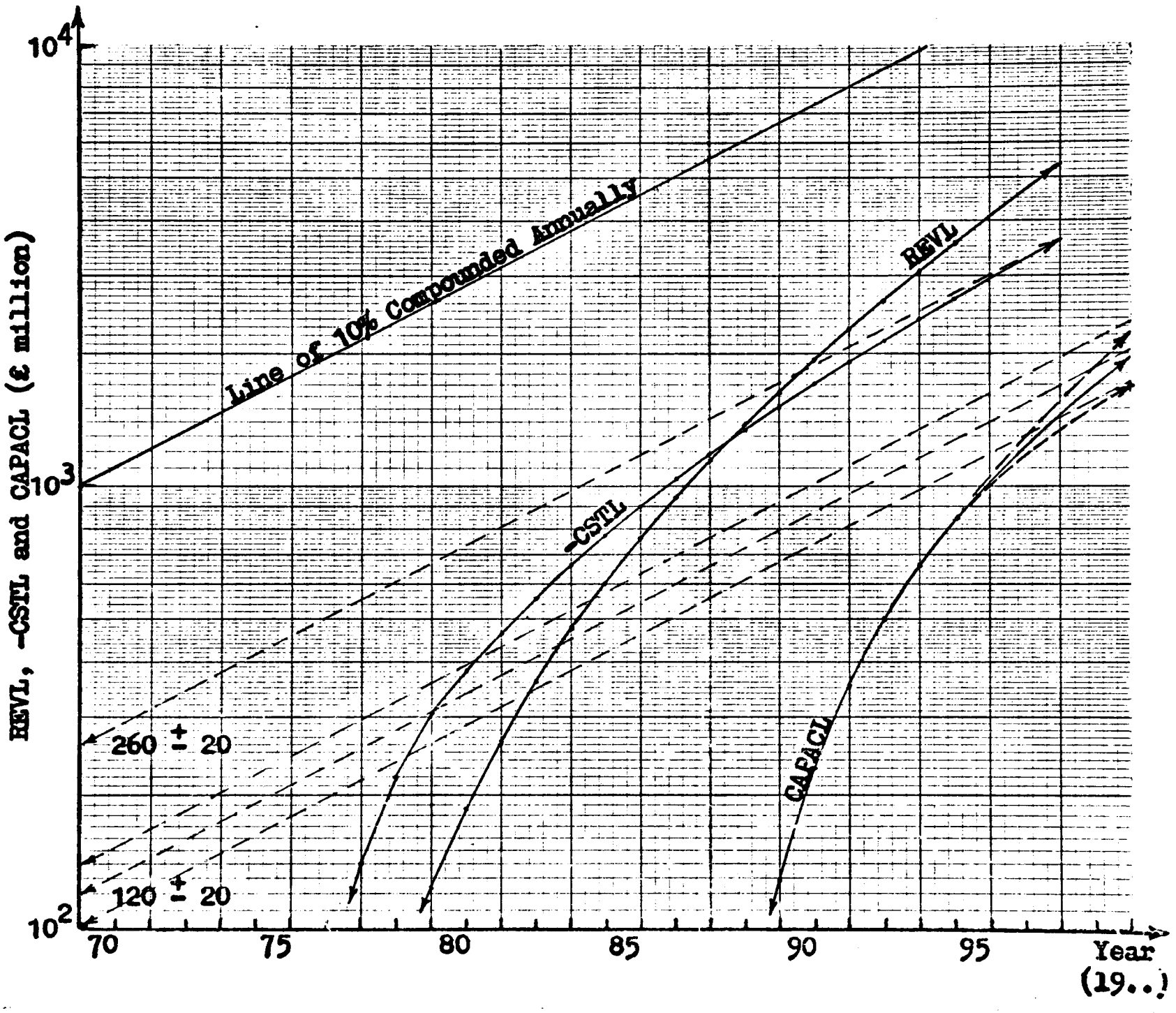
cost is formed from the levels corresponding to the rates of equation 5.21 as

$$CSTL(I) = CSTRSL(I) + CSCNL(I) + CSXGL(I) \qquad \ldots(5.25),$$

in Figure 5.5 suggests that the present value is

$$PV \text{ (Total direct costs)} \approx £260 \pm 10 \text{ million} \qquad \ldots(5.26).$$

Figure 5.5: The Estimation of Net Present Values.



The estimation of the overall net present value of the investment project involves plotting CAPACL in Figure 5.5. Unfortunately, however, the determination of a limit line is difficult, since far future NPV contributions from revenues do not taper off very quickly, as the plot of REVL indicates. Thus the more uncertain estimate is obtained that

$$NPV_{\text{Overall}} \approx £120 \pm 20 \text{ million} \qquad \ldots(5.27).$$

5.7 Computed results : Parametric Sensitivity Analysis

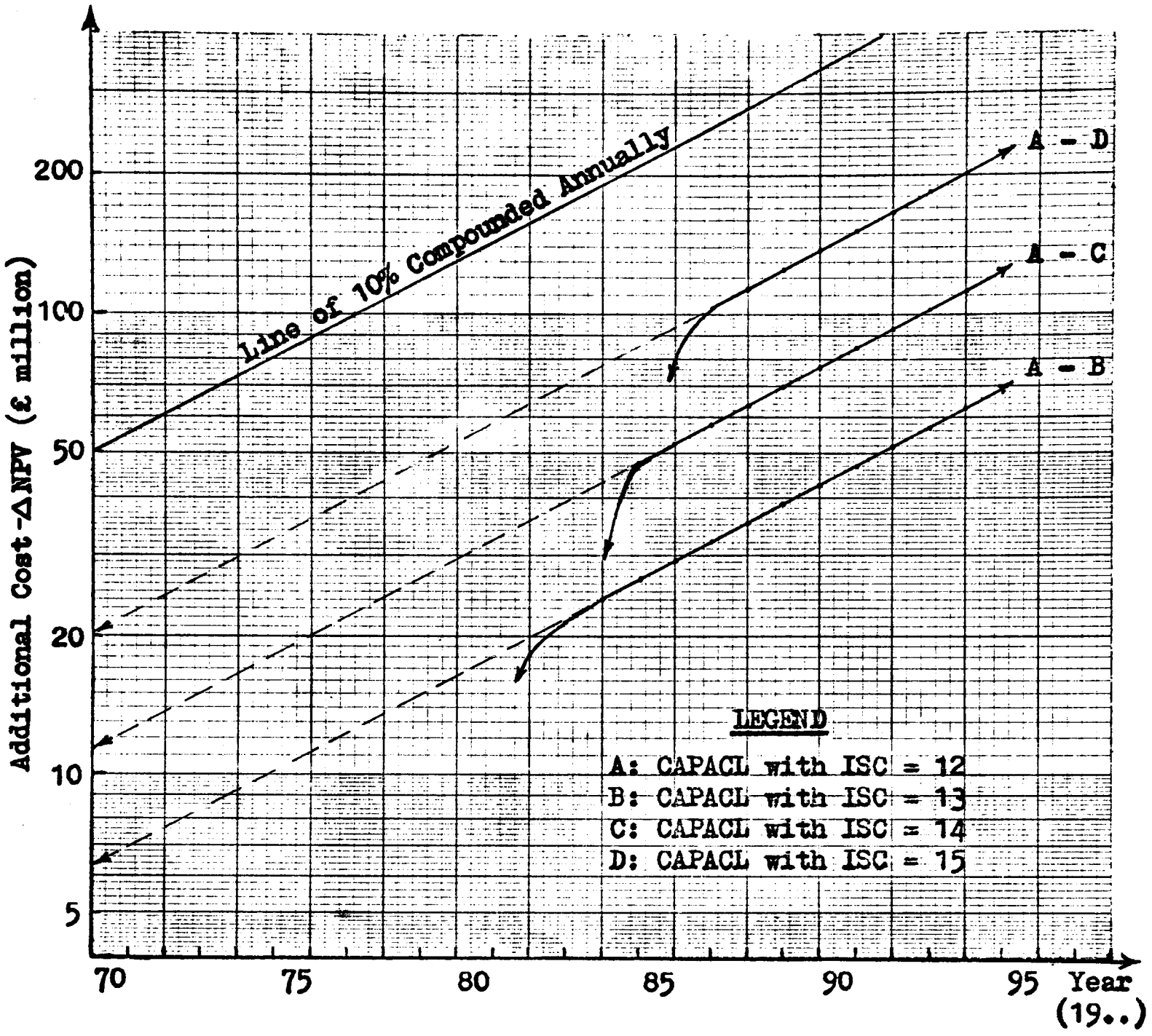
The computer model developed in this chapter makes easy a parametric sensitivity analysis in which the sensitivity of the results of the previous section to variations in parameter values may be considered. While all parameters could be considered, and alternative methods of modelling could be examined, this section deals only with four parameters whose choice of values are management decisions; thus the computer program developed is used as a decision-making tool.

The first parameters examined are ISC and IC (equation 5.7). Keeping IC=7, ISC is given the new values of 13, 14 and 15, so that the data network becomes operational on 1.1.1976, 1.1.1977 and 1.1.1978 respectively; thus the provisioning period IDIFC is extended from 4 to 5, 6 and 7 years respectively. As is expected, computer runs of the standard program (Section C.3), with ISC redefined as above, indicate (Table 5.1) that CAPACL goes deeper "into the red" and that the break-even point is delayed; the latter parts of the CAPACL curve (Figure 5.4) are shifted downwards as the provisioning period is extended. To determine the effect on the overall NPV of increasing ISC, the differences between CAPACL curves calculated for each ISC value and the curve for ISC=12 are plotted in Figure 5.6. These differences are discounted back (to 1.1.1970 at 10% p.a.) to give the additional costs (-ΔNPV, where Δ... refers to a "positive change in") incurred; these are given in Table 5.1.

Table 5.1 : Variation of Results with Increased Provisioning Period.

ISC (year)	12 (Standard)	13	14	15
Provisioning Period (Years)	4	5	6	7
CAPACL :				
Lowest point: level	-£196 m.	-£214 m.	-£206 m.	-£212 m.
time	early 1982	early 1982	early 1984	mid-1984
Break-even time	early 1988	late 1988	mid-1989	early 1990
Additional Costs(-ΔNPV)	0	£6.3 m.	£11.4 m.	£20.7 m.

Figure 5.6: Determination of Additional Costs Incurred by Increasing the Provisioning Period.



These additional costs should be of particular interest to the Post Office, for they quantify the increases in costs which result from longer provisioning periods. Thus they could be used to suggest bonuses to be offered to contractors to encourage them to speed up production and so reduce the provisioning period; alternatively, these additional costs could be used to indicate the contractual penalties that the Post Office should impose upon "critical" suppliers (i.e. those whose deliveries, etc. lie on the "critical path") for delays beyond the agreed delivery date.

The next parameter varied is the year of go-ahead, IC. Keeping a constant provisioning period of four years, so that

$$ISC = IC + 5 \qquad \ldots(5.28),$$

the standard program was run for IC = 7,8 and 9 years; another modification was also made to the standard program: the PENIC formulation was used for the period from I=7 to IC (Section 5.5). Similar results to those described above are obtained: these are given in Table 5.2, which indicates that the additional cost increases rapidly as the decision to go-ahead is delayed.

Table 5.2 : Variation of Results with Delayed Go-ahead Decision.

IC (Year)	7 (Standard)	8	9
CAPACL :			
Lowest point:time	mid-1982	early 1983	early 1985
Break-even time	mid-1989	early 1990	late 1990
Additional Costs(-ΔNPV)	0	£8.6 m.	£14.6 m.

The additional costs given in these two tables may be considered as penalty costs (Thomas, Motz, Young & Keefer, 1970, p.60) which result from delays in making a decision and in implementing it. These costs also estimate the Post Office's evaluation of time.

The next parameter considered is the payback period PBC. The standard program was run with PBC values of 6, 8, 10 and 12 years, giving the sensitivity of results to PBC variations; these results are given in Table 5.3. As expected from Section 5.3, a small PBC value is financially far more beneficial to the Post Office than is a larger PBC value.

Table 5.3 : Variation of Results with Payback Period PBC.

PBC (Years)	6	8	10 (Standard)	12
FDITC	0.2296	0.1874	0.1627	0.1468
Annual charges for network use:				
Service 1	£227 p.a.	£198 p.a.	£181 p.a.	£169 p.a.
Service 2	£339 p.a.	£296 p.a.	£271 p.a.	£252 p.a.
Service 3	£679 p.a.	£592 p.a.	£541 p.a.	£504 p.a.
Service 4	£1022 p.a.	£891 p.a.	£814 p.a.	£758 p.a.
CAPACL:				
Lowest point : level	-£129 m.	-£164 m.	-£196 m.	-£227 m.
time	early 1980	early 1981	early 1982	early 1983
Break-even time	late 1983	early 1986	early 1988	mid-1990
$NPV_{Overall}$	∿£260 m.	∿£180 m.	∿£120 m.	∿£80 m.

The final parameter considered here is the rate of return ROIC; the examination of the sensitivity of results to this parameter was particularly appropriate, since the rate used by the Post Office was raised from 8½% p.a. to 10% p.a. in July 1970 (Daily Telegraph, 1970). The standard program was run with ROIC values of 0.085, 0.100 and 0.115, giving the results of Table 5.4. It is interesting to note that increasing ROIC does not decrease the overall NPV as much as might have been expected. The reason for this is that there is a negative feedback process: as the rate of return increases, the annual charges (and hence revenues) increase. Thus a larger revenue stream is discounted back at the higher rate of interest in obtaining the overall NPV.

Table 5.4 : Variation of Results with Rate of Return ROIC.

ROIC	0.085	0.100 (Standard)	0.115
FDITC	0.1524	0.1627	0.1734
Annual charges for network use:			
Service 1	£174 p.a.	£181 p.a.	£189 p.a.
Service 2	£260 p.a.	£271 p.a.	£282 p.a.
Service 3	£520 p.a.	£541 p.a.	£563 p.a
Service 4	£782 p.a.	£814 p.a.	£848 p.a.
CAPACL:			
Lowest point: level	-£195 m.	-£196 m.	-£197 m.
time	early 1982	early 1982	early 1982
Break-even time	late 1988	early 1988	end 1987
$NPV_{Overall}$	∿ £145 m.	∿ £120 m.	∿ £95 m.

5.8 Applications of Computer Model

The real value of this chapter is its provision of a computer simulation which models the cash flows involved in building up a new data network. Since this program may easily be modified to incorporate alternative suggestions (including changed parameter values), it provides a valuable managerial decision-making tool.

One possible application involves the classic dilemma of the Post Office in choosing tariffs: if tariffs are low, demand will build up quickly (Chapter 10) so that the service is soon provided on a wide basis, to the benefit of the nation (Chapter 9); but if tariffs are high, then the Post Office can pay off its investments quickly and show a good profit. The resolution of this dilemma is

essentially a political problem (Section 2.4) and requires a good understanding of the whole situation; this could be provided by the use of a computerized simulation model (Section 12.3).

Another possible application of this computer model involves network planning considerations. In constructing the model, it became apparent that the amount of additional expenditure (about £400 million, by Section 4.4) required to increase the size of the network to carry the 1983 traffic directly affects the break-even time and the amount by which CAPACI goes "in the red". Since the Post Office wants an early break-even and a minimal dip "into the red", the use of this model should enable network planners to find how to modify the growth of additional investment in order to achieve these ends.

CHAPTER 6 : A PRELIMINARY DECISION ANALYSIS : DATEL SERVICES vs A NATIONAL DATA NETWORK

As was mentioned in Section 2.4, the first decision facing Post Office Corporation planners is whether to go ahead with a new national data network at all, or whether simply to continue to provide Datel facilities on the analogue network. This chapter analyzes this decision within the social value analysis framework; this "decision analysis" will indicate that the national data network is highly favoured. The viewpoints of four interested groups - data users, telephone users, the Post Office, and the country as a whole - will be examined.

6.1 Viewpoint of Data Users

It is first observed (Sections 4.2 and 4.3) that essential user requirements of data subscribers simply cannot be satisfied by the existing (or by extended) Datel services. These technical requirements include a wide range of speeds, lower error rates, faster set-up times, message multiplexing, etc. (I.C.L., 1969a). With these shortcomings, the Datel services are limiting and expensive for the data user who requires a widespread network of facilities (Hughes, 1969).

We now compare the typical annual cost of public Datel usage (estimated in Table B.2) with those suggested in equation 5.14 for a general national data network. (A comparison with private wire Datel services is not made, since these are obviously greatly restricted in addressee location.) It is observed that both Service 1 (which would replace Datel 100, 200 and 600) and Service 2 (which would replace Datel 2400) would probably be considerably cheaper than the Datel services which they would replace. The one exception, where typical annual costs might appear to be higher, is Telex. But a comparison of possible tariff-only charges (from equation 5.15) with the minimum current Telex transmission charge of £3.3/Mb (corresponding to 1p per minute of local transmission at 50 b/s) suggests that far greater Telex traffic than that now current has been considered in the Post Office Data Traffic Model for 1973/74. (In fact, transmission charges alone, at the present rate, would average £215 p.a. for the traffic forecast by that Model!)

Service 3 cannot really be compared to any existing Datel service, and although Service 4 may not be compared with a public

Datel service, it is relevant to note that it would replace 48 KHz Wideband circuits, the rentals of which start at about £3,000 p.a. and rise rapidly with distance (Post Office, 1968c).

The above comments suggest that data users should almost invariably prefer a change to the new national data network from the old Datel services. The economic aspect of a change should be universally beneficial. This is especially true when it is observed that the cost of data transmission should really be considered with other costs involved in data usage: a firm making use of a national data network will actually be using a whole data communication and processing system, with both computer costs - for hardware and software - and data movement costs - for terminals and data transmission - being involved. With digital data transmission, the interface between transmission medium and computer may be considerably simplified; this saving over Datel usage is noted but is not quantified.

The greatest obstacle to a new network is usually the persuasion of users of the old network it replaces that a change to the new is in their interest. In most cases the offer of a better service for less should provide sufficient inducement to change. But in some cases, private wire Datel users may be reluctant to leave the known security of their own networks; to carry these subscribers digitally, the new network is visualized as having leased-line traffic as a third major component with circuit switching and packet switching (Section 4.3).

6.2 Viewpoint of Telephone Users

The ordinary telephone user is particularly concerned about the quality of service he obtains: he appreciates any improvement in service and he vehemently opposes any decisions which might lead to a degradation of service. His reaction to a serious deterioration of service is typified by the recent public clamour in New York City (Financial Times, 1969).

Since the requirements of data transmission are basically different from telephone requirements (Section 4.2), the Datel services impose a quite disproportionate load on an already congested telephone network. Few telephone exchanges in the country can take the additional loads resulting from lines concentrating at a single point. Since the average holding time of a public Datel call is up to ten times that of a normal telephone call, Datel services play

havoc with the loading of exchange equipment and junction lines (Hughes, 1969). It is thus apparent that additional investment is required if traffic sensitive plant is to be provided in sufficient quantities to avoid imposing a heavy burden upon telephone users. If this additional investment is not made, the rapid growth of demand for data facilities (indicated by Figure 4.1), leading to a far greater use of Datel services, will cause a considerable deterioration of telephonic quality of service. The actual quantification of the losses involved and of the costs to telephone users is very difficult; it may, however, be assumed that these costs would be fairly high.

The position of the telephone user is straightforward: he wants his present level of service to remain where it is, or even to improve a little. To keep him satisfied in the face of rapidly growing demand for data facilities, increased investment must be made in the analogue network; alternatively, data users must leave the analogue network and be served by a new network - the national data network.

6.3 Viewpoint of the Post Office

Following the discussion of the previous two sections, the viewpoint of the Post Office may be presented. The Post Office is faced with three choices:

1. It may continue with its present rate of analogue investment.
2. It may increase analogue investment in accordance with increased Datel usage.
3. It may create a new national data network.

It is fairly obvious from Section 6.2 that the first choice is a "non-starter", since the mass of telephone users would not tolerate an increasing deterioration in the level of service.

The second choice involves increasing investment in analogue plant to carry the Datel services while maintaining the present level of telephone service. The following cost analysis estimates the investment required to effect the necessary strengthening of the telephone network to handle the forecast low- and medium-speed traffic for 1973/74 on a public Datel basis; to this must be added the cost of handling the forecast high-speed traffic using Wideband circuits.

Unfortunately, however, the Post Office does not publish accounts giving the costs of providing the Datel services; it is thus necessary to estimate these costs from what little published

data is available. It is first necessary to determine what fraction of the average present cost to add one subscriber (or exchange connection) to the telephone network may be considered to be "traffic sensitive". In setting up the research studies mentioned in Section 1.1, the Post Office provided the figure of £400† as the average capital expenditure per subscriber. Taking the proportion of expenditure on trunk and junction circuits and on exchange equipment to give the traffic sensitive part, it is found (Select Committee on Nationalised Industries, 1967) that this is about 55% of all expenditure, or about £220 per subscriber.

It is assumed that the £400 figure given above relates to an average busy hour traffic (or channel occupancy) of 0.04 E (Hartley, 1969). It is further assumed that an ordinary telephone line can carry data with a transmission rate of up to 1200 b/s (Table B.1). While the above discussion has related directly to the public Datel services, it is now assumed that the costing may also be applied to a typical private wire Datel subscriber. This assumption becomes important in considering the cost of providing a 2.4 Kb/s data transmission service which is taken to be able to carry the service D traffic forecast by Table 4.1; the additional costs involved are incorporated in a "multiplying factor for service" of value 1.5; this factor has unit value for speeds below 1200 b/s. (This 1.5 factor seems reasonable since the Post Office had a surcharge of $12\frac{1}{2}\%$ for each of three improvements needed to modify the transmission characteristics of a Tariff "S" line to enable it to carry 2.4 Kb/s.) The above assumptions give the general equation:

$$\left(\begin{array}{c}\text{Average}\\ \text{Investment}\\ \text{per Terminal}\end{array}\right) = \left(\begin{array}{c}\text{Multiplying}\\ \text{Factor for}\\ \text{Service}\end{array}\right) \times \left(\begin{array}{c}\text{Average Basic}\\ \text{Traffic Sen-}\\ \text{sitive Cost}\end{array}\right) + \left(\begin{array}{c}\text{Average Basic}\\ \text{traffic Insen-}\\ \text{sitive Cost}\end{array}\right) \quad \ldots(6.1).$$

† Since following calculations are highly sensitive to the choice of this value, confirmation was sought by dividing annual planned and actual capital expenditure on telecommunication plant (T.E.M.A., 1966, 1967, 1968; Post Office 1966, 1967b, 1968b) by the net increases in the number of subscribers. The figures thus obtained are, however, over-estimates, since only 55% of expenditure is devoted to new subscribers; the rest is the "standing still" expenditure and that required to maintain existing subscribers' service (Select Committee on Nationalised Industries, 1967). The corrected figures are observed to rise from the average historical cost per connection of £250 (Lönnström *et al.*, 1965; Anderson, 1964) to the Post Office estimate given above. This estimate is also confirmed by other sources (Jacobaeus, 1967; C.C.I.T.T., 1968).

Now since several of the services forecast by Table 4.1 would have an average busy hour traffic per terminal of well over 0.04 E, it is necessary to estimate the appropriate traffic sensitive cost. Various references on telephone trunking and grading (Neilson, 1966) suggest that, to maintain the British Post Office "grade of service" of 1 in 200 (Siemens Bros., 1955; Newstead, 1961), the number of switches or circuits required for busy hour traffic of X erlangs is about $(X/0.04)^{\frac{1}{2}}$ times the number required for busy hour traffic of 0.04 E (Morgan, 1958). Thus traffic sensitive costs are taken to increase as the square root of the ratio of busy hour traffic to the 0.04 E for which the costing was £220. Equation 6.1 thus becomes

$$\left\{\begin{array}{c}\text{Average}\\ \text{Investment}\\ \text{per Terminal}\end{array}\right\} = \left\{\begin{array}{c}\text{Multiplying}\\ \text{Factor for}\\ \text{Service}\end{array}\right\} \times \left\{\left\{\frac{\text{Average Busy Hour Traffic per Terminal}}{0.04\ \text{E}}\right\}^{\frac{1}{2}} \times £220 + £180\right\} \quad \ldots(6.2).$$

The total investment actually required to augment the analogue network to enable it to accommodate the low- and medium- speed data traffic forecast for 1973/74 as Datel traffic may now be estimated; using Table 4.1, the results of Table 6.1 are obtained. These results obviously give only a first approximation. In fact, certain totals, particularly those for Services A and D, appear to be rather lower than would be expected. (For example, compare these with the estimates of Table 4.5.) Nevertheless, some confirmation may be made: all of the average investments per terminal are in excess of £400, as is expected. And the service B (bureau) subscriber estimate of £965 is close to an estimate of £1,000 made by Hartley (1969) for a 0.6 E London connection. (Indeed, equation 6.2 gives an estimate of £1,030 for 0.6 E.)

Now the total of £33.5 million (Table 6.1) only covers the transmission plant costs incurred by Datel users; to this sum must be added certain additional Post Office investments. Modems must be supplied for low- and medium-speed Datel subscribers, and these modems each cost about £300 and £600 respectively. (These figures are estimated from the annual rentals given in Table B.1.) Taking Service 1 to be low-speed and Services 2 and 3 to be medium-speed, Table 6.1 indicates that the Post Office investment in modems would be about £21.2 million. Thus the total Post Office investment required to carry the 1973/74 low- and medium-speed data traffic

Table 6.1: Total Investment Required to Augment the Analogue Network for 1973/74 Datel Traffic.

Service	Average Busy Hour Traffic per Terminal (E)	Multi-plying Factor for Service	Average Investment per Terminal			Number of Terminals	Total Investment (£ million)
			Traffic Sen-sitive (£)	Traffic Insen-sitive (£)	Total (£)		
A	0.0869	1	324	180	504	16,915	8.52
B	0.510	1	785	180	965	17,230	16.63
C	0.0426	1	227	180	407	3,800	1.55
D	0.00972	1.5	163	270	433	2,867	1.24
T	0.112	1	368	180	548	10,114	5.55
Totals	Service 1 :				747	31,144	23.73
	Service 2 :				500	16,915	8.52
	Service 3 :				440	2,867	1.24
	TOTAL :				648	50,926	33.49

by Datel would be about £55 million. This does not compare very favourably with the £50 million suggested in Section 4.4 for a whole new national data network.

The comparison becomes particularly unfavourable when it is noted that the national data network would also carry 1650 Service 4 (48 Kb/s) terminals. For these subscribers to be carried by the Datel Wideband service, a considerable investment would be required. Typical annual rentals for Wideband circuits might possibly be about £5,000 (Post Office, 1968c). Supposing that the inclusive capital cost to provide these would be some £12,000 each (and this is probably a considerable underestimate), then the total investment required to provide high-speed data transmission facilities would be about £19.8 million; in addition, there would probably be about £4.5 million worth of high-speed modems required. Taking all of these estimates together, it appears that the Post Office would have to invest some £79 million to carry the data traffic forecast for 1973/74 by Datel means!

The third choice - creating a new national data network - thus seems to be favoured, since this could provide data services better and more cheaply than could an extension of the present net-

work. Although revenues from the new network's subscribers would be lower than are comparable Datel revenues, they would definitely pay for the new network, while this cannot be said of all Datel services. (A comparison of Tables 6.1 and B.2 suggests that the provision of the Datel 200 service for bureau subscribers is not profitable.) Indeed the new network's revenues should so exceed its costs that the investment project should have a net present value of about £120 million! (Equation 5.27) The Post Office should also favour the national data network for non-financial reasons: since all information transmission may eventually be by the digital mode, the creation of this new network would provide valuable experience in digital transmission.

6.4 Viewpoint of the Country as a Whole

It is suggested in Chapters 9, 10 and 11 that the introduction of a national data network should be highly beneficial to the country as a whole. The economic advantages of speeding up flows of information within the economy, and of thereby securing a better national competitive position, are obvious, though difficult to quantify. Indeed, the general conclusion of Chapter 9 is that national resources should definitely be allocated to this investment project. (See Section 2.4.)

6.5 The Decision

The decision to introduce a new national data network to replace the existing Datel services and to cater for growing data demand should thus be fairly straightforward. The Post Office (and the Government) should favour an investment project with an NPV of some £120 million, which also has important and beneficial social and economic consequences for the country, with few negative benefits. Part of this NPV appears in the form of a benefit which would be received when analogue equipment, now used by Datel subscribers, was freed for telephonic use. Telephone users would thus favour the creation of the new network since this effective increase in analogue investment would give them a slightly higher standard of service. Data users obviously favour the creation of a national data network since it could offer them a better service at a lower cost than is now available.

The above decision analysis is obviously carried out at a preliminary level: costs are fairly well known, but benefits remain a far more uncertain quantity. Succeeding chapters will endeavour to consider this latter more difficult aspect of social value analysis in some detail.

CHAPTER 7 : THE ASSESSMENT OF BENEFITS

7.1 The Essence of Data Telecommunication

The fundamental approach used in this thesis to evaluate the proposed national data network involves assessing the benefits which should be received by typical users of the network; the overall benefit is then determined by aggregation. The approach is the reverse of the usual one in which various technical systems are costed by users, then their benefits are examined to see whether they exceed the costs; here possible benefits are considered first, and the cost of actual implementation becomes a secondary consideration. By quantifying the value of the possible benefits a user establishment might receive, it is possible to determine the amount that it could reasonably budget to pay for a system which would give the benefits considered.

The assessment of benefits is achieved by considering the essential function of data telecommunication. Man's activities may be considered to take place within an environment bounded by certain (relatively) unchanging constraints. Since these constraints limit activities, a reduction in the influence of any constraint could have important and far-reaching consequences. Examining data telecommunication, it is noted that a national data network could cause

- a reduction of the time constraint,
- a reduction of the distance constraint, and
- a reduction of the physical constraint (i.e. one could transfer information and ideas rather than people or things).

Since these constraints of time, distance, and "physical being" are of primary importance (indeed, they condition our whole way of thought), it is obvious that a reduction in their effect, resulting from the introduction of a national data network (which would change the whole telecommunication infrastructure), would be profound.

The actual enumeration and evaluation of benefits is considered at two levels. "First order" benefits are taken to be those which result when the introduction of a national data network improves the performance and efficiency of already existing procedures, operations, etc. The description of, and quantification of, several such benefits follows in Section 7.3 and in Chapter 8; this may be considered as an attempt to assess the fundamental potential of the network in first order applications. Since these benefits would be the first to be noted and received from the network, it might be assumed that

businessmen and Post Office planners would emphasize the consideration of these rather than the "second order" benefits mentioned below. These latter benefits are those which result when the existence of the national data network makes possible completely new approaches, operations, etc. Since we now consider possible future benefits involving quite new applications, our vision is somewhat blurred. This more qualitative exploratory technological forecasting, which involves enumeration but not evaluation of possible social consequences (or benefits) resulting from the introduction of a national data network, is attempted in Chapter 11.

It is interesting to note that the constraint-based approach mentioned above corresponds closely to Cherry's recent advice (1970) to senior management concerning how to choose equipment from the "cornucopia" of information technology. He suggests that the values of specific new techniques cannot be generalized, since their evaluation depends upon their environment of application. Thus one should think in terms of function and not of things; the real value of the new information technology is that it removes or changes constraints upon organizational action. He suggests that one should attempt to identify the various constraints which exist to limit present operations of the business or industry; one then tries to determine what functions are needed to diminish their effect. Cherry feels that the crucial decision-making lies in this analysis of constraints and functions, especially if these can be quantified; the examination of the equipment available is then the next step.

Implicit in the above discussion is the fact that only the business sector will be examined in this thesis; the domestic sector will be excluded since any benefits received there as a result of national data network usage will be far distant second order benefits. With the tariff levels now envisaged (Section 5.3), it is difficult to see a substantial domestic market developing for many years; its consideration would thus require a highly futuristic study.

7.2 The Isolation of Data Telecommunication Benefits

In attempting to apply the approach described above to evaluate the benefits of a national data network, difficulties are encountered since the data network cannot really be considered separately from the rest of the data communication and processing system (Section 2.4). Indeed, it may be argued that data communications and computing are essentially complementary technologies (Maddox, 1968; I.C.L., 1969b),

although they are also substitutes to an extent (as indicated by the addition of computing power to terminals in order to minimize data transmission). When an establishment joins the national data network, it would probably do this in conjunction with increased computerization and using management consultants. It thus becomes extremely difficult (and almost impossible) to isolate the benefits of data network usage from those of computerization and systems analysis; the benefits of data processing (DP) cannot easily be subdivided.

As an illustration of this difficulty we note the following "concepts relating to applications of good, fast, accurate basic DP". Greenwood (1969, p.6) suggests that four main benefits result from DP. Firstly, DP improves basic clerical work, making it faster, cheaper and more accurate. Secondly, DP enables an improved utilization of corporate resources to be made. With faster, more complete, and more accurate information, a firm can:

- handle a given volume of sales with a lower inventory and with a shorter production-delivery cycle,
- attain a higher percentage of on-time deliveries,
- reduce emergency costs,
- schedule men and machines to a higher percentage of their productive capacity,
- decrease losses from obsolescence and unsaleability, and
- improve product quality.

Thirdly, DP can give a firm a competitive advantage, or can restore a competitive equality; this is of distinct, though hard to measure, value. Finally, DP aids planning, decision-making, and control, thus making possible better managerial performance. It will be noticed that virtually all of these benefits will be directly attributed in the next chapter to the faster information flow (and hence to the overall time saving) which would be made possible by a national data network. It is thus a matter of debate whether this time saving should be attributed to DP or just to data network usage.

The isolation of the benefits of data network usage from others is made even more difficult by the fact that these benefits are small in comparison with the others. This is partly due to the fact that data transmission forms only one small part of the huge framework of information technology. For example, the Hoskyns Group Ltd. (1969) predicts that the following percentages of the total DP market will be devoted to data transmission: ½% in 1968, 1% in 1970, 3% in 1975 and 4½% in 1980. These low figures are not unreason-

able: a typical bureau subscriber (in the bureau's local STD area) now pays less than 1% of his total bill for the actual data transmission costs. Turning to the predominating areas of computers and systems analysis, it is recognized that the systems analysis involved in implementing a new computer system, rather than the speed of calculation, often provides the real savings (Ensor, 1969). It thus appears that the data network is very much the "junior partner" in DP considerations.

One possible approach to isolating the benefits attributable to a national data network involves considering the benefits which result when a firm moves from a system, now optimized as much as possible, to a comparable also-optimized system based upon the new network; these benefits would result entirely from the use of digital data transmission. In the more realistic situation where other improvements - better data terminals, better software, faster computers, etc. - are simultaneously introduced, the DP system must somehow be made divisible so that the data network may be isolated and considered separately. This may be done if one takes the approach of the next section that the real contribution of the national data network is to introduce a time saving, thus reducing the time constraint.

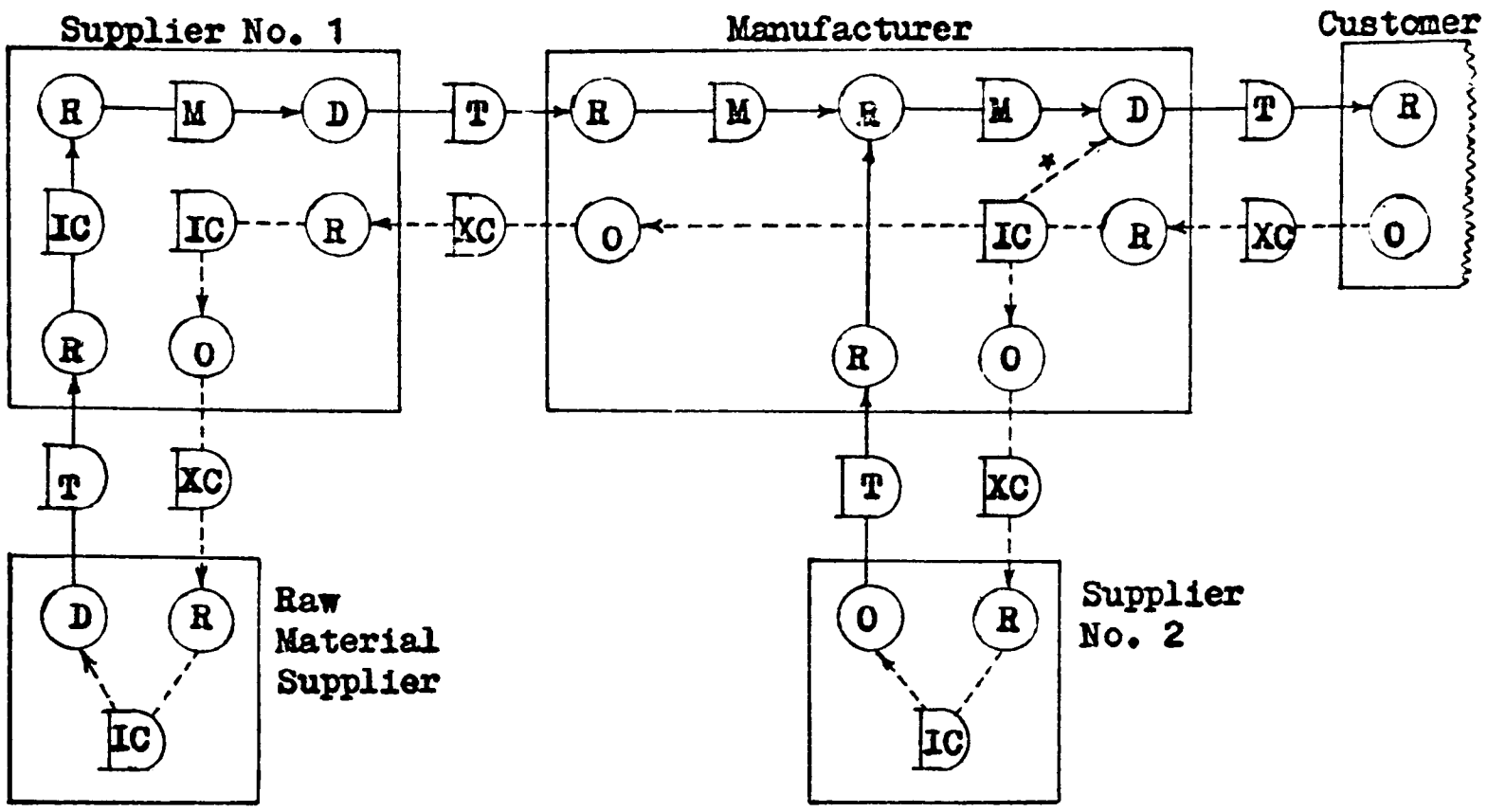
7.3 The Reduction of the Time Constraint

It is now assumed that the real benefit of national data network usage will be the reduction of the time constraint within which firms operate. Since the value of information is obviously highly dependent upon its timeliness, it is relevant to consider the value to an organization of faster information. Unfortunately the usual approaches available (Section 2.4) cannot be generalized, although the results they produce are valuable in particular cases; however, in assessing a national data network, it is essential that the benefits to result can be generalized.

The generalization approach now used involves attempting to quantify the adage: "Time is Money". Consider a simple model consisting of a number of firms linked together by several networks. Following orders sent over communications channels, products are manufactured and shipped *via* channels of physical transportation, then payment is made *via* monetary channels. It is apparent that time delays would play an important part in this model.

Figure 7.1 gives an example of how this model might operate: flows of information and materials are shown for the cases of a

Figure 7.1: Flows, Operations and Delays in a Simple Model.



customer ordering an article made-to-specification and ordering a stock item. (The latter case is indicated by the starred flow.) Successive flows and operations would have times attached to them (as in a critical path analysis); these are assumed to be the minimum possible (including any temporal buffers required for smoothing). While these times are taken to be minimal, it is noteworthy that they might be reduced with new technological improvements. Excess delays (occurring where time is wasted) are for simplicity entirely attributed to the flow channels.

If a critical path analysis is now applied to the network of Figure 7.1, the excess delays on the critical path may be taken to give the "critical delay"; the magnitude of this delay is a function of the characteristics of several interconnected systems: telecommunication, transportation, management structure, etc. If this critical delay is now shortened, a social benefit is created, as long as instability problems do not arise. (Such problems are discussed in Section 9.2.) Depending upon the evaluation placed on this

benefit and upon the competitiveness of the market situation, this social benefit may be shared between suppliers and customers. The evaluation of this social benefit will be attempted in following chapters: Chapter 8 develops models which may be used to quantify the value of reducing the time constraint; Chapter 9 uses these to attempt a macro-economic assessment of the total social benefit, and Chapter 10 uses them to estimate benefits to individual establishments in various sectors of the economy.

So far in this discussion of the model, the means by which overall time savings might be obtained to reduce the critical delay have not been mentioned. It is thus apparent that this approach is very general, for it enables the benefits of using management consultants, of computerization, of using a national data network, etc. to be (to an extent at least) assessed. Thus an overall time saving is used as an effectiveness criterion: this enables the benefits resulting from various proposed systems to be evaluated.

7.4 The Reduction of Other Constraints

In the above sections it has been claimed that the real contribution of a national data network will be to reduce the time constraint; nevertheless, several other benefits should also result as other constraints are reduced. For example, the reduction of the distance and physical constraints with respect to people might occur as the necessity of business travel was reduced. (See Figure 11.4.) While there will be some benefits received here as travel time and expense are saved, these are difficult to quantify in general. (However, the methodology developed below could obviously be applied to the consideration of this constraint reduction.) A quantification attempt will not be made, since little change in personal travel habits is envisaged, at least as a first order effect, since the preference for personal contact will remain for some time.

It is the reduction of the physical and distance constraints with reference to things which is now considered: with a national digital data network, information could be transferred over the wires of the network by facsimile or coded forms rather than by the mails and other physical carriers. From Section 5.3, it is noted that 110 Kb might be transmitted for a tariff of $\frac{1}{2}$p; taking 40 bits to correspond to one coded word, this suggests a very low transmission cost for some 2700 words. Since the usual one- or two-page business

letter would have less content than this, it follows that this "super-Telex" service could have a tremendous impact, replacing much of the current communication between businesses. For this forecast new type of service would be extremely competitive with telephone calls, Telex, business mail, etc.; this would be especially true if a cheaper "second class" service involving night-time transmission (similar to the telegraph system's "LT") were also introduced. The possible benefits available to an establishment sending these "electronic business letters" (EBLs) can scarcely be over-emphasized. Indeed, a recent American proposal (Gifford, 1969) for a satellite-based domestic communications network suggests that the real value of such a network would be its replacement of much business mail by data messages.

The quantification of the savings or benefits available to an establishment sending EBLs will now be attempted. Consider an establishment which spends an amount PTTC (in pounds) each year on postage, telephone, telegrammes and cables. (Such figures are given, for 1963, in Table G.3.) Suppose now that a fraction δ of this amount of traffic could be carried in the form of EBLs at an average unit cost of a_2, rather than in the old form at an average unit cost of a_1. Then the annual saving available from this aspect of digital data network usage would be

$$\left\{\begin{matrix}\text{Annual}\\ \text{Saving}\end{matrix}\right\} = \text{PTTC} \times \delta \times \left\{1 - \frac{a_2}{a_1}\right\} \qquad \ldots(7.1).$$

A general estimate of δ may now be made. The amount PTTC really gives an establishment's annual payment for communications services. Thus an estimate of PTTC may be obtained from an input-output table's "sales by the communications industry to other industries" (Table G.3). These sales include those provided by the Post Office, by Cables and Wireless Ltd., and by other miscellaneous sources; the latter two categories comprised some 7% of the gross communications output in 1963 (Economic Trends, 1968). It is assumed that the use of EBLs will only replace services included in the Post Office's 93% share of gross output, and that about one-quarter of business postal traffic would be replaced by EBLs. (This is reasonable, since about 1/3 of business mail is business-business; our 25% estimate compares with Gifford's estimate (1969) of 20%.) While some telecommunication traffic would also be replaced, this is considered to be only a small fraction. Now the Post Office income for 1963

may be subdivided into 43.7% attributed to the postal services and 56.3% to the telecommunications services (Post Office, 1964). Thus the estimate for δ is

$$\delta \approx 0.93 \times 0.25 \times 0.437 = 0.10 \qquad \ldots(7.2).$$

In the sensitivity analyses to follow (in Chapter 10), a range of uncertainty of $\pm$ 0.05 about this value will be used.

The parameters a_1 and a_2 may now be considered. If EBLs at $\frac{1}{2}$p each (Section 5.3) replace ordinary business letters for which the first class postage will be about 3p, then these parameters have the approximate values

$$a_1 \approx 3\text{p}$$

$$a_2 \approx 0.5\text{p} \qquad \ldots(7.3).$$

Using these values, equation 7.1 becomes

$$\begin{pmatrix}\text{Annual}\\ \text{Saving}\end{pmatrix} \approx \text{PTTC} \times 0.083 \quad (\text{£/year}) \qquad \ldots(7.4),$$

and taking r (= 0.10) as the appropriate discount rate for this stream of annual savings, the total lump sum benefit available here, Δ_1, is

$$\Delta_1 = \frac{\text{Annual Saving}}{r} \approx \text{PTTC} \times 0.83 \quad (\text{£}) \qquad \ldots(7.5).$$

While specific parameter values would have to be determined in any particular case, these latter two equations will be held to be generally applicable, at least as a first approximation.

It is noteworthy that the data network terminal cost and the annual fixed cost for network usage have not been included in the unit cost a_2. This cost is taken as the marginal (or variable) cost which may actually be attributed to any particular EBL sent; an attempt is not made to attribute part of the fixed costs to each EBL, since considerable difficulties are encountered in attempting to divide fixed costs among the various benefits (including those of Chapter 8) which result from network usage. Thus it will be assumed now and in following chapters that a data terminal has already been installed; the benefits are then estimated, and these are compared with the cost of terminal usage to see if the data terminal should have been installed in the first place. (cf. Cherry's approach in Section 7.1.)

A refinement may now be introduced. While it has been as-

sumed above that only business mail would be replaced by EBLs, it is fairly obvious that other more expensive telecommunication services - trunk telephone calls, telegrammes, Datel services, etc. - would also be replaced. Even "Datapost" (which costs about 0.06 £/Mb. for magnetic tape, 0.93 £/Mb. for paper tape and 6.96 £/Mb. for punched cards (Piper, 1970)) and similar bulk services could be replaced by direct data transmission (with competitive tariffs derived from equations 5.15). With these further replacements, the value of the coefficient in equation 7.4 should be somewhat increased, since both δ and a_1 would be increased, while a_2 might even be slightly decreased.

Section 7.3 and this section thus suggest that national data network usage should not only give considerably faster information transfer; it should also give a cheaper service than is now available.

One further constraint may be mentioned: the "manpower" constraint. It is expected that a national data network should have very little effect on a company's labour force, at least as a first order effect. While some clerical staff might be laid off, other highly trained staff would be needed. A situation similar to that involved in computerization is thus expected, with very little change being noted in the payroll bill.

CHAPTER 8 : THE VALUE OF TIME TO AN ESTABLISHMENT

8.1 Introduction

Figure 7.1 suggests various excess delays involved in a simple model of manufacturing flows. An establishment should benefit if it can reduce what it considers to be its "critical delay"; this critical delay will include an "internal communication" excess delay, an "external communication" excess delay and a "transportation" excess delay.

In order to quantify the first order benefits which an establishment could receive as a result of an overall time saving (OTS) which reduces the critical delay, an analytical framework consisting of a series of general working hypotheses (or "hypothetical modes of behaviour") is established in this chapter. Within this framework, several quantitative (and qualitative) models are developed to describe the benefits received in particular operational situations: these models are of course communications-oriented, although their range of applicability is far wider (Section 7.3). Particularly useful in later chapters are the models which indicate that an OTS may be used to increase the efficiency of an operation, so that a manufacturer may increase his capacity utilization (Section 8.2), or so that an inventory-holder may reduce his mean level of inventory on hand (Section 8.3); also useful is the indication that an OTS may be used to speed up an operation, so that payments from customers are received sooner (Section 8.4). All of these models are concerned with an absolute time saving which is available to all establishments within Britain; this is obviously the form of OTS which would result from the introduction of a national data network. (A relative time saving obviously only gives temporary benefits, until competitors obtain the same time saving (Section 8.6).)

In order to apply these models to any particular establishment, it is first necessary to estimate the OTS involved. The use of a national data network will obviously reduce an establishment's internal and external communications excess delays; the benefit of the former reduction may be received entirely by the establishment, while the benefit of the latter reduction will be shared between those at each end of the communications link. The actual distribution of this latter benefit will depend upon market conditions; as a first approximation it is assumed to be 50:50.

Now Section E.3 suggests that the internal communications excess delay is about 5 working days; it is assumed that national data network usage could reduce this by about 3 working days. The corresponding external communications excess delay is probably about 2 working days, and national data network usage should eliminate this entirely. It is thus estimated that the total OTS available to an establishment as a result of national data network usage would be about 4 working days.

It would obviously be unrealistic for an establishment to receive an OTS of this magnitude directly; rather, it would be received over a period of some time. Thus benefits would grow in a transient manner. To quantify these, a comparative statics approach is used; this is equivalent to discounting back future benefits to determine their net present value, as if they had been received directly.

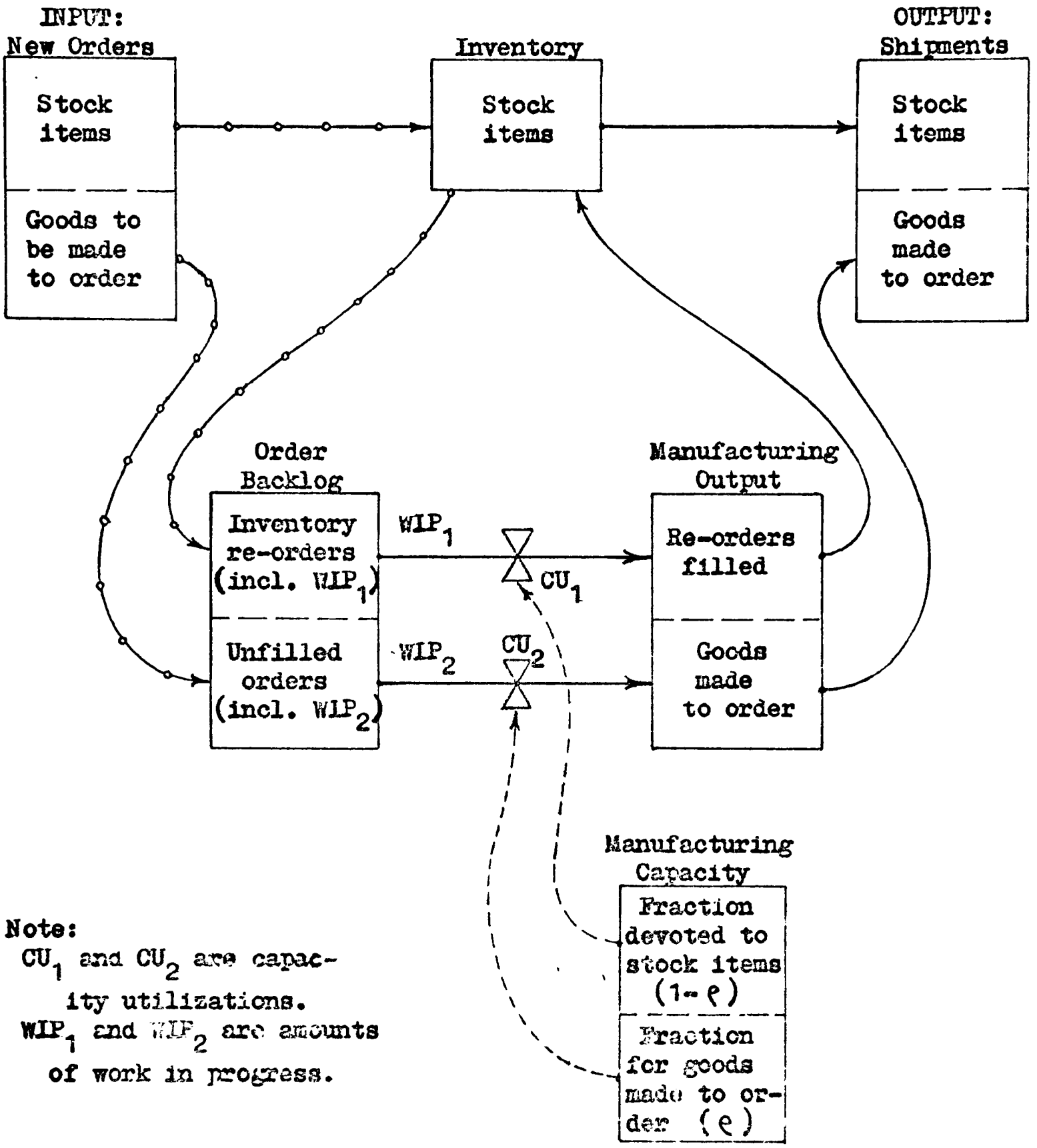
8.2 Increases in Capacity Utilization

a) General Model of a Manufacturing Establishment

Since manufacturing production may be divided into production for stock and production to order, it is first assumed that a typical manufacturing establishment may be subdivided into two corresponding components. This subdivision and the appropriate flows are shown in Figure 8.1, which is based upon published accounts of the American derivation of the statistical series of "shipments", "inventories", "unfilled orders" and "new orders" (U.S. Department of Commerce 1967, Blue page 24; U.S. Bureau of the Census, 1968, pp. 2-5).

The above subdivision is modelled by assuming the existence of a relatively constant fraction (ρ) of the establishment's manufacturing capacity which is devoted to manufacturing goods to order. Incoming new orders are subdivided into those for stock items and those to be made to order; it is assumed that the ρ fraction is also applicable here. Since orders for stock items are filled directly from inventory stock, they may be shipped directly (although there will be a short lag, as discussed in Section E.3). Thus new orders and shipments for stock items are virtually equal in any accounting period. As long as new orders do not exceed the amount held in inventory, there is no backlog of unfilled orders; if new orders exceed this amount, they are treated in this model as orders for goods to be made to order, since these orders must be scheduled into the production process. From time to time re-orders are placed by the inventory

Figure 8.1: Flows in a Typical Manufacturing Establishment.



section to the manufacturing section, giving a backlog of inventory re-orders. After a period of time equal to the procurement time, these re-orders are filled and the inventory stock is replenished.

Orders for goods to be made to order (or to specification) join the backlog of unfilled orders; when these orders are filled, after a time interval equal to the scheduling delay (or queuing time in the backlog) plus the actual worktime, they are shipped. The net change in unfilled orders in any accounting period obviously equals the excess of new orders over shipments during the period. Thus, for goods made to order, new orders and shipments are *not* virtually identical, since the latter series lags the former (Popkin, 1965). Nevertheless, over reasonably long time intervals it is expected that the fraction ρ approximates the proportion of total shipments that are of goods made to order.

It is apparent from the above discussion that the estimation of the fraction ρ is of considerable importance. For an individual establishment it should be possible to estimate ρ fairly easily. It is now desired to extrapolate the model of Figure 8.1 to the macro-level, so that it models the whole manufacturing sector; this is not unreasonable since the model is based upon macro-economic definitions. The obvious approach to estimating an overall ρ value, as the fraction of manufacturing industry which manufactures goods to order, would involve determining a weighted average of individual ρ values. Since this cannot readily be done, an estimating procedure must be used. Taking the value of finished goods (FG) in inventory as a measure of the relative importance of manufacturing stock items, and the value of unfilled orders (UO) as a measure of the relative importance of manufacturing goods to order, an estimator α may be obtained as

$$\alpha \equiv \frac{UO}{UO + FG} \qquad \ldots(8.1).$$

This first approximation estimator is quantified in Section G.1, using American statistics; the mean value $\bar{\alpha}$ is taken as a long-term estimator of the fraction ρ.

b) A Relationship Between Capacity Utilization and Buffer Length

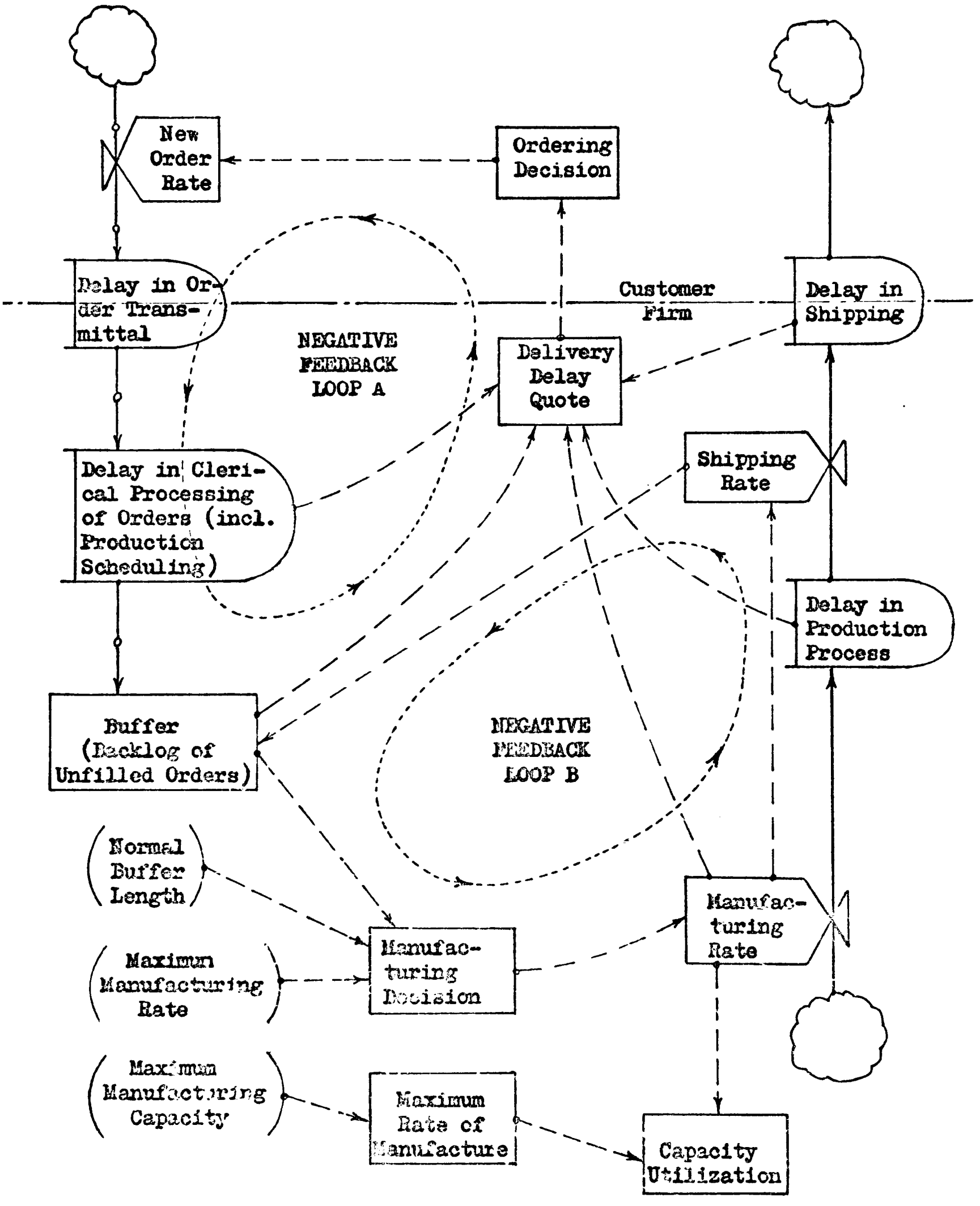
This subsection is concerned with the "lower" series of flows (relating to goods manufactured to order) in Figure 8.1; in particular, the possibility of a relationship between the size of the unfilled order backlog and the manufacturing rate (or, alternatively, the capacity utilization) will be examined.

Since the unfilled order backlog is really a queue of orders which are dealt with at the manufacturing rate, it might be suggested that queuing theory could be applied to our model of an establishment (Thomas *et al.*, 1970, p.61). Appendix F indicates that this cannot easily be done; nevertheless, it does suggest that there might exist a positive long-term relationship between the average queue length (measured in units of the "work in progress") and the capacity utilization. Such a relationship is not, of course, unreasonable: ordinary experience indicates that establishments with considerable overcapacity can usually deal with new orders quickly, while establishments with a long order backlog can be expected to be working as close to full capacity as possible.

A long-term relationship as suggested above seems even more reasonable when it is noted that the order backlog provides a "buffer" which cushions the establishment's relatively constant rate of manufacture from the uncertainty of randomly arriving orders by uncoupling the ordering and manufacturing processes. Thus a measure of certainty is provided in the uncertain world beset by randomly arriving orders, random fluctuations in the manufacturing rate, etc. From the point of view of the production manager, certainty is provided to the extent that he can schedule production for the full length of the order backlog. He requires more overcapacity (and thus a lower capacity utilization) if he is faced with relatively more uncertainty (as indicated by and produced by a shorter buffer).

The actual buffer length which will be maintained in the long run should be fairly constant. This is suggested by various feedback loops which may be determined from the Forrester-type (1961) model of customer-firm interactions given in Figure 8.2. For example, if the buffer length increases, the delivery delay quote to customers is increased, so the new order rate decreases, thus reducing the buffer length (Negative feedback loop A). Another feedback loop (Negative feedback loop B) might involve the buffer length increasing, causing the manufacturing rate to be increased, thus increasing the shipping rate and thus reducing the buffer of unfilled orders. These feedback loops deal with medium-term fluctuations; in attempting to derive a relationship as described above, we are not really concerned with short-term, wholly random fluctuations: these latter fluctuations are removed by the use of medium-term (quarterly and annual) averages in the following derivation.

Figure 8.2: Flow Chart of Simple Customer-Firm Interactions for Goods Manufactured to Order.



Of particular note is the second feedback loop suggested above, where an increase in the buffer length could cause the manufacturing rate (and thus the capacity utilization) to be increased. The reverse causality may also be noted: an increase in the manufacturing rate should reduce the delivery delay quote, thus increasing the new order rate and increasing the length of the buffer. Thus medium-term changes in capacity utilization are expected to cause corresponding changes in buffer length, and *vice versa*. Such causation should lead to a positive long-term relationship between these two quantities, as suggested above.

Following the above discussion, it is now possible to give the first working hypothesis (H-1):

H-1 : In non-recession conditions, the absolute buffer length is positively related to the capacity utilization.

The "absolute buffer length" (ABL) is defined, following Appendix F, as the ratio of the value of the backlog of unfilled orders (UO) to the value of that fraction (ρ) of the work in progress (WIP) that is devoted to manufacturing to order. Thus

$$ABL \equiv \frac{UO}{WIP \times \rho} \qquad ...(8.2).$$

And hypothesis H-1 is taken to refer to non-recession conditions for obvious reasons: in steady or growth conditions, both the capacity utilization and the buffer length will be affected by economic conditions, the state of certainty, etc.; any relationship derived for such conditions might be inapplicable in recession conditions of stagnation, uncertainty, etc.

Since this thesis is concerned with a British national data network, it was hoped that suitable statistics might be available for hypothesis H-1 to be examined. Unfortunately, however, the series required - capacity utilization, UO, WIP, and ρ - are virtually unknown in Britain. A few capacity utilization (CU) figures are, however, available; fourth quarter estimates of CU in mechanical engineering for the period from 1958 to 1964 (N.I.E.R., 1965) indicate an average value of about 83%. This value, which compares with an average of 83 1/3% for all American manufacturing industries for the period from 1959 to 1964 (U.S. Bureau of the Census, 1967), will be taken as a point estimate of the current British level of capacity utilization. Thus

$$CU = 0.83 \qquad ...(8.3).$$

Since British statistics are simply not available, it is necessary to use available American statistics and make the assumption that the conclusions derived may be applied to British industry. It is first assumed that hypothesis H-1 is applicable both at the sector level and at the individual establishment level; this is reasonable, since the existence of such a relationship throughout the micro-level should make it noticeable at the macro-level. Of the (sector level) statistical series required, all but ρ are available (in Table G.2). Unfortunately, however, the estimator α (of equation 8.1 and Section G.1) cannot really be used since it is subject to medium-term fluctuations (as UO and FG fluctuate); the ρ fraction should be constant in the medium-term. Thus the approach taken involves redefining the absolute buffer length as

$$ABL' \equiv \frac{UO}{WIP} \qquad \ldots(8.4).$$

Using statistical data from Section G.2, the plot of Figure 8.3 is now obtained; this suggests a positive relationship between CU and ABL' (thus confirming hypothesis H-1), for the whole American manufacturing sector, of

$$\Delta CU = \Delta ABL' \times (0.186 \pm 0.028) \qquad \ldots(8.5)$$

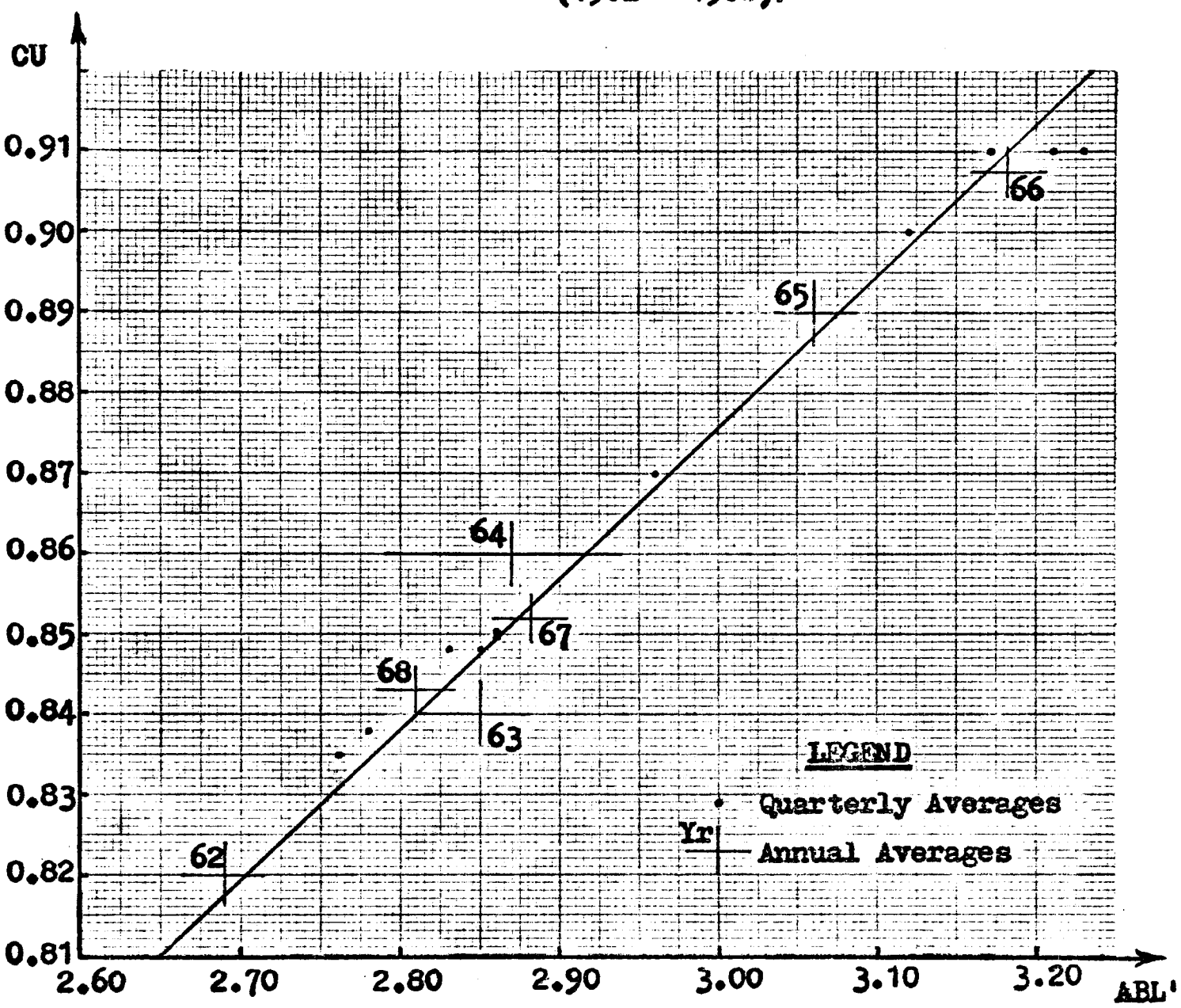
for the period from mid-1962 to the end of 1968.†

Equation 8.5 suggests that, with an increased absolute buffer length, a production manager should be able to manufacture at a higher level of capacity utilization since he would be operating in a slightly more certain environment. While the points plotted in Figure 8.3 are nearly linear, it is expected that there would be a "rounding off" so that increases in ABL' would lead to progressively smaller increases in CU; this is predicted by an approximate queuing theory model (Appendix F) and is expected on practical grounds, since constraints (of manpower, etc.) will reduce CU increases. For simplicity, the linear relationship of equation 8.5 will, however, be used here.

To determine what might be the benefit received as the result of an overall time saving, it is noted that the production

† Similarly sloped relationships are also found for the periods 1955 to 1961 and for 1969 to the present; it is observed that the fitted trend lines shift to the left, or alternatively shift upwards. This shift is not unexpected (Popkin, 1965), and might be explained as resulting from improvements in production techniques.

Figure 8.3: A Relationship Between CU and ABL' for American Manufacturing Industries (1962 - 1968).



Source: Table G.2

manager might expand his buffer into the removed excess delay time of delays adjacent to his operation; customers would receive the same service as before, but the buffer would be increased. This possibility is generalized as the second working hypothesis (H-2):

H-2 : An overall time saving may be used by an establishment to increase its absolute buffer length, without decreasing the level of service.

Since time is now being added to the buffer length, the buffer length must be expressed in temporal units. The "temporal buffer length" (TBL) is defined as

$$TBL \equiv \frac{UO}{S_A \times \rho} \qquad \ldots(8.6)$$

where S_A is the total rate of shipment for the manufacturing sector.

To change from ABL' to TBL, the conversion factor is

$$\Delta ABL' = \frac{S_A \times \rho}{WIP} \times \Delta TBL \qquad ...(8.7).$$

Since hypothesis H-1 is concerned with non-recession conditions, it is reasonable to attempt to quantify equation 8.7 for such conditions. The period from mid-1962 until early 1966 was a period of fairly constant growth of the American manufacturing sector; using the corresponding values of S_A (Table G.1) and WIP (Table G.2) gives the calculated average

$$\overline{S_A/WIP} = 1.96 \pm 0.01 \qquad ...(8.8).$$

Using this value with the $\bar{\alpha}_A$ (equation G.4) estimator of ρ gives the modified form of equation 8.5 as

$$\Delta CU = \Delta TBL \times (0.200 \pm 0.033) \qquad ...(8.9)$$

with ΔTBL being expressed in units of a month.

c) <u>The Value of an Increase in Capacity Utilization</u>

Equation 8.9 may be rewritten with "OTS in Months" replacing ΔTBL, following hypothesis H-2. Taking a month as 21 working days, this gives

$$\left[\begin{array}{c}\text{Increase in}\\ \text{Capacity Utilization}\end{array}\right] = \left[\begin{array}{c}\text{OTS in}\\ \text{Working Days}\end{array}\right] \times (0.0096 \pm 0.0016)$$

...(8.10).

It is now assumed that this equation may be applied to a typical British manufacturing establishment. To determine what might be the value of such an increase in capacity utilization, it is first assumed that the establishment is already manufacturing at the highest average manufacturing rate (MR) compatible with the uncertainty of order arrivals, of production delays and of the environment. This rate MR is taken to be a linear function of the product of CU and the total manufacturing capacity (Cap.), so that

$$MR \propto CU \times Cap. \qquad ...(8.11).$$

Since we shall be concerned with the fraction (F) of total capacity which is devoted to manufacturing items for which demand is unpredictable (and this will be discussed below), the corresponding fractional manufacturing rate (FMR = FxMR) is given by

$$FMR \propto CU \times C \qquad ...(8.12)$$

where C (= F x Cap.) is the corresponding fractional capacity.

Suppose now that the establishment is in a growth period, with a gradually rising new order rate; new investment is required to keep pace with this rising demand. If an OTS is received and used to lengthen the effective buffer length, it follows that the production manager may increase his average capacity utilization CU by the amount ΔCU. Since the longer production schedule also gives less fluctuation in capacity utilization, a higher manufacturing rate should be achievable with the same stock of capital plant. The increase in the fractional manufacturing rate from FMR to (FMR + ΔFMR) corresponds to an effective capacity increase of amount ΔC:

$$\frac{\Delta C}{C} = \frac{\Delta CU}{CU} \left(= \frac{\Delta FMR}{FMR} \right) \qquad \ldots(8.13).$$

This benefit is generalized as the third working hypothesis (H-3):

H-3 : In growth conditions, an establishment may use a capacity utilization increase to increase the manufacturing rate; this corresponds to an effective capacity increase.

Suppose however that the establishment is in a fairly steady market, with a fairly constant rate of new orders. In this case, the reduced fluctuations in capacity utilization enable the capital plant to be reduced (if this is possible), thus reducing the overcapacity of the establishment. The fractional capacity may now be reduced from C to (C - ΔC), with ΔC given by

$$\frac{\Delta C}{C} = \frac{\Delta CU}{CU + \Delta CU} \qquad \ldots(8.14).$$

This benefit is generalized as the fourth working hypothesis (H-4):

H-4 : In steady conditions, an establishment may use a capacity utilization increase to reduce its level of overcapacity.

Of course, if demand is moving downward, a different approach is required: in this case, an establishment should pass on an OTS to its customers in an attempt to improve its competitive position (Section 8.6).

Since the economy is in fact growing, equation 8.13 is appropriate; the relationship of this equation is of course very close to that of equation 8.14, especially for small ΔCU. From equations 8.3, 8.13 and 8.10,

$$\Delta C = C \times \left(\frac{\text{OTS in}}{\text{Working Days}} \right) \times (0.0116 \pm 0.0019) \qquad \ldots(8.15).$$

This equation is taken to quantify hypothesis H-3. For this equation to be applied to any particular establishment, it is necessary to

determine the fraction F which relates C to Cap. (Of course, to apply this methodology to an actual establishment, it would be necessary to derive the appropriate equations of the form of equations 8.3 and 8.10.)

An examination of Figure 8.1 indicates that F must be at least as great as ρ, for equation 8.10 is obviously applicable to that manufacturing capacity devoted to making goods to order. Equation 8.10 is not applicable to that capacity devoted to manufacturing stock items for which demand is fairly predictable: incoming orders for such goods are usually smoothed using a moving average, so that an element of prediction is included in the production schedule. An OTS is of little value (at least in the sense of equation 8.10) in this case. But with stock items for which demand is not really predictable, re-orders are not placed by the inventory section until the inventory level falls to the re-order level (Section 8.3.b). Since an OTS would now enable the re-order to be placed sooner, the backlog of inventory re-orders could be lengthened. Thus equation 8.10 would be applicable to a fraction f of the manufacturing capacity devoted to stock items. It is now possible to quantify the fraction F as

$$\rho \leq F = \rho + f(1 - \rho) \leq 1 \qquad \ldots(8.16).$$

Making the arbitrary estimate of f = 1/3 sets F = 0.7 and gives the lump sum benefit Δ_2 of

$$\Delta_2 = \left\{\begin{matrix}\text{Effective Capacity} \\ \text{Increase}\end{matrix}\right\} \approx \left\{\begin{matrix}\text{OTS in} \\ \text{Working Days}\end{matrix}\right\} \times \text{Cap.} \times 0.0081 \qquad \ldots(8.17).$$

This equation suggests that a manufacturer should be able to increase his effective manufacturing capacity by almost 1% for each working day's OTS received. As noted in Section 8.1, an OTS will build up in a transient manner; the only restriction on this rate of build-up is that the growth of benefits cannot be received faster than the establishment's rate of growth. Since the overall real growth of the economy is at 2-3% p.a., this constraint is unlikely to have any noticeable effect.

d) Time Savings and Uncertainty

A fundamental thesis of this chapter is that an overall time saving reduces uncertainty. To see how this might occur, it is noted that excess delay values (Figure 7.1) will have a probability

distribution about a mean value. Whatever this distribution may be, it is possible to choose some of its defining parameters to indicate the variation of actual values about the mean in terms of the "absolute uncertainty" and the "relative uncertainty" (Baird, 1962). Now when an OTS reduces an excess delay in a system, it is expected that the absolute uncertainty of the delay will be reduced, while the relative uncertainty will remain relatively constant. These two (equivalent) expectations are generalized in the fifth working hypothesis (H-5):

H-5 : When an overall time saving reduces an excess delay, the relative uncertainty of the delay time remains approximately constant.

It is really the reduction of absolute uncertainty which permits an establishment to increase its CU as suggested by equation 8.10; this uncertainty reduction also permits the inventory reductions described in Section 8.3 following. Since variations in delivery times should also be reduced in both of these cases, a benefit is also received by customers. The establishment concerned should thus receive a competitive advantage (Section 8.6).

8.3 Inventory Reductions

a) Introduction

Inventories are maintained in both predictable and unpredictable environments to uncouple the processes of customer ordering and of manufacturing. Since an overall time saving (OTS) will only produce the benefits to be considered below when there is unpredictability, it is necessary to examine how this arises.

In inventory operation the important forecasting period is the "procurement lead time" (pt), which is the time needed to make any current production or purchasing decisions effective. Since production and delivery times fluctuate, this lead time may be considered to be a random variable (with expected value PT). Further uncertainty is introduced by the randomness of customers' orders to the inventory; thus the daily demand (dd) is also taken to be a random variable (with expected value DD). The following discussion will make it apparent that these two sources of uncertainty make the whole operation of any real inventory highly probabalistic.

The approach of this section is one of comparative statics, in which it is assumed that inventories are initially at the lowest

possible levels compatible with the uncertainty of the environment. A comparison is then made with the new optimum situation after an OTS has been achieved; any further inventory reductions achieved may be attributed to the OTS.

To simplify the following analysis, and to make it widely applicable (to both of the basic types of inventory control: fixed re-order size and fixed re-order times), expected values will be used. The following characterization of parameters is used here: lower case letters indicate random variables; upper case letters indicate the corresponding expected values; a bar indicates the average value over time of expected values, and Greek letters indicate constants.

b) Basic Inventory Operation

The most common re-ordering system is that in which there is a fixed re-order (or replenishment order) size (Ω), with a variable interval (ct) between re-orders (Magee, 1958, p.44). The simplest case is shown (with expected values) in Figure 8.4a. Whenever the level of inventory on hand (ih) falls to the re-order level of inventory (Γ), a replenishment order is placed; at this re-order point in time (rt), the level of inventory on order and on hand (ioh) increases by an amount Ω. Since orders are filled from inventory at the rate dd, both ioh and ih fall at this rate. After a time equal to pt the replenishment order arrives, making ioh equal ih. The level of ih continues to fall at rate dd until it reaches the level Γ; the cycle then repeats, with cycle time ct.

The re-order level Γ is chosen to cover the expected demand (at rate DD) during the expected lead time PT. Since this lead time demand is a random variable, the inventory on hand when the procurement arrives is also a random variable. It is thus reasonable to have a safety stock (of expected value SS) to minimize costs of lost sales and/or back-orders. Thus

$$\Gamma = DD \times PT + SS \qquad \ldots(8.18).$$

The level of SS is governed by the lead time and the reliability of the forecast usage DD; the actual determination of SS involves balancing the costs of stock-holding with the likelihood of, and cost of, stock-out. Since Γ also depends upon this forecasting and balancing of costs, it may be rewritten as (Magee, 1958, pp. 70 ff):

$$\Gamma = MD \times PT \qquad \ldots(8.19)$$

where MD is the maximum expected rate of demand which might occur during the lead time PT.

Figure 8.4: Two Simple Inventory Situations.

Fig. 8.4a: $CT \geq PT$; $\theta \geq PT$

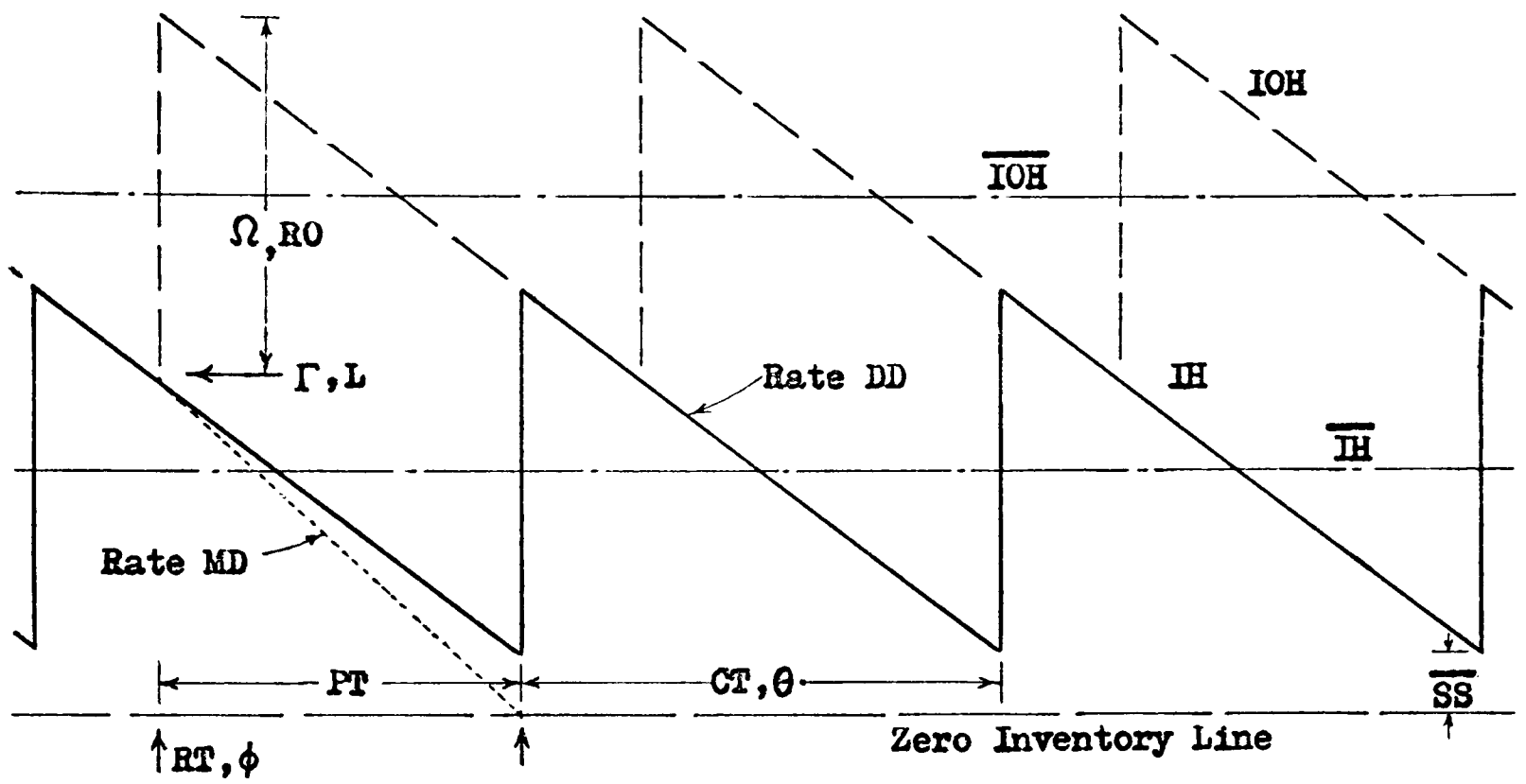
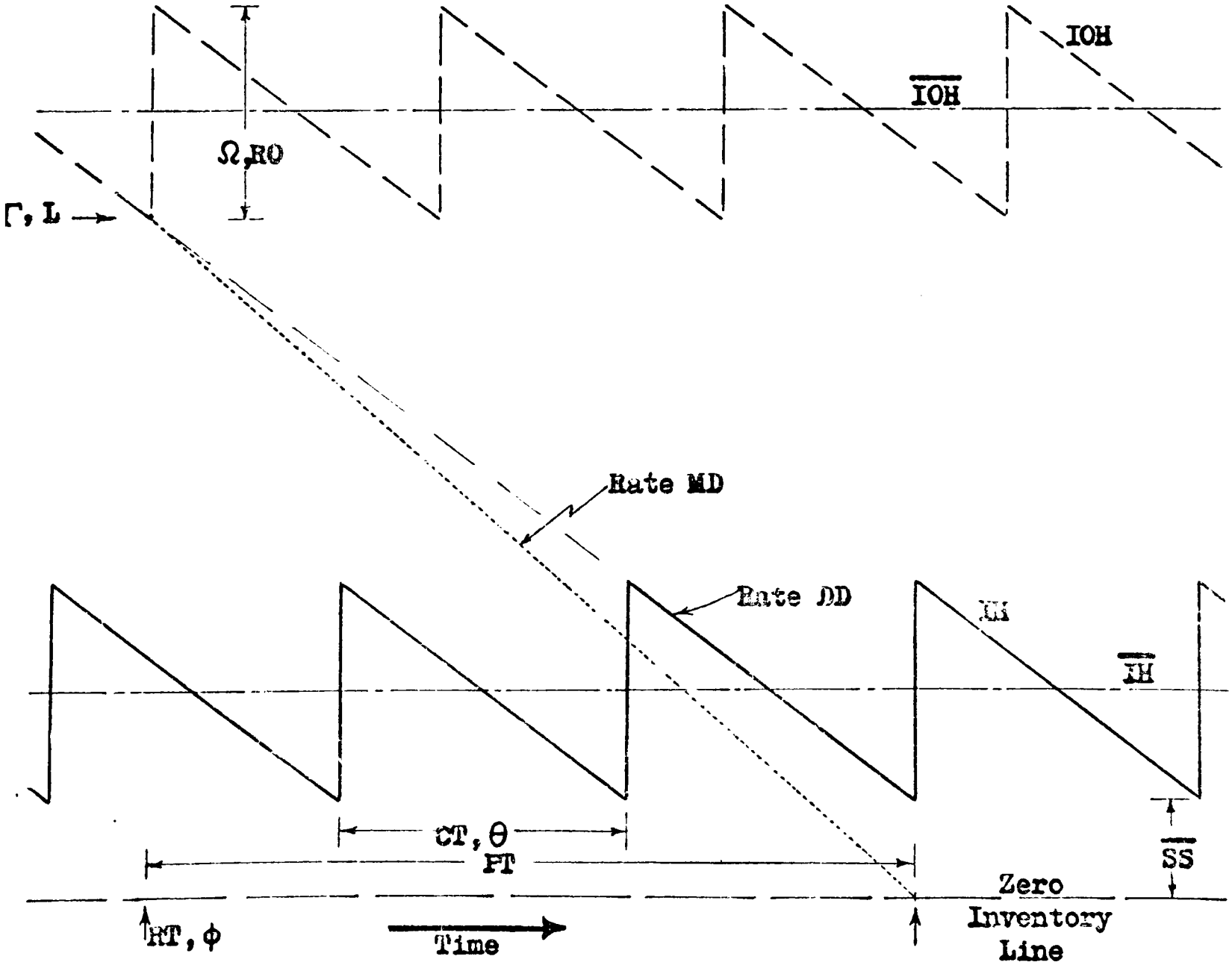


Fig. 8.4b: $PT > CT$; $PT > \theta$



Legend: See text.

The replenishment order size Ω is also determined by balancing costs, here the costs of ordering and of carrying inventory. From Figure 8.4a,

$$\Omega = ct \times dd = CT \times DD \qquad ...(8.20).$$

It is noted that although SS (= $\overline{SS}$) and Ω are independently derived, they are interrelated, since the size of Ω determines the frequency of exposure to the risk of stock-out. Thus a smaller Ω usually requires a larger SS.

From Figure 8.4a, the following averages are obtained. The average size of inventory on hand, $\overline{IH}$, is

$$\overline{IH} = \overline{SS} + \Omega/2 \qquad ...(8.21).$$

The average size of the inventory on hand and on order, $\overline{IOH}$, is

$$\overline{IOH} = \Gamma + \Omega/2 \qquad ...(8.22).$$

From equations 8.18, 8.21 and 8.22,

$$\overline{IOH} - \overline{IH} = DD \times PT \qquad ...(8.23).$$

Thus the average amount on order equals the expected lead time demand.

The use of Figure 8.4a has implied that CT $\geq$ PT; the possibility of PT > CT is also noted. For this case, typified by Figure 8.4b, it may be shown that equations 8.18 to 8.23 inclusive are all applicable.

Now equation 8.21 indicates the average size of inventory on hand, which gives the amount of money tied up. Since management obviously wants to reduce inventories, while maintaining the same level of service as before, it is instructive to examine how $\overline{IH}$ might be reduced. From equations 8.20 and 8.21,

$$\overline{IH} = \overline{SS} + \frac{DD \times CT}{2} \qquad ...(8.24).$$

This equation suggests that $\overline{IH}$ may be reduced by reducing either $\overline{SS}$ or CT (or, equivalently, Ω). Suppose that PT is already at its minimum value. (This constraint will be lifted in Section 8.3.c.) Then CT may be reduced by re-ordering a smaller quantity Ω more frequently; this has the effect of shrinking the size of the saw-teeth in Figure 8.4, until the minimum cost of operation situation is reached. The limiting minimum-Ω operation involves a transaction-reporting system in which a re-order is placed whenever an article is taken out of inventory; here the economic replenishment order size is just one unit and the average level of inventory on hand is really only

the safety stock level, since

$$\overline{IH} = \overline{SS} + \tfrac{1}{2} \underset{\sim}{\omega} \overline{SS} \qquad \ldots(8.25).$$

If Ω is already at its minimum economic size (determined by quantity discounts, minimum order quantities, etc.), it follows that the only way in which $\overline{IH}$ can be reduced is through reducing the safety stock level $\overline{SS}$. Means by which this may be achieved are discussed in following subsections.

We now examine the other basic type of inventory control: inventory systems with fixed re-order times. These systems are popular and are frequently used, especially with book inventory control and where it is convenient to examine inventory stocks over a fixed time cycle (Magee, 1958, pp. 78 ff).

Using expected values, Figure 8.4 may again be used to model the operation of this type of inventory system. Periodic reviews occur at fixed times (ϕ) separated by an interval equal to the constant cycle time (θ). At each of these review (or re-order times), the level ioh is compared with the expected level (L) of inventory, where L now replaces Γ in equation 8.19. A replenishment order of size ro is now placed to raise the level of the inventory on order and on hand to the level L plus a fixed amount RO. Thus

$$ro = (L + RO) - ioh \qquad \ldots(8.26).$$

Since the expected value of ioh is L, the expected value of ro is RO.

It is apparent that the equations and discussions given above for the fixed re-order size case apply equally well to this fixed re-order times case, with the following transformation required to change the constants of one case to the expected values of the other:

Ω	$\rightarrow$	ro, RO, or $\overline{RO}$ as required
ct or CT	$\rightarrow$	θ
Γ	$\rightarrow$	L
rt or RT	$\rightarrow$	ϕ

$\ldots(8.27).$

The actual operation of the fixed period inventory system obviously depends upon uncontrollable factors as well as upon controllable factors. Uncontrollable are the procurement lead time PT, the forecast usage or demand rate DD during this time, and the distribution of demand-forecast errors (which gives MD). Controllable are the cycle time or review period θ and the allowable risk of back-order or run-out (which decides what MD value will actually be used).

The average level of inventory on hand is still given by equation 8.24, though modified by equation 8.27. To reduce $\overline{IH}$, we are interested in reducing $\overline{SS}$: this is discussed in the following subsections. It is assumed that the cycle time θ is already at its minimum-cost value; this value will depend upon ordering costs (including clerical costs, communication costs, etc.), holding costs of inventory, and upon constraints (such as quantity discounts) affecting the choice of RO (= θ x DD). Now an OTS will obviously be of value if it enables the minimum-cost time θ to be reduced to a new minimum-cost value. (This might occur with a data network and computerized stock control.) With a reduced cycle time, the exposure of the inventory to stock-out is increased, so a slightly greater safety stock may be needed; nevertheless, the $\overline{IH}$ reduction resulting from the θ reduction should far overshadow this opposing effect. Thus, taking ΔSS to be positive, the reduction in $\overline{IH}$ is

$$\Delta\overline{IH} = \frac{DD}{2} \times OTS - \Delta SS \lesssim \frac{OTS}{2} \times DD \qquad \ldots(8.28).$$

This result is generalized as the sixth working hypothesis (H-6):

H-6 : An overall time saving of OTS in the cycle time permits a reduction in the average level of inventory on hand of about OTS/2 average days' sales.

It is noteworthy that the OTS which might be used here to evaluate national data network benefits is fairly small, since θ-OTS (or CT-OTS, since hypothesis H-6 applies to both types of inventory operation considered) must still be minimum-cost, and the ordering cost reduction resulting from data network usage is not expected to be too large.

c) Reduction in the Procurement Lead Time

As indicated in Section 8.3.a above, both PT and DD involve uncertainty since they are expected values of random variables. It is now suggested, following hypothesis H-5, that a reduction in the procurement lead time will also lead to a reduction in the uncertainty of this lead time. With less uncertainty the average level of the safety stock could be reduced.

The easiest way of considering these uncertainties graphically involves using the dotted line which indicates the maximum reasonable daily demand (at rate MD); the deviation of this line from the solid line indicating the expected daily demand (at rate DD) includes the effects of both uncertainties. (This is indicated in Figure 8.5, which is applicable to all types of inventory considered in Section 8.3.b

Figure 8.5: A Reduction in the Procurement Lead Time.

Fig. 8.5a: Situation Before.

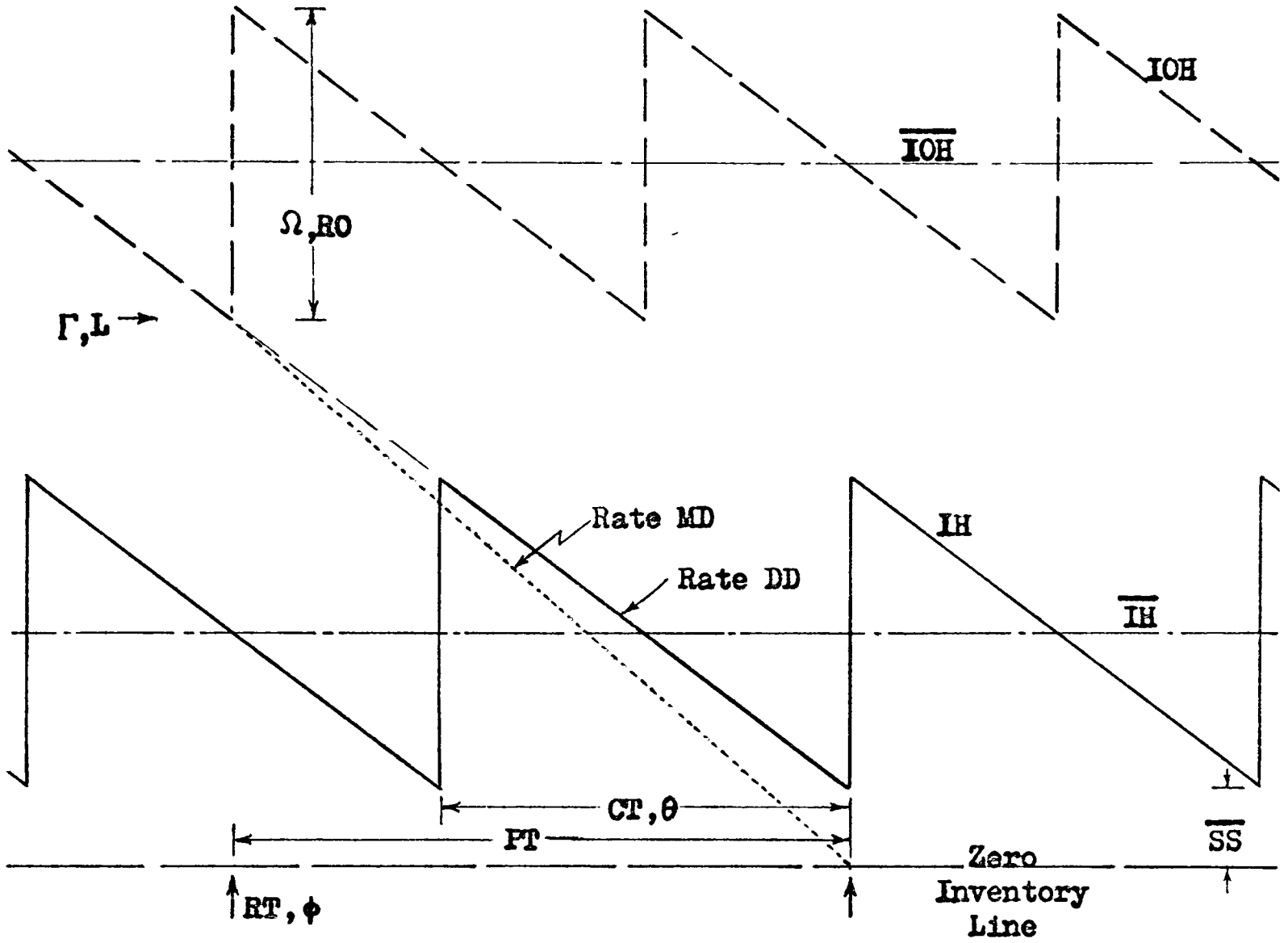
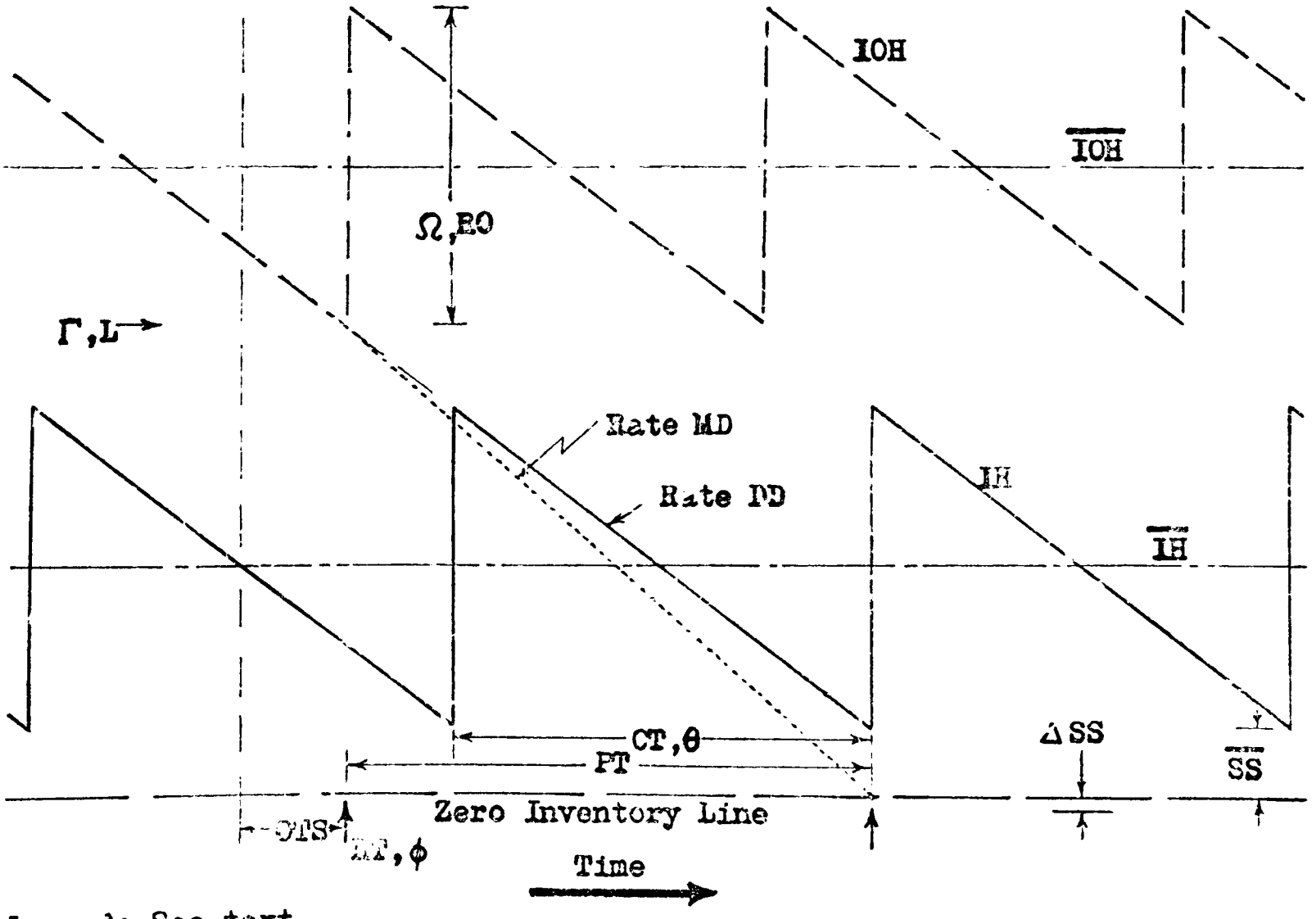


Figure 8.5b: Situation After Reduction by Time OTS.



Legend: See text.

above.) Since the procurement lead time PT gives the time needed to make re-ordering actions effective, the safety stock SS, of size

$$SS = PT \times (MD - DD) \qquad ...(8.29),$$

may be considered to protect the inventory-holder from stock-outs due to an unpredictable short-term increase in the order arrival rate. Such an increase is taken to be merely short-term; in the longer term both MD and DD (and their probability distributions) are assumed to remain unchanged.

We now consider Figure 8.5; the following analysis uses the terminology of the fixed re-order size case, but results are obviously convertible to the fixed re-order times case using the transformation of equation 8.27. The situation before an OTS is received is indicated by Figure 8.5a and is described in Section 8.3.b; Figure 8.5b indicates the result of reducing the procurement lead time from PT to (PT-OTS). It may be shown that the expected safety stock level is reduced from SS to SS - ΔSS, where (from equation 8.29)

$$\Delta SS = OTS \times (MD - DD) \qquad ...(8.30).$$

And defining MD with respect to DD as

$$MD \equiv \varepsilon \times DD \qquad ...(8.31)$$

where $\varepsilon > 1$

gives

$$\Delta SS = OTS \times DD \times (\varepsilon - 1) \qquad ...(8.32).$$

It follows that the mean level of inventory on hand $\overline{IH}$ is reduced by the same amount, so $\Delta\overline{IH} = \Delta SS$. This result is generalized as the seventh working hypothesis (H-7):

H-7 : An overall time saving of OTS in the procurement lead time permits a reduction in the average level of inventory on hand of about OTS x (ε - 1) average days' sales.

An approximate quantification of the lump sum benefit Δ_3 suggested by hypothesis H-7 may now be made. Suppose that P gives the annual amount of purchases (for a year of 250 working days) made by an establishment, so P = 250 x DD. It is arbitrarily assumed that

$$\varepsilon \approx 1.3 \qquad ...(8.33)$$

so that

$$\Delta_3 \approx 0.0012 \times OTS \times P \qquad ...(8.34).$$

It is also important to examine how the OTS affects the average level of inventory on order and on hand ($\overline{IOH}$), since management wants to minimize $\overline{IOH}$ as well as $\overline{IH}$. (This is particularly obvious in the case where money is actually sent with re-orders, and in highly volatile markets where the demand pattern could change radically.) From equations 8.18, 8.22 and 8.30, the possible reduction in $\overline{IOH}$ is

$$\Delta\overline{IOH} = DD \times OTS + \Delta SS = MD \times OTS \qquad ...(8.35).$$

d) Reduction in the Customer Order-Handling Time

Up to this point it has been assumed that customers' orders are filled immediately they are received. While this is true in most of the retail sector, in many other inventory operations there will be a delay of up to the expected customer service time (CST); all normal demand on a stock point should be filled within time CST of its receipt. Since the expected customer order-handling time (COT) only forms part of this delay, there is an expected allowable extra time (AET) of

$$AET \equiv CST - COT \geq 0 \qquad ...(8.36).$$

If CST = COT, then AET = 0 and we have the situation considered previously. But if AET > 0, then it can provide a buffer and make the inventory on hand effectively larger. This is noted when ih reaches the zero inventory line (ZIL). If AET is zero, customers' orders must be back-ordered (with their knowledge) or sales are lost; with a positive AET, customers' orders may be "internally" back-ordered within the AET, and if the replenishment order arrives within time AET, these orders may be filled satisfactorily without customers even knowing that their orders had been back-ordered. (Of course, if the replenishment order arrives later, orders must be back-ordered (with customers' knowledge) and sales may be lost; this loss of sales is, however, less likely than before since the existence of a non-zero AET suggests that some delay is acceptable.)

The situation considered is shown (with expected values) in Figure 8.6a. Since internal back-ordering of amount AET x MD is now allowed, it follows that the effective average level of inventory on hand, $\overline{IH}_e$, is larger than the actual average level $\overline{IH}$ by this same amount.

$$\overline{IH}_e = \overline{IH} + AET \times MD \qquad ...(8.37)$$

Figure 8.6: A Reduction in the Customer Order-Handling Time.

Fig. 8.6a: Situation Before.

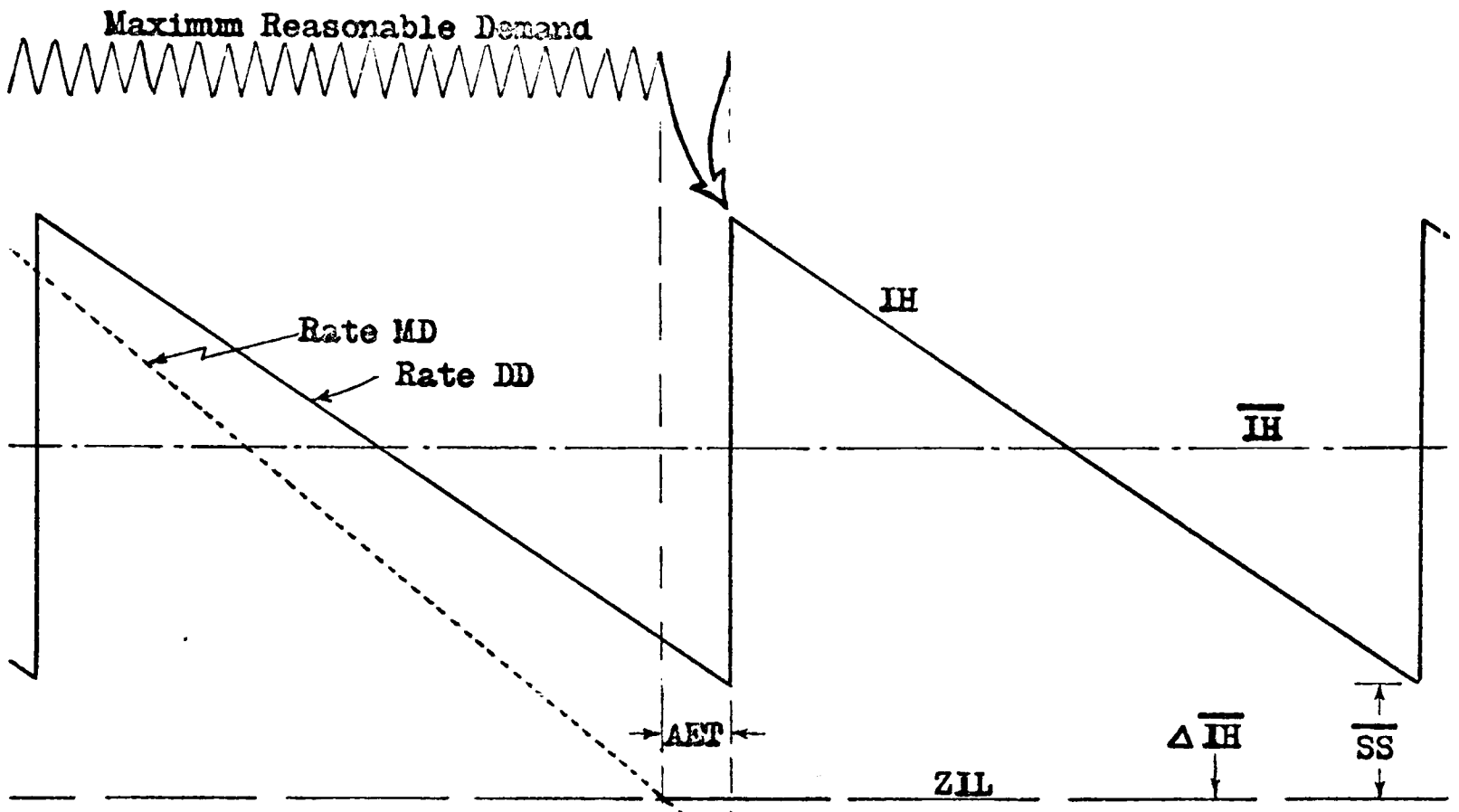
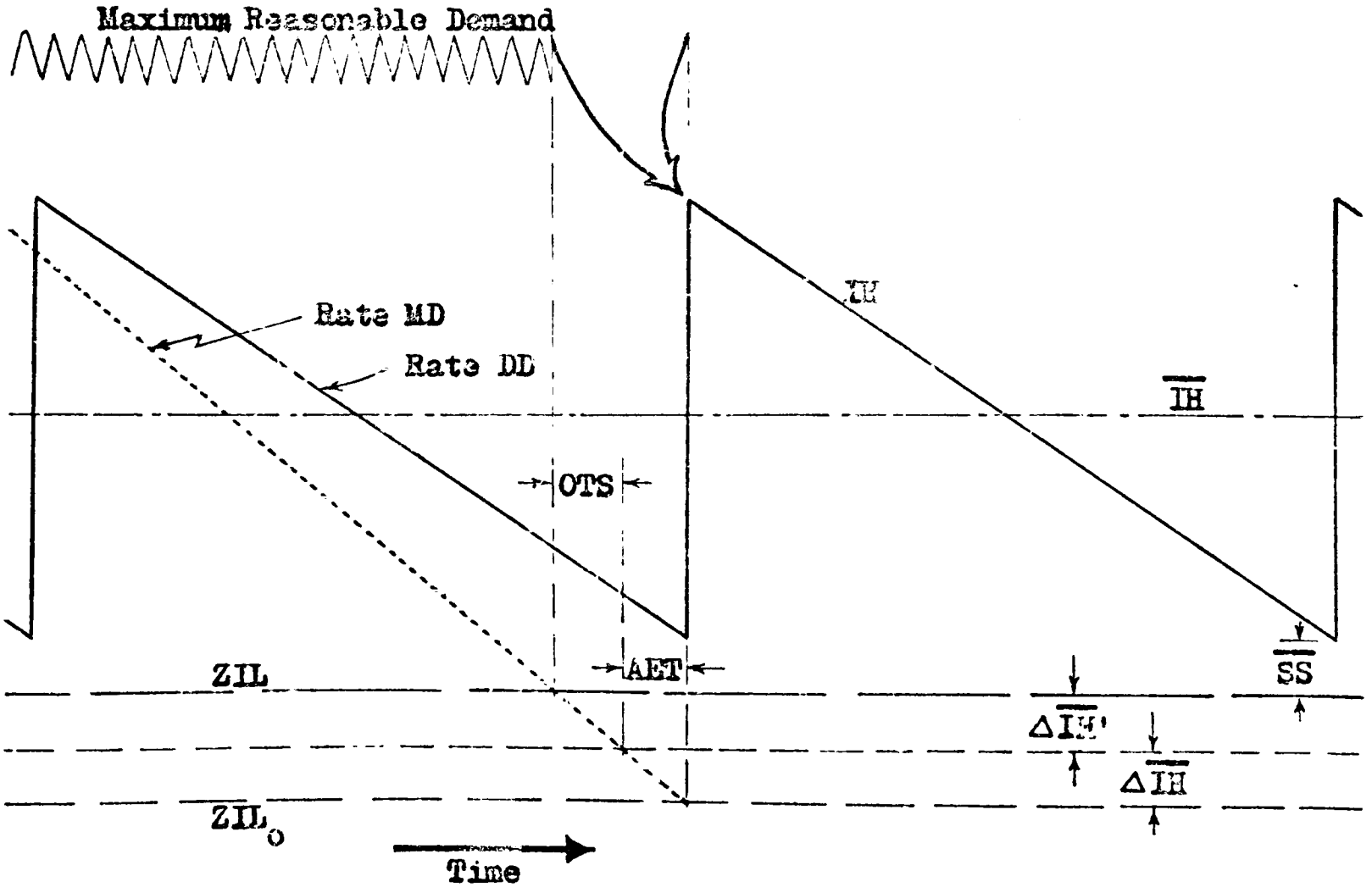


Fig. 8.6b: Situation After Reduction by Time OTS.



Legend: See text.

Since equation 8.21 gives the effective average inventory on hand required to offer a particular (and constant) grade of service to customers, it follows that the existence of a non-zero AET enables the actual average level to be reduced by $\Delta\overline{IH}$, where

$$\Delta\overline{IH} = AET \times MD \qquad ...(8.38).$$

The same reduction is noted in the average safety stock level, so $\Delta\overline{SS} = \Delta\overline{IH}$. These reductions are indicated in Figure 8.6a, where the zero inventory line has moved from its former position ZIL_o (for zero AET) to ZIL. It is noteworthy that the delay of (up to) AET occurs only for orders which arrive when there is a stock-out condition; otherwise, orders are filled in the order-handling time COT.

Suppose now that there is an OTS, either in COT or in an adjacent operation. Since CST is constant (for a constant grade of service to be offered), it follows from equation 8.36 that AET may be increased by an amount equal to OTS. (This expansion of the buffer AET is not unlike that suggested by hypothesis H-2.) It is now possible to reduce the actual average level of inventory on hand by the further amount

$$\Delta\overline{IH'} = OTS \times MD \qquad ...(8.39).$$

The safety stock and the average level of inventory on hand and on order are also reduced by this amount; this is the situation of Figure 8.6b.

While equation 8.39 gives the lump sum benefit received by an inventory-holder whose operation is as shown in Figure 8.6, a correction is required if the ZIL is moved to the extent that the IH is expected to fall beneath it once each cycle. In this case, a back-order time is expected in each cycle; before an OTS is obtained this back-order time is taken to be BOT_1, where

$$BOT_1 = \begin{cases} 0 & \text{if } AET \times MD \leq \overline{SS} \\ \dfrac{AET \times MD - \overline{SS}}{DD} & \text{if } AET \times MD > \overline{SS} \end{cases} \qquad ...(8.40).$$

Orders arriving during the period BOT_1 will not be shipped until an average time $BOT_1/2$ after their receipt; thus cash receipts for these orders are also delayed by an average time $BOT_1/2$. Following Section 8.4, the opportunity cost of delayed revenues in each cycle is

$$(\text{Opportunity Cost/Cycle}) = (DD \times BOT_1) \times \frac{BOT_1}{2} \times \frac{r}{365} \qquad ...(8.41)$$

where r is the prevailing annual interest rate.

Since there are 365/CT cycles per year (if CT is expressed in days), it may be shown that the net present value of the stream of opportunity costs given in equation 8.41, or the total opportunity cost TOC_1, is

$$TOC_1 = (DD \times BOT_1) \times \frac{BOT_1}{2CT} \qquad ...(8.42).$$

With an OTS, the inventory-holder may operate with a new back-order time BOT_2:

$$BOT_2 = \begin{cases} 0 & \text{if } (AET + OTS) \times MD \leq \overline{SS} \\ \dfrac{(AET + OTS) \times MD - \overline{SS}}{DD} & \text{if } (AET + OTS) \times MD > \overline{SS} \end{cases} \qquad ...(8.43).$$

The total opportunity cost is now TOC_2, defined as in equation 8.42. It now follows that the increase ΔTOC in total opportunity cost resulting from the OTS is

$$\Delta TOC = TOC_2 - TOC_1$$

$$= \frac{OTS \times MD}{2CT} \times (BOT_1 + BOT_2) \qquad ...(8.44).$$

Taken with equation 8.39, the total benefit to result from the OTS is

$$\left[\begin{matrix}\text{Total}\\ \text{Benefit}\end{matrix}\right] = (OTS \times MD)\left[1 - \frac{BOT_1 + BOT_2}{2CT}\right] \qquad ...(8.45)$$

$$\lesssim OTS \times MD$$

since $CT >> BOT_1$ or BOT_2 in the most usual situation. From equations 8.31 and 8.33 it is possible to make the approximation

$$\left[\begin{matrix}\text{Total}\\ \text{Benefit}\end{matrix}\right] \gtrsim OTS \times DD \qquad ...(8.46).$$

These last two results are generalized as the eighth working hypothesis (H-8):

H-8 : An overall time saving of OTS in the customer order-handling time (or in adjacent operations) gives a total benefit equivalent to at least OTS average days' sales.

An approximate quantification of the lump sum benefit Δ_4 suggested by hypothesis H-8 may now be made. Taking "Sales" as the annual amount of sales of stock items (for a 250 working day year), and assuming arbitrarily that a multiplicative factor of 1.2 applies in equation 8.46 (to reconcile equations 8.33 and 8.45), gives

$$\Delta_4 \gtrsim 1.2 \times OTS \times \frac{Sales}{250} = 0.0048 \times OTS \times Sales \qquad ...(8.47).$$

8.4 Earlier Receipt of Revenues

An overall time saving (OTS) may also be used by an establishment to speed up operations, so that the customer receives faster service. The customer obviously benefits; in addition, the establishment benefits since the revenue stream is advanced by time OTS. Taking expected daily revenues to be DD, this latter benefit is of magnitude DD x OTS. Thus

$$\text{(Total benefit)} = DD \times OTS \qquad \ldots(8.48).$$

It is of interest to examine how this usage of an OTS may benefit an inventory-holder. The cost stream (of periodic payments for replenishments) is assumed to remain unchanged, while the revenue stream (of payments from customers) is advanced by time OTS; this is achieved by reducing the customer order-handling time COT by OTS. In each cycle there is now a saving of

$$\text{(Saving/Cycle)} = \Omega \times OTS \times r/365 \qquad \ldots(8.49)$$

where r is the prevailing annual interest rate.

Since there are 365/CT cycles per year, the annual saving is

$$\text{(Saving/Year)} = \Omega \times OTS \times r/CT \qquad \ldots(8.50).$$

The net present value of this stream of annual savings is obviously the lump sum saving

$$\text{(Lump Sum Saving)} = \Omega \times OTS/CT = DD \times OTS \qquad \ldots(8.51).$$

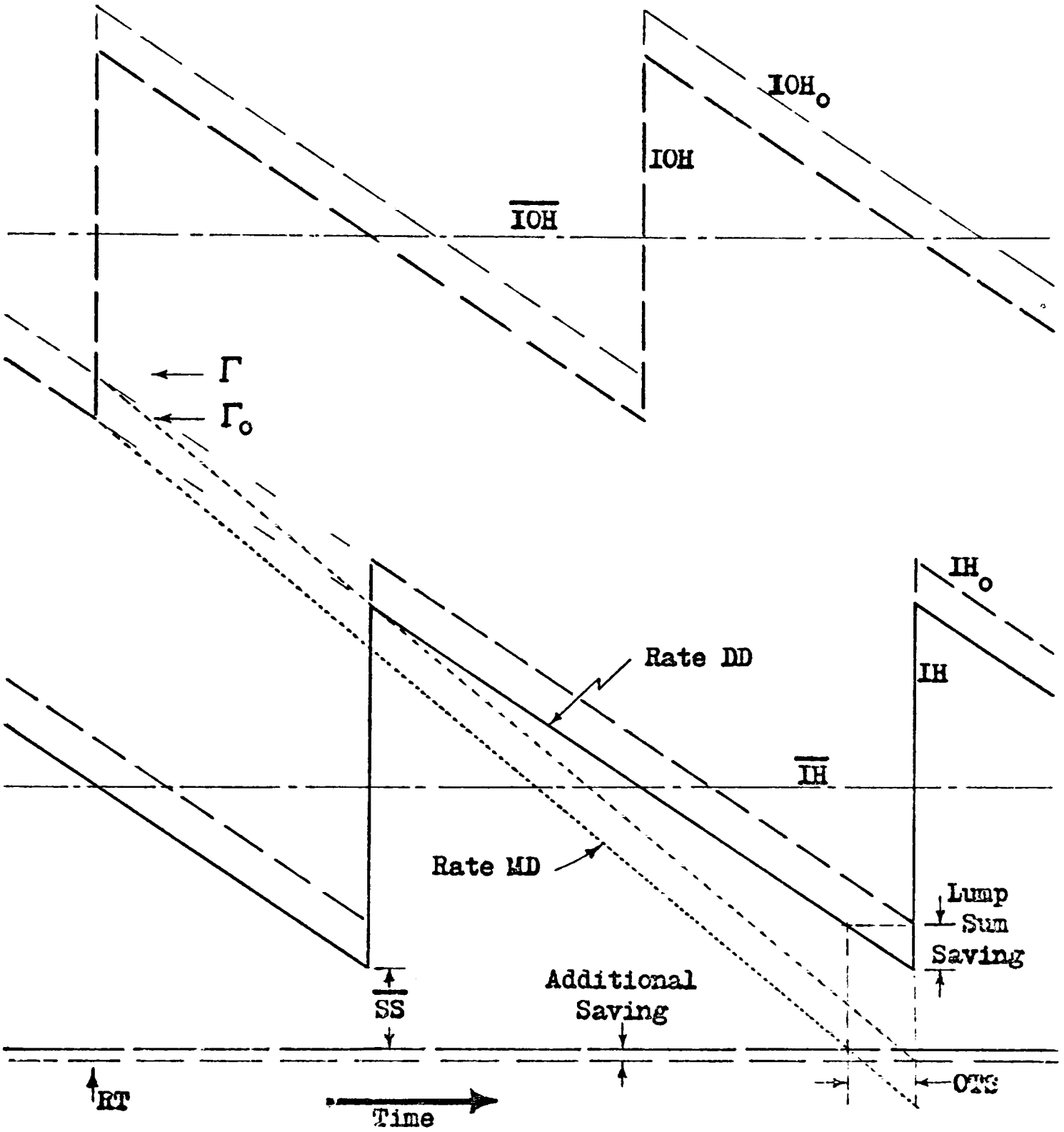
This saving, equal to that suggested by equation 8.48, is shown in Figure 8.7. The expected level of inventory on hand IH is lower than its former level by this amount; the new re-order level r, from which the forecast dotted line of maximum reasonable demand (at rate MD) is drawn, is also lower than its former level r_o by the same amount. This MD rate line cuts the old zero inventory line (ZIL_o) a time OTS x DD/MD before the procurement is expected.

Since internal back-ordering would be allowable within the whole of the time saving OTS, it follows that the zero inventory line may be raised (as shown in Figure 8.7), giving an additional saving since IH and SS may be further reduced.

$$\text{(Additional Saving)} = OTS \times (MD - DD) \qquad \ldots(8.52)$$

From equations 8.51 and 8.52, the total saving available as a result

Figure 8.7: Alternative Approach to Considering a Reduction in the Customer Order-Handling Time.



Legend: See text.

of an OTS is

$$\text{(Total Saving)} = \text{OTS} \times \text{MD} \qquad \ldots(8.53).$$

This saving, indicating the reduction made in $\overline{IOH}$, $\overline{IH}$ and $\overline{SS}$, corresponds to the result of equation 8.39. (Obviously, if IH crosses the ZIL, then the correction of equation 8.44, with AET = 0 in this case, must also be made.)

The results of equations 8.48 and 8.53 may be generalized as the ninth working hypothesis (H-9):

H-9 : An overall time saving of OTS used to advance a revenue stream gives a total saving of at least OTS average days' revenues.

Following equation 8.48, this hypothesis is quantified as the lump sum benefit Δ_5:

$$\Delta_5 \approx \text{OTS} \times \frac{\text{Revenues}}{250} = 0.004 \times \text{Revenues} \qquad \ldots(8.54)$$

where "Revenues" are for a year of 250 working days.

8.5 Improved Control

It is not unreasonable to suggest that *control* forms the basis of all of a firm's activities (Hodge & Hodgson 1969, Chapter 6). Visualizing a firm as a series of control loops (Forrester, 1961, pp. 61 ff), it is apparent that an overall time saving in any of these loops should enable the decision-maker to exert an improved form of control since decisions would be based upon more timely information (Bonney, 1969, p.122). This improvement will be particularly important in operational areas of unpredictability.

With a national data network, present communications links could be improved and new (control) links could be created, making possible real-time control of all operations; the benefits which might result from such control could be immense (Willis, 1969, p.16).

While improved control is certainly beneficial (since some now-existing uncertainty would be eliminated), it is almost impossible to quantify this benefit in general, although particular cases may obviously be examined in detail (Ensor, 1970). The tenth working hypothesis (H-10) thus takes the general form:

H-10 : An overall time saving, usually resulting from improved communications, can be used by a firm to secure improved control of its activities.

8.6 Improved Competitive Position

The total social benefit arising from an overall time saving may be defined as

$$\begin{pmatrix}\text{Total Social}\\ \text{Benefit}\end{pmatrix} = \begin{pmatrix}\text{Suppliers'}\\ \text{Benefit}\end{pmatrix} + \begin{pmatrix}\text{Customers'}\\ \text{Benefit}\end{pmatrix} + \begin{pmatrix}\text{Residue}\\ \text{Benefit}\end{pmatrix} \qquad \ldots(8.55).$$

Previous sections have modelled situations in which the suppliers' (manufacturers' and inventory-holders') benefit may be quantified; this section examines the customers' benefit. It was suggested in Section 8.4 that a customer also benefits when a supplier benefits, since the service offered is more reliable. It is fairly obvious

that, when a customer receives the benefits of faster and more reliable delivery (whether resulting from his own OTS or from a supplier's OTS), this will also benefit the supplier concerned since his competitive position is improved (N.E.D.O., 1969).

The competitive advantage which thus arises is really unquantifiable in general, since its quantification depends upon the market structure for any particular case, and must be considered dynamically: the dynamic responses of customers and competitors to any change must be included. While the examination of particular cases is of value in their own context (Keefer, 1969c), a more general approach is required here.

Since a customer is really interested in the "delivered price" of goods, rather than in the f.o.b. price (N.E.D.O., 1968), it is possible to write the actual cost of goods to a customer as

$$(\text{Actual Cost}) = (\text{Price}) + (\text{Delay Cost}) \qquad \ldots(8.56)$$

where the delay cost is a weighted function of the expected (or quoted) delivery delay and of the probability that the delivery delay will be excessive (i.e. that it will exceed some predetermined value). Thus

$$\begin{bmatrix}\text{Delay}\\ \text{Cost}\end{bmatrix} = W_1 \times \begin{bmatrix}\text{Expected}\\ \text{Delay}\end{bmatrix} + W_2 \times \begin{bmatrix}\text{Probability of}\\ \text{Excessive Delay}\end{bmatrix} \qquad \ldots(8.57)$$

where W_1 and W_2 are appropriate weights. The "competitive costing" (CC) of a supplier may now be defined as a function of this delay cost. CC may be taken as a measure of a supplier's competitiveness; a low value of CC (relative to the CC values of other suppliers in a market) corresponds to rapid and reliable delivery. Since an OTS should reduce both delay times and their expected variability (hypothesis H-5), it should also reduce a supplier's CC. Such a reduction would give a supplier a (relative) competitive advantage (albeit only a marginal one) over the others in his market.

Within Britain it is expected that such relative competitive advantages, resulting from national data network usage, would only be temporary (Section 8.1), since competitors could also join the network and "even the score"; indeed, this competitive jockeying (for increased market shares) will probably be largely responsible for the (transitional) build-up of network usage. When Britain is considered as an exporter in the world market, however, the national data network could be viewed as an internal improvement in communications

facilities. Since British exporters could now have better control (Section 8.5) of order-handling operations, they could be expected to gain a considerable absolute competitive advantage (N.E.D.O., 1968, p.4). The possible importance of this at the national level can scarcely be over-emphasized (Section E.1).

Since a benefit (or surplus) is received by both suppliers and customers, it is of interest to examine just how the total social benefit involved might be distributed between these two groups. Chapter 9 provides an estimated quantification of the macro-economic social benefit to result from an OTS; Section 9.3 suggests that the actual distribution of benefits will depend upon both customers' and suppliers' evaluation of an OTS and upon the market structure. Vigorous competition may be expected to ensue, as suggested by the eleventh working hypothesis (H-11):

H-11 : Suppliers and customers will each strive for that distribution of benefits which maximizes their own net benefit (or surplus).

8.7 Conclusion

This chapter has provided several models which describe how an overall time saving might benefit an establishment. While some of these models (Sections 8.5 and 8.6) are only qualitative, the other models are quantitative; these latter models are applied at the macro-level in the following chapter, and at the micro-level in Chapter 10, in an attempt to estimate the benefits to society of an OTS resulting from the introduction of a national data network.

This estimate will in fact apply only to the business sector; as noted in Section 7.1, the domestic sector is excluded from consideration, since domestic usage of a national data network would involve second order benefits. While the above sections have referred to manufacturers and inventory-holders, it is fairly obvious that the benefits considered will also apply to establishments (of the "service industries") which might be termed "information-handlers": insurance, banking, finance, business services, etc. (The overall importance of information-handling is suggested by Appendix H.) An OTS should permit such establishments to reduce personnel or to increase the through-put of existing personnel, since efficiency of operation could be increased (following the conclusions of Section 8.2); this usage of an OTS corresponds to a reduction in the manpower constraint. Alternatively, an OTS could be used to carry out work faster, and

thus advance the revenue stream; this benefit is discussed in Section 8.4.

The models of this chapter attempt to quantify the benefits which might result from an OTS, particularly from an OTS attributable to national data network usage. It must be emphasized that these models make no claim to be exclusive: there may well be other benefits available. What is given here, and indeed throughout this thesis, is a new methodological framework within which all of these benefits might be incorporated.

CHAPTER 9 : QUANTIFIABLE MACRO-ECONOMIC BENEFITS OF OVERALL TIME SAVINGS RESULTING FROM A NATIONAL DATA NETWORK

9.1 Introduction

It is assumed (Section 7.3) that the real benefit of a national data network will be the reduction of the time constraint that its usage can give; it is further assumed (Section 8.1) that a typical establishment using the network could receive an overall time saving (OTS) of about four working days.

Since the build-up of network usage, and thus the build-up of the total social benefit, may both be considered as long-term transient phenomena, it is of interest to examine the limit lines which these transients approach: this chapter is concerned with obtaining macro-economic (first approximation) 1970 estimates of the total social benefit - the latter limit line. A conservative approach is taken of aggregating only the quantifiable benefits of an OTS described in the previous chapter. These benefits, which are linearly dependent upon OTS (although a correction could be incorporated to account for the "rounding off" of equations 8.5 and 8.45), may be added to give an equation which relates the total social benefit (for suppliers) to an average OTS; this equation is extended to the whole economy in Section 9.3. The other limit line - that of network usage - is considered in Chapter 10.

9.2 The Problem of Instability

While Chapter 8 has suggested that the introduction of a number of OTS's into an economic system should lead to numerous benefits, the possibility that the reduction of "slack" (Section 9.5.b) in the system could lead to instability must also be examined; at the macro-economic level, an attempt to achieve growth might lead to instability as business cycles were accentuated (Brooman, 1967, Chapters 11 and 12; Allen, 1968). This possibility arises from the fact that the dynamic behaviour of a complex economic system depends critically upon the time-lags within the system (Forrester, 1961).

Certainly a complete removal of slack from a system would make the system totally unstable, so that the slightest disturbance could cause chaos. A certain amount of slack is thus required to uncouple various operations; this "buffering" action is achieved by order backlogs,

inventories, etc. (Thus, contrary to Gomersall (1964), a certain amount of work in progress is needed to smooth operations.) In the simple model of Figure 7.1 this controllable buffering slack is already included as part of the flow and operation times; OTS's are taken (in Sections 7.3, 8.1 etc.) to reduce the uncontrollable slack of excess delays.

Whether this excess delay reduction (of size OTS) is passed on to the customer or is maintained within the establishment (to increase the buffer length), it is made controllable; thus there is a reduction in uncertainty (hypothesis H-5). There is certainly no reason to presume that there would be an accompanying increase in instability.

If the OTS results from an improvement in telecommunication facilities (such as the introduction of a national data network), there will be an additional stabilizing influence: the increased information flows should provide numerous stabilizing informational short-circuits in the system. Fluctuations over time and between markets in the economy are obviously wasteful since they introduce an element of uncertainty and since they indicate a non-optimal allocation of resources. If these fluctuations can be reduced, through an arbitrage process (Keefer, 1969b) facilitated by increased (and faster) information flows, it follows that the operation of the economy should be stabilized; this corresponds to a considerable social benefit.

It thus appears that a limited OTS (which is used to reduce excess delays) should lead to considerable benefits without increasing economic instability; indeed, the economy might well be stabilized. And this should be especially true if the OTS results from improved telecommunication facilities.

9.3 The Transferability of Social Benefits

In Section 9.1 it is suggested that the equations of Chapter 8 may be applied at the macro-economic level to estimate the supplier's total benefit from an OTS. But, following equation 8.55, the real interest of this chapter lies in assessing the total social benefit which might result. Neglecting the (assumed constant and unquantifiable) residue of equation 8.55, that equation may be rewritten in terms of the direct social benefit (DSB), with

$$DSB = V_s(t_o) + V_c(t_o) \qquad \ldots(9.1)$$

where $$V_s(t_o) = \int_0^{t_o} v_s(t)\, dt$$

and

$$V_c(t_o) = \int_0^{OTS-t_o} v_c(t)\, dt \qquad \ldots(9.2).$$

Here benefits are taken as the total value of time to suppliers, $V_s(t_o)$, and to customers, $V_c(t_o)$; thus only the benefits of an OTS, which is divided between suppliers and customers at the division point t_o, are examined at this stage. While the equations of Chapter 8 are linear, it is more realistic to take both $V_s(t)$ and $V_c(t)$ to be decreasing functions of t; thus the "valuation of time" functions $v_s(t)$ and $v_c(t)$ are also decreasing functions of t.

If the marginal time valuations $v_s(t_o)$ and $v_c(OTS-t_o)$ are equal, then DSB is maximized; since the costs of providing the OTS are assumed to be fairly constant, it follows that maximizing DSB corresponds to a maximization of the net social benefit, or social surplus. Thus the social optimum (Foster, 1960) is obtained when

$$v_s(t_o) = v_c(OTS-t_o) \qquad \ldots(9.3).$$

If this equation does not hold, then a greater DSB can be obtained by changing the distribution of time between supplier and customer towards this social optimum. (It is apparent that DSB is *not* a constant quantity.)

The actual distribution of an OTS will be determined by vigorous competition between suppliers and customers. Since suppliers usually have the stronger hand (due to monopolies, oligopolistic agreements, restrictive practices, etc.), it may be expected that the social optimum will not be attained; this is because suppliers will overvalue their own time and undervalue that of their customers, so that at the division point

$$v_s(t) \Big|_{\text{according to supplier}}^{\text{division point}} \gtrsim v_s(t) \Big|_{\text{actual}}^{\text{division point}}$$

and

$$v_c(t) \Big|_{\text{according to supplier}}^{\text{division point}} \lesssim v_c(t) \Big|_{\text{actual}}^{\text{division point}}$$

$\ldots(9.4).$

Recognizing the competitive importance (Section 8.6) of offering benefits to customers, competitive suppliers should attempt to operate at what they consider to be the social optimum, where

$$v_s(t)\Big|_{\text{according to supplier}}^{\text{division point}} = v_c(t)\Big|_{\text{according to supplier}}^{\text{division point}} \qquad \ldots(9.5).$$

This attempted optimization will be made (possibly unconsciously) in choosing optimum capacity utilizations, inventory levels, etc.

From equations 9.4 and 9.5 it follows that a likely situation will have

$$v_c(t)\Big|_{\text{actual}}^{\text{division point}} \gtrsim v_s(t)\Big|_{\text{actual}}^{\text{division point}} \qquad \ldots(9.6).$$

Thus the use of "benefits to suppliers resulting from an OTS" to estimate the "benefits to customers resulting from an OTS" will lead to underestimation.

The direct estimation of customers' benefits from an OTS (or, equivalently, of $v_c(t)$) is of course very difficult. It is now suggested that a possible indirect estimation could be achieved by assuming that the customers' benefits could be (conceptually) transferred to the suppliers by transferring the customers' share of an OTS to the suppliers. (From Section 8.1, this transferred OTS should be at least one working day, and it might be up to 4 working days if customers are also establishments.) According to equation 9.6, this approach would lead to an underestimate of customers' benefits and thus of the total direct social benefit DSB. But since the case for a national data network is presented conservatively throughout this thesis, this is perfectly acceptable.

9.4 Quantification According to the Models Developed

a. An Effective Increase in Manufacturing Capacity

Section 8.2 indicates that manufacturers may use an OTS to obtain an effective capacity (or capital plant) increase. Using the Cap. value of equation G.7 (for the whole British manufacturing sector) in equation 8.17 gives the lump sum benefit

$$\Delta_2 = \left[\begin{array}{c}\text{Effective Capacity}\\ \text{Increase}\end{array}\right] = \left[\begin{array}{l}\text{OTS in}\\ \text{Working Days}\end{array}\right] \times \pounds(0.191 \pm 0.059) \times 10^9 \qquad \ldots(9.7)$$

where the uncertainty range includes the uncertainty of equation 8.15 with that of a ± 0.1 range about the F value of 0.7 used in deriving equation 8.17. Equation 9.7 (which is plotted in Figure 9.1 without uncertainty) suggests that each working day's OTS corresponds to an effective increase in capital stock of some £190 million; with an average OTS of about 4 working days (Section 9.1), national data network usage could lead to an effective capital stock increase of about £760 million for manufacturers. And following the approach of Section 9.3, the social benefit to customers (who are assumed to receive an OTS of about two working days) should be about £380 million.

The corresponding increase in the fractional manufacturing rate (ΔFMR) may be obtained using the equation (from equations 8.12, 8.13 and 8.15)

$$\Delta FMR = F \times MR \times \begin{pmatrix} \text{OTS in} \\ \text{Working Days} \end{pmatrix} \times (0.0116 \pm 0.0019) \qquad \ldots(9.8).$$

With F = 0.7 ± 0.1, and with MR taken to be the contribution of the manufacturing sector to the G.D.P. (equation G.9),

$$\Delta FMR = \begin{pmatrix} \text{OTS in} \\ \text{Working Days} \end{pmatrix} \times £(0.115 \pm 0.035) \times 10^9/\text{year} \qquad \ldots(9.9).$$

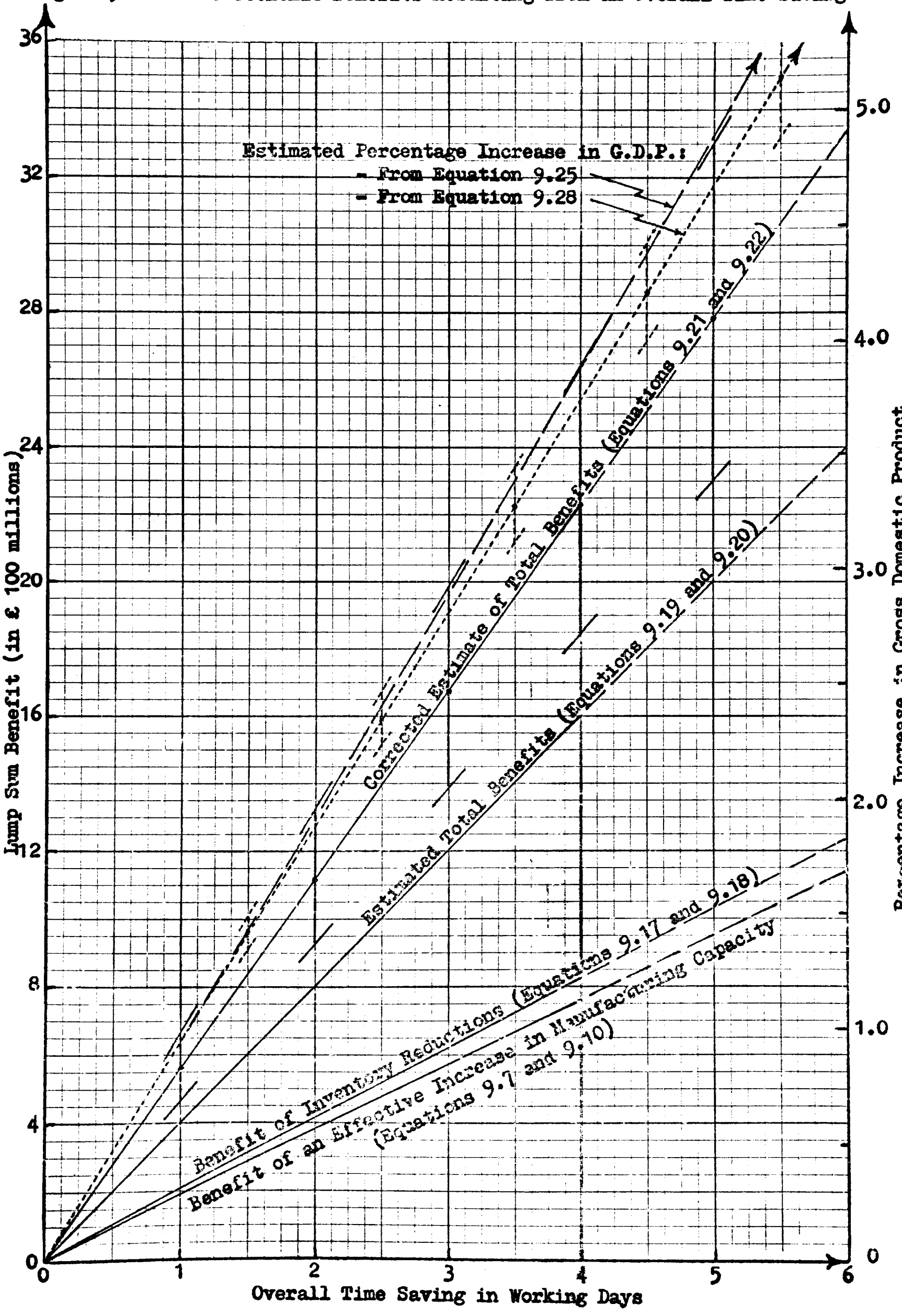
Thus each working day's OTS corresponds to an increase in manufacturing output of about £115 million each year. With net profits running at about 10% of output (C.S.O., 1969a, p.39), this corresponds to an increased profit of some £11.4 million each year.

Using equation G.8, equation 9.9 may be converted to give an indication of the percentage increase in G.D.P. made available by an OTS used to increase the effective capacity utilization of manufacturers.

$$\frac{\Delta G.D.P.}{G.D.P.} \times 100\ \% = \begin{pmatrix} \text{OTS in} \\ \text{Working Days} \end{pmatrix} \times (0.281 \pm 0.086)\% \qquad \ldots(9.10)$$

This equation (which is plotted in Figure 9.1 without uncertainty) suggests that each working day's OTS used to increase manufacturing capacity will increase the G.D.P. by over $\frac{1}{4}$%; a four working day OTS will increase the G.D.P. by 1.1%, and the customers' social benefit of two working days OTS corresponds to a further increase of over $\frac{1}{2}$%.

Figure 9.1: Macro-economic Benefits Resulting from an Overall Time Saving.



Of course, the actual capital stock would remain constant, although equation 9.7 indicates that it would effectively be increased. Thus the OTS resulting from national data network usage may be taken as an index of "capital-augmenting technical progress" (Allen, 1968). Equations 9.8 and 9.9 indicate that the increase in capacity utilization which resulted from the OTS corresponds to an increase in the output-capital ratio (which is the inverse of the ordinary capital-output ratio).

b. Inventory Reductions

Section 8.3 indicates that inventory-holders may use an OTS to reduce their average inventory levels; these reductions relate to manufacturing stocks of materials, stores and fuel (M,S&F) and of finished goods (FG), as well as to wholesale and retail stocks. They do not apply to work in progress, although the increased certainty accompanying an OTS (hypothesis H-5) might enable this to be reduced as well.

Equation G.11 suggests that the 1970 (end-of-year) book value of all British stocks, excluding work in progress, is about £12.6 x 10^9. To determine what inventory reductions might be possible, a generalized approach is made. Equation 8.34 gives the possible inventory reduction Δ_3 made available by a reduction in the procurement lead time; this equation may be applied to purchased stocks (PStock), giving the proportional inventory reduction

$$\frac{\Delta_3}{\text{PStock}} = 0.0012 \times \text{OTS} \times \frac{\text{P}}{\text{PStock}} \qquad \ldots(9.11).$$

Equation 8.47 gives the possible inventory reduction Δ_4 made available by a reduction in the procurement lead time; this equation is not applied at wholesale or retail levels (where immediate filling of orders is expected), although it may be applied to stocks of manufactured finished goods (FG), giving the proportional inventory reduction

$$\frac{\Delta_4}{\text{FG}} = 0.0048 \times \text{OTS} \times \frac{\text{Sales}}{\text{FG}} \qquad \ldots(9.12).$$

For these two equations to be applied to particular inventory stocks, it is necessary to calculate the ratios P/Stock and Sales/FG;

the former ratio is calculated in Table 9.1.

Table 9.1 : Calculating the Ratio P/Stock.

Industry	Year	Reference	End-of-Year Stocks PStock (£m)	Purchases P (£m)	Ratio: $\frac{P}{PStock}$
Mining and quarrying (other than coal mining)	1963	Table G.12	7.1	47.0	6.62
All Manufacturing	1963	Table G.10	2,159	14,876	6.88
Construction	1963	Table G.12	128.4	1,269	9.88
Wholesale Businesses Trading with Stock	1965	Table G.17	1,119	10,845	9.68
All Retail Trade (Ratio estimates)	1966	Table G.14	1,271	8,599	6.77

Assuming that these P/PStock ratios may be applied to other years than those for which they were derived (since the stock/output ratios remain roughly constant over time (Economic Trends, 1969)), a weighted average value may be obtained by weighting the calculated values of Table 9.1 with the appropriate end-of-1968 stocks (from Table G.8). Thus

$$\left.\frac{P}{PStock}\right|_{\text{weighted average}} \approx 9.17 \pm 0.50 \qquad \ldots(9.13).$$

An estimate of the ratio Sales/FG may be determined directly from Table G.10 and equation G.4, taking "Sales" of finished goods (or stock items) as the product of the fraction $(1-\bar{\alpha}_A)$ of manufacturing capacity devoted to stock items and the value of "goods produced and work done". Thus

$$\frac{Sales}{FG} \approx 8.12 \pm 0.08 \qquad \ldots(9.14).$$

Equations 9.11 and 9.12 now become

$$\frac{\Delta_3}{PStock} \approx OTS \times (0.0110 \pm 0.0006) \qquad \ldots(9.15)$$

and

$$\frac{\Delta_4}{FG} \approx OTS \times (0.0390 \pm 0.0004) \qquad \ldots(9.16).$$

It is now assumed that these equations may be applied to the £12.6 x 10^9 total stock; equation 9.16 is applied to that part

($\sim$£2.43 x 10^9) which refers to manufacturing FG, while equation 9.15 is taken to apply to the remainder of the total stock. The estimate of the total inventory reduction lump sum benefit is

$$\Delta_3 + \Delta_4 = \left\{\begin{matrix}\text{Total Inventory} \\ \text{Reduction}\end{matrix}\right\} = \left\{\begin{matrix}\text{OTS in} \\ \text{Working Days}\end{matrix}\right\} \times £(0.206 \pm 0.010) \times 10^9 \quad \ldots(9.17).$$

This equation (which is plotted without uncertainty in Figure 9.1) suggests that each working day's OTS corresponds to a reduction in average inventory levels of some £210 million; a 4 working day OTS (from national data network usage) corresponds to a saving of about £820 million for inventory-holders, and the social benefit of customers receiving a 2 working day OTS is about £410 million. It is noteworthy that this latter figure is of the same order as that suggested in Section 9.4.a.

Assuming that the capital released from being tied up in inventory may be used effectively by the inventory-holder in such a manner that the G.D.P. is increased by an amount proportional to that suggested by equation 9.10, the percentage increase in G.D.P. made available by an OTS used to reduce inventories is

$$\frac{\Delta G.D.P.}{G.D.P.} \times 100\% = \left\{\begin{matrix}\text{OTS in} \\ \text{Working Days}\end{matrix}\right\} \times (0.303 \pm 0.015)\% \quad \ldots(9.18).$$

This equation (which is plotted without uncertainty in Figure G.1) suggests that each working day's OTS used to reduce inventories will increase the G.D.P. by almost $\frac{1}{3}$%; this is of the same order as that suggested by equation 9.10.

c. Total First Order Macro-economic Benefits

The first order macro-economic benefits calculated in the previous two subsections may now be totalled, giving estimates of the total lump sum benefit available,

$$\left\{\begin{matrix}\text{Estimated Total} \\ \text{Lump Sum Benefit}\end{matrix}\right\} \simeq \left\{\begin{matrix}\text{OTS in} \\ \text{Working Days}\end{matrix}\right\} \times £(0.40 \pm 0.07) \times 10^9 \quad \ldots(9.19)$$

(from equations 9.7 and 9.17), and of the percentage increase in G.D.P. possible,

$$\left\{\begin{matrix}\text{Estimated Total Percentage} \\ \text{Increase in G.D.P.}\end{matrix}\right\} \simeq \left\{\begin{matrix}\text{OTS in} \\ \text{Working Days}\end{matrix}\right\} \times (0.58 \pm 0.10)\% \quad \ldots(9.20)$$

(from equations 9.10 and 9.18) as a result of an OTS. (These equations are plotted, again without uncertainty, in Figure 9.1.) The total benefit to result from a national data network which gives suppliers an average OTS of four working days and customers an average OTS of two working days is now estimated as a lump sum benefit of some £2,400 million; this corresponds to an increase in the G.D.P. of some 3.5%. And while this latter estimate is time-independent, the former estimate may be expected to grow in the future as the economy expands.

However, these estimates are probably underestimates for several reasons. The important benefits of improved control and of improved competitiveness (Sections 8.5 and 8.6) have not been included, since they could not be quantified. Moreover, the "service industries" (Section 8.7) have not been considered at all; since services account for approximately 28% of the G.D.P. (C.S.O., 1969a, p.13), a very rough approximation of the total benefits might involve multiplying the above estimates by the factor ∿1.4, giving

$$\left\{\begin{array}{c}\text{Corrected Estimate of}\\ \text{Lump sum Benefit}\end{array}\right\} \sim \left\{\begin{array}{c}\text{OTS in}\\ \text{Working Days}\end{array}\right\} \times £(0.56 \pm 0.10) \times 10^9 \quad \ldots(9.21)$$

and

$$\left\{\begin{array}{c}\text{Corrected Estimate of}\\ \text{Percentage Increase in}\\ \text{G.D.P.}\end{array}\right\} \sim \left\{\begin{array}{c}\text{OTS in}\\ \text{Working Days}\end{array}\right\} \times (0.82 \pm 0.14)\% \quad \ldots(9.22).$$

These equations are plotted in Figure 9.1. (Also plotted are dotted lines for which the equations are derived in Section 9.5 following.)

In addition, the above estimates have only considered applications in which a national data network can now be seen to be of value; other beneficial applications are of course bound to arise. As a first approximation, this factor will be assumed to be offset by the fact that the full amount of benefits suggested above would not be received, since establishments below the cut-off sizes (Chapter 10) could not afford network usage. (These factors are assumed to be roughly offsetting since further beneficial applications would obviously reduce cut-off sizes.)

A further reason for the benefits suggested being underestimates is that the only type of benefit considered has involved the reduction of the time constraint. Possible benefits of other

constraint reductions are mentioned in Section 9.6.

9.5 Telecommunications in a Dynamic Input-Output Model

This section takes a completely different approach to estimate the percentage increase in the G.D.P. which might result from an OTS.

a. The Dynamic Input-Output Model

An input-output model attempts to provide a comprehensive view of the structure of an economy and of its complex interrelations by portraying the physical flows of money (goods, etc.) between different sectors (and industries) of the economy (Chenery & Clark, 1959; Stone & Brown, 1962; Stone, 1964). An ordinary input-output table gives the aggregations over a specified period of time (usually a year) of these flows, giving a static description of the economy; to obtain a realistic picture of the working of the economy, a truly dynamic model is required which will portray the various flows as they actually occur over time.

One can visualize the creation of an enormous dynamic Model (possibly along the lines of an Industrial Dynamics (Forrester, 1961) model with numerous closed loops) in which all relevant flows, including the informational linkages between (and within) firms, would be included. If this Model could be "solved", to determine those parameters or features of the Model to which total welfare (measured by some index such as G.D.P.) was particularly sensitive, one might expect to find that welfare was a function of certain characteristics of the telecommunication system, of the transportation system, etc.; this Model could thus estimate the total welfare resulting from a change in these characteristics.

The dependence of the G.D.P. upon telecommunications is twofold. There is first the direct contribution of earnings from the services which transfer information. (Section G.3 indicates this for the British economy for 1963.) Far more important is the (hidden) contribution of telecommunications to the G.D.P. *via* the improvement made upon the efficiency and productivity of those services and industries which make use of the telecommunication services. Since both of these contributions depend upon various characteristics of the telecommunication services, it should be possible to determine the total net social benefit of changing these characteristics. Important

questions such as "What is the economic effect of the delays caused by a poor telecommunication service?" might then be answered.

Although a substantial literature exists on the influence that the G.D.P. (and other macro-economic indicators) may have upon telecommunication development (Neilson, 1969), no references have been found which explicitly consider the reverse causation, as suggested above. Nevertheless, several attempts have been made to assess the social welfare to result from an improvement in transportation facilities.

Following a method proposed by Tinbergen (1957), Bos & Koyck (1961) constructed a general equilibrium model of a simple economy with three areas and four goods; a comparative statics study indicated that a reduction in transport costs (resulting from the construction of a new road) would raise national income by much more than the amount of benefits customarily estimated by transport economists. Their general approach, with a much fuller allowance for ramifications, indicates the limitations of (ordinary) partial analysis (Prest & Turvey 1965, p.714). But since their approach requires knowledge of all of the supply and demand equations in the economy, it is not really applicable.

Another approach to the assessment of improved traffic facilities on the welfare of the areas affected is given by Larsen (1968), who suggests that welfare depends upon the number of interactions per unit time which society's members are able to undertake. Using a traffic formula usually reserved for the estimation of the traffic between two areas (Jipp, 1960), Larsen claims that his working theory is a good predictor of the changes in income (his measure of welfare) which result from new roads. This conclusion is, however, questioned by Johnson (1970).

In spite of the fact that these approaches are not readily usable, it is suggested that it should be possible (at least conceptually) to assess the possible welfare changes (or macro-economic benefits) to result from an improvement in telecommunication facilities, particularly from the introduction of a national data network.

b. <u>The "Conceptual Cycle" Approach</u>

Section 7.3 suggests that the flows (of information, material, etc.) in our Model are in fact discrete, with delays attached to each. If these flows are now considered (for simplicity) to be continuous,

then the succession of discrete delayed flows in each channel is replaced by a continuous flow whose rate is regulated as if by a "valve".

Suppose now that the introduction of a national data network leads to an OTS which reduces the excess delays in telecommunication channels; it is assumed that customers receive the corresponding benefit in the form of faster service. (Thus this section may be taken to estimate customers' evaluation of an OTS.) In our Model, this excess delay reduction takes the form of a transient opening of the regulating channel "valves", so that flows briefly occur more rapidly. But each flow that is speeded up will not necessarily contribute an increased amount to the G.D.P., because many flows will have considerable "slack"† (or an excess delay) at one end. This organizational slack exists as a characteristic of the system: firms cannot use all of the goods, etc. emerging from flow channels immediately after their receipt. These flow channels may thus be considered to be "open loop"; the effect of an OTS is merely transient for such flows.

It is apparent that we are really concerned with the effect of the time saving OTS upon those flow channels which are critical (or which are "subcritical" at first and later become critical when some slack is removed). Such channels will include those usually considered as "chronic bottle-necks" which directly hold up later activities. Since we are now concerned with sequences of linked channels which will form closed loops, it is obvious that the effect of an OTS in these channels will be to increase the average flow rates over time.

For the purposes of this section, a huge computer simulation of the flows in the whole Model would thus have considerable redundancy, since the effect of an OTS upon the G.D.P. should be derivable from the critical channels alone. (Indeed, an increase in the G.D.P. should be achievable merely by reducing the delays in critical channels, but since these are difficult to identify,

† The concept of "slack" used here is exactly analogous to the "float" associated with activities in a critical path analysis; speeding up an activity with float will not affect the total time for completion of the whole project until the float has been eliminated (Battersby, 1967).

it is assumed that both critical and slack delays will be reduced.) A simplified approach is now made in which the G.D.P. is considered to represent the annual aggregation of flows around a huge "conceptual cycle", whose overall rate of flow is regulated by a "valve" corresponding to the valves of the critical channels. A "cycle time" (ψ) is associated with this conceptual cycle, so that flows make one cycle in ψ years. If VR (in £/year) is taken as the value rate of cyclic flow, then the total value V (in £) contained in one cycle is

$$V \equiv \psi \times VR \qquad \ldots(9.23).$$

Since the G.D.P. is the aggregation of $^1/\psi$ cyclic flows,

$$\text{G.D.P.} = V(£) \times \frac{1}{\psi}\,(\text{year}^{-1}) \times 1\,(\text{year}) = VR\,(£) \qquad \ldots(9.24).$$

This approach is analogous to the "Quantity Theory of Money" which holds that the G.D.P. is proportional to the velocity of circulation of money, provided that the quantity of money in circulation remains constant (Friedman, 1956; Lipsey, 1966. pp. 706-714; Brooman, 1967, pp. 215-220); the analogy is continued in Section G.11, with this velocity taken to be $^1/\psi$.

Following this theory, it is now assumed that an overall time saving which reduces the cycle time ψ by the amount OTS will also increase the G.D.P., if the value V (of products, money, etc. contained within the cycle) remains constant and if there are no problems of increased instability. (This latter aspect is discussed in Section 9.2.) The (comparative statics) multiplicative factor which would apply to the G.D.P. to indicate the increase which would result from an OTS is

$$\left(\begin{matrix}\text{Multiplicative}\\ \text{Factor}\end{matrix}\right) = \frac{\psi}{\psi - OTS} = 1 + \frac{OTS}{\psi} + \left(\frac{OTS}{\psi}\right)^2 + \left(\frac{OTS}{\psi}\right)^3 + \ldots \qquad \ldots(9.25)$$

$$\simeq \left(1 + \frac{OTS}{\psi}\right) \quad \text{when } \psi \gg OTS \qquad \ldots(9.26).$$

Table G.19, which gives statistics for both G.D.P. and ψ, indicates that G.D.P. has been increasing while ψ has been decreasing. But while a correlation is indicated by these statistics (and by further statistics extending both series back in time), there is not a simple empirical relationship between G.D.P. and ψ. This result does not contradict equation 9.23 which suggests that the G.D.P. should have increased as ψ decreased over time (due to OTS's which might

have resulted from increased mechanization, better managerial control techniques, better transportation or telecommunication facilities, etc.), since this equation is derived for fixed V. But it is not much use to reflate the G.D.P. figures of Table G.19 to a constant "stocks and work in progress" (S&WIP) requirement, for this merely gives a hyperbola with G.D.P. proportional to the inverse of the cycle time (equation 9.24).

The cycle time is obviously the important parameter to be quantified if equation 9.25 is to be useful. This concept of the cycle time is not noted in the literature, although its reciprocal, the "income velocity" (equation G.19) is much used (Selden, 1956; Welham, 1969). Thus, while ψ cannot really be estimated by micro-economic means (for how can one determine the average times for orders to work their way through the chronic bottle-necks in the economy?), macro-economic approaches are possible. Two such approaches are given in Section G.11, giving the estimate (equation G.22) that the British cycle time has now levelled off at the value

$$\psi \approx 107 \pm 5 \text{ working days} \qquad \ldots(9.27).$$

For the overall time savings which will be considered (of up to 6 working days), the inequality $\psi >> \text{OTS}$ always holds. Equations 9.26 and 9.27 give the percentage increase in the G.D.P. expected to result from an OTS as (the underestimate)

$$\begin{Bmatrix}\text{Estimated Percentage} \\ \text{Increase in G.D.P.}\end{Bmatrix} \approx \begin{Bmatrix}\text{OTS in} \\ \text{Working Days}\end{Bmatrix} \times (0.935 \pm 0.045)\% \qquad \ldots(9.28).$$

If (following Section 9.3) it is now assumed that this overall social benefit of an OTS is transferable, then this G.D.P. increase should be of the same order as that estimated in Section 9.4.c. However, a difficulty might arise since different definitions of OTS have been used: in equation 9.22 the OTS is the average time saving in a supplier-customer link, while in equation 9.28 the OTS is the time saving in the conceptual cycle; it is possible that this cycle could include several such links, making the latter OTS several times the size of the former. But since equations E.3 and E.6 suggest that the average order-to-despatch time for a good made to order is about 85 working days, it is not unreasonable to suppose that only one (slightly more delayed) critical link is involved in the cycle time of equation 9.27. Thus the OTS's may be taken to correspond.

Equation 9.28 may now be plotted directly in Figure 9.1; also plotted is the exact equation corresponding to eauation 9.25, rather than tc the approximation of equation 9.26. A good correspondence between these equations and that of equation 9.22 is noted.

9.6 Total Macro-Economic Benefits of a National Data Network

Equations 9.21, 9.22 and 9.28 indicate that the macro-economic benefit of one working day's OTS should involve a lump sum benefit of some £560 million; this corresponds to an increase in G.D.P. of almost one percent. With a total OTS of about six working days estimated (Section 9.3) to result from national data network usage (after transients have ended), the overall social benefit should total some £3,400 million, corresponding to an increase in the G.D.P. of about 5%!

Now the benefits so far examined in this chapter have been first order benefits resulting from a reduction in the time constraint. Benefits to the domestic user of data network facilities, and other second order benefits (Section 7.1), have been neglected, since they could not be quantified. It is expected that the above estimates could considerably understate the actual benefits (Section 9.4.c).

Part of the underestimation error may be eliminated by considering how the national data network might reduce other constraints. For example, considerable savings are expected to result from a reduction in the cost of transmitting information (Section 7.4). This reduction of the distance and physical constraints with respect to things is quantified by equation 7.5. Taking industrial expenditure on communications (of £360 million in 1963, by Table C.3) to estimate an overall PTTC value, it follows that the overall benefit available to industry from this constraint reduction is about £300 million for 1963. Assuming that PTTC grows with the G.D.P. (Figure G.2), then this lump sum saving would be about £460 million for 1970. By equations 9.7 and 9.10, this corresponds to a G.D.P. increase of about 0.68%. A considerable additional benefit should also result from the reduction of the distance and physical constraints with respect to people, as personal travel is also replaced by information transmission. (However, no *net* social benefit will result from speeding up cash flows throughout the economy, as suggested by Section 8.4.)

9.7 A Preliminary Social Value Analysis

The overall (first order) lump sum social benefits to result from national data network usage might be as high as £4,000 million (in 1970 pounds), corresponding to an increase in the G.D.P. of about 6%. A preliminary social value analysis may now be made using these estimates of social benefits.

Social costs may be estimated from some predictions made by the Hoskyns Group Ltd. (1969, p. 10) as to the relative importance of the data processing (DP) market in Britain. From forming 1.2% of the 1968 G.N.P., the DP market should constitute 3% of the G.N.P. in 1975, and should finally settle at about 4% of the G.N.P. in 1980. Taking G.N.P. and G.D.P. as roughly equivalent (C.S.O., 1969a, Table 1), the cost of DP may be seen to rise by some 2.8% of G.D.P. by 1980. Equations 9.22 and 9.28 suggest that an OTS of only three working days would justify this expenditure; an increase of 6% resulting from the national data network alone would more than justify the whole DP expenditure! And since the total inclusive capital cost of the data network should be somewhere in the neighbourhood of £1,000 million (from Figure 4.1 and Section 4.4), while the present value of this cost is about £260 million (equation 5.26), the investment project is seen to be overwhelmingly beneficial. These conclusions obviously complement those of Chapter 6 above.

It is suggested that a considerable excess of benefits over costs should result from the introduction of a national data network; thus this investment project is "absolutely" recommended. But for this project to be "relatively" recommended (with respect to all other possible investments), many analyses similar to that of this thesis would be required. When such macro-economic analyses are available, it should be possible to optimize welfare through an optimal allocation of national resources (Section 2.4).

CHAPTER 10 : A THEORY OF DEMAND FOR A NATIONAL DATA NETWORK

10.1 Introduction

This chapter presents a general theory of demand for a national data network. Sections 10.2 and 10.3 estimate market saturation levels for various sectors of the 1970 British economy; Section 10.4 develops a theory of the build-up of demand which may be used to derive appropriate theoretical S-shape curves. Since the unknowns mentioned at the start of Section 3.3 are then quantified, estimates of market growth over time may be made using a curve-fitting technique (Section 10.5).

Following Sections 3.3 and 7.1, it is assumed that one becomes a data network subscriber when the direct benefits of network usage are seen to exceed the costs (particularly the tariff charges) involved. Using the quantifiable models of Chapters 7 and 8, with data on establishment sizes, sales, etc. from Appendix G, an attempt is made to "see into the minds" of decision-makers to determine what network usage would be economically justifiable. Since the build-up of demand follows directly from the difference between benefits and costs, it is of paramount importance that these are estimated as accurately as possible. But in using the models, several parameter values must be chosen intuitively; a sensitivity analysis is carried out (Section 10.2) to indicate the sensitivity of results to the assumed values.

One particularly important parameter is the "cost of network usage" (CNU). If this cost is low there will be a rapid build-up of demand (Section 10.4), but a low CNU also corresponds to a deep dip "in the red" and a late break-even point for the capital account level CAPACL (Section 5.8). There is thus a conflict of interest between the Post Office (which wants a high CNU for rapid profits) and the country as a whole (which wants a low CNU to enable the data transmission service to spread rapidly). The estimation of a future CNU is therefore particularly difficult, since political considerations will be involved.

Since the benefits to be quantified in the following section are attributed entirely to the national data network, CNU should only involve the tariff charges of equation 5.14. (The justification of the exclusion of terminal rentals is apparent for a firm changing from its present batch-processing system to a future on-line system

with a data network connection.) To simplify our calculations, the concept of the "terminal equivalent" (TE) is introduced: the annual cost and benefits of one Service 1 terminal are taken to correspond to those of one TE. Following equation 4.1, it is assumed that

$$\left\{\begin{array}{c}\text{Number}\\ \text{of TEs}\end{array}\right\} = (\text{Number of Service 1 Terminals}) + 1.5 \times (\text{Number of Service 2 Terminals}) + 3.0 \times (\text{Number of Service 3 Terminals}) + 4.5 \times (\text{Number of Service 4 Terminals}) \quad \ldots(10.1).$$

Estimates of numbers of terminals will now be made entirely in TEs; from equation 5.14, the annual cost of network usage for one TE is about £180. But since the benefits of Chapters 7 and 8 are expressed as lump sums, this annual cost is converted to the lump sum (or present value) CNU, following equation 7.5.

$$\text{CNU} = \frac{£180}{r} = \begin{array}{c}£1800\\ \text{(in 1970 pounds)}\end{array} \quad \ldots(10.2)$$

Since the sensitivity of results to this parameter is particularly important, sensitivity analyses are made (Sections 10.2.b and 10.2.f) in which CNU is varied over the range £900 to £3600 (in 1970 pounds); other parameters varied (Section 10.2.b) are the overall time saving OTS and the fraction parameter δ.

10.2 Market Saturation Levels

a. General Approach

This section estimates the limiting number of data terminal equivalents which would be economically justified for any given CNU. The lump sum benefit available to a typical establishment within the sector or industry under consideration is first calculated; this benefit is expressed as a function of the size of the establishment. Comparing this benefit with CNU gives a cut-off establishment size below which network usage cannot be justified by the models used; this cut-off is then applied to a distribution of establishment sizes to determine how many establishments are economically justified in using how many TEs.

Since this procedure is based upon quantifiable first order benefits (to the business community, the domestic market being neglected (Sections 7.1 and 9.6)) alone, it is apparent that many other benefits are not included. Since these would be "carried on the back" of

the first order benefits which are expected to pay the CNU, the national data network can be shown to be beneficial in a social value analysis (or cost-benefit) sense.

The exclusion of other benefits from this analysis should not invalidate it, since businessmen are also expected to make a conservative estimate of benefits. This chapter thus uses economically justifiable business decisions as a basis for the theoretical determination of a market plateau. Since the Post Office should be able to market the date network service wherever it can be shown to be economically justifiable, this theory should be of particular marketing interest. Unfortunately, however, as general establishment size distributions are only available for the production and distribution sectors, only these sectors could be treated rigorously.

b. Production: The Manufacturing Sector

The first order benefits that a typical manufacturing establishment should receive from national data network usage - reduced communication costs, increased effective capacity, reduced inventories of materials, stores and fuel, and reduced inventories of finished goods - are examined using Section G.7. Taking $\delta = 0.1$ and OTS = 4 working days, the total lump sum benefit (Δ) is

$$\begin{aligned}\Delta &= \Delta_1 + \Delta_2 + \Delta_3 + \Delta_4 \\ &= (\text{PTTC} \times 0.83) + (\text{Cap.} \times 0.0324) \\ &\quad + (\text{P} \times 0.0048) + (\text{Sales} \times 0.0192) \qquad \ldots(10.3)\end{aligned}$$

using equations 7.3, 8.17, 8.34 and 8.47. (No Δ_5 benefit is expected, since terms of trade make it impossible to retain the benefit of earlier receipt of revenues.)

Now since the establishment size distributions of Figures G.4.a and G.4.b are given in terms of net output (NO), equation 10.3 may be rewritten as

$$\frac{\Delta}{\text{NO}} = 0.83 \times \frac{\text{PTTC}}{\text{NO}} + 0.0324 \times \frac{\text{Cap.}}{\text{NO}} + 0.0048 \times \frac{\text{P}}{\text{NO}} + 0.0192 \times \frac{\text{Sales}}{\text{NO}} \qquad \ldots(10.4).$$

Values of the ratios PTTC/NO, Cap./NO and P/NO are given in Table G.10; the ratio Sales/NO is obtained as $(1-\bar{\alpha}_A)$ times the GP&WD/NO ratio

of Table G.10, since the lump sum benefit Δ_4 refers only to stock items (Section 8.3.c).

Using the average ratio values from Table G.10, with $\bar{\alpha}_A$ taken from equation G.4, the result

$$\Delta \approx 0.0778 \times NO \qquad ...(10.4)$$

is obtained for a typical manufacturing establishment. Similar calculations made for each of the sixteen Standard Industrial Classification (S.I.C.) Orders of the sector are indicated in column 1 of Table 10.1. These results give the total lump sum benefit Δ as a function of the size of the establishment, expressed in terms of net output.

The cut-off net output (NO_{co}) is now obtained by equating Δ to CNU (equation 10.2), giving

$$NO_{co} = \frac{CNU}{\Delta/NO} \approx \text{£23,100 per year (in 1970 pounds)} \qquad ...(10.5).$$

All manufacturing establishments of at least this size (or, more accurately, of at least the appropriate size given in the second column of Table 10.1) should find national data network usage economically justifiable.

In order for the size distributions of Figure G.4 to be used to estimate how many establishments are of at least size NO_{co}, it is necessary to convert the NO_{co} values of column 2 of Table 10.1, which are in 1970 pounds, to values in 1963 pounds, since the size distributions refer to the 1963 Census of Production (Board of Trade, 1969). From this Census report it is noted that the number of establishments remained roughly constant (although it did fall slightly) between 1958 and 1963. It is now assumed that the relative shape of the distribution of establishment sizes remains constant, and that all establishments increase in size by a relatively constant amount each year. These assumptions are justified by observations made by Jewkes (1969): from an examination of Lorenz curves and other measures of concentration, Jewkes concludes that there has been no tendency for concentration over the past half century (so that distributions of firm and establishment sizes have remained fairly constant) and that the rate of growth has been independent of size.

Table 10.1 : Table of Calculations of Estimated Numbers of Terminal Equivalents for 1970 Manufacturing Establishments.

S.I.C. Order	Industry	$\Delta/NO = \frac{1}{NO} \sum_{i-1}^{4} \Delta_i$	NO_{co} (in 1970 pounds) (£ p.a.)	$\frac{NO_{1963}}{NO_{1970}}$	NO_{co} (in 1963 pounds) (£ p.a.)	Estimated Number of Establishments #	Estimated Number of Terminal Equivalents NTE
	Source →	Equation 10.4 and Table G.10	Equation 10.5	Equation 10.6 and Figure G.3	Equation 10.7	Figure G.4	Equation 10.10 and Table G.9
	Column →	1	2	3	4	5	6
III-XVI	All Manufacturing	0.0779	23,100	0.646	14,900	53,000	693,000
III	Food, drink and tobacco	0.0768	23,400	0.625	14,700	5,300	84,000
IV	Chemicals and allied industries	0.1066	16,900	0.640	10,800	3,300*	97,500
V	Metal manufacturing	0.1323	13,600	0.673	9,150	3,000*	90,100
VI	Engineering and electrical goods	0.0635	28,400	0.580	16,500	10,000	145,000
VII	Shipbuilding and marine engineering	0.0560	32,200	0.728	23,400	530	8,730
VIII	Vehicles	0.0779	23,100	0.700	16,200	1,550	89,000
IX	Metal goods not elsewhere specified	0.0739	24,400	0.616	15,000	5,350	36,000
X	Textiles	0.0819	22,000	0.760	16,700	5,200	46,400
XI	Leather, leather goods and fur	0.0524	34,400	0.776	26,700	500	1,710
XII	Clothing and footwear	0.0430	41,900	0.765	32,000	3,800	10,400
XIII	Bricks, pottery, glass, cement, etc.	0.0613	29,400	0.663	19,500	2,600	19,700
XIV	Timber, furniture, etc.	0.0447	40,300	0.650	26,200	2,200	8,700
XV	Paper, printing and publishing	0.0737	24,400	0.620	15,200	5,400	51,600
XVI	Other manufacturing industries	0.0631	28,500	0.557	15,900	2,000	23,100
	TOTALS					51,700	712,000

Note: * indicates that all establishments in industry are included.

For the whole manufacturing sector, contributions to the G.D.P. may be used to convert NO_{co} from 1970 pounds to 1963 pounds. But since the contributions of each manufacturing industry are not available, another estimator must be used: "wages and salaries" in each industry. Series plotted in Figure G.3 enable the ratio

$$\frac{(\text{Net output})_{1963}}{(\text{Net output})_{1970}} \approx \frac{\text{Wages and Salaries}_{1963}}{(\text{Estimated wages and salaries})_{1970}} \qquad \ldots(10.6)$$

to be evaluated; the results, which estimate the rate of growth of establishments over time, are given in column 3 of Table 10.1.

Taking the value of 0.646 for the whole manufacturing sector,

$$NO_{co}\Big|_{\text{in 1963 pounds}} \approx 0.646 \times \left[NO_{co}\Big|_{\text{in 1970 pounds}}\right]$$

$$\approx \text{£}14{,}900 \text{ (in 1963 pounds)} \qquad \ldots(10.7).$$

Separate industrial estimates of NO_{co} in 1963 pounds are given in the fourth column of Table 10.1.

An examination of the corrected curve (for the whole sector) in Figure G.4.b indicates that about 53,000 establishments have at least this annual net output. Thus the estimated number (#) of manufacturing establishments which could justify data network usage is

$$\# \approx 53{,}000 \text{ establishments} \qquad \ldots(10.8).$$

Similar estimates for each industry are given in column 5 of Table 10.1; the total of these industrial estimates approximates that of equation 10.8.

Well over 53,000 data terminals are anticipated, however, since larger establishments may be expected to have more than one terminal. It is now assumed that one TE will be justified for every £14,900 (in 1963 pounds) annual net output of an establishment. (This corresponds to about one TE for every 11 people employed (Board of Trade, 1969, p. 131/52).)

One approach to estimating the total number of terminal equivalents (NTE) at saturation involves adding 35,000 TEs for those establishments whose net output was at least £29,800 p.a., 27,500 TEs for those establishments whose net output was at least £44,700

p.a., etc. This "skimming" approach, using Figure G.4.b, gives the series

$$NTE = 53{,}000 + 35{,}000 + 27{,}500 + 22{,}500 + 19{,}500 + 17{,}000 + \ldots \qquad \ldots(10.9).$$

Since this series converges very slowly, a simpler approach is now made. From Table G.9 it is noted that, of the total net output of £10,709 million, some £10,329 million (or £(10,709-X) million, where X is a small correction factor) is attributable to the 53,000 establishments which would use the data network. If one TE is justified by every £14,900 of this total, then

$$NTE \approx \frac{(10{,}709-X) \times 10^6}{NO_{co}} \approx \frac{10{,}329 \times 10^6}{14{,}900} = 693{,}000 \qquad \ldots(10.10).$$

(A comparison of this estimating procedure with that of equation 10.9 indicates that equation 10.10 provides a somewhat larger†, though possibly equally justifiable, estimate of NTE. The latter estimate, which exceeds the former by about 5%, is preferred for ease of further calculations.) Similar NTE estimates for each industry, calculated using analyses of individual manufacturing industries by size of establishment (Board of Trade, 1969, Volume 131, Table 4), are given in column 6 of Table 10.1; the total of these industrial estimates approximates that of equation 10.10.

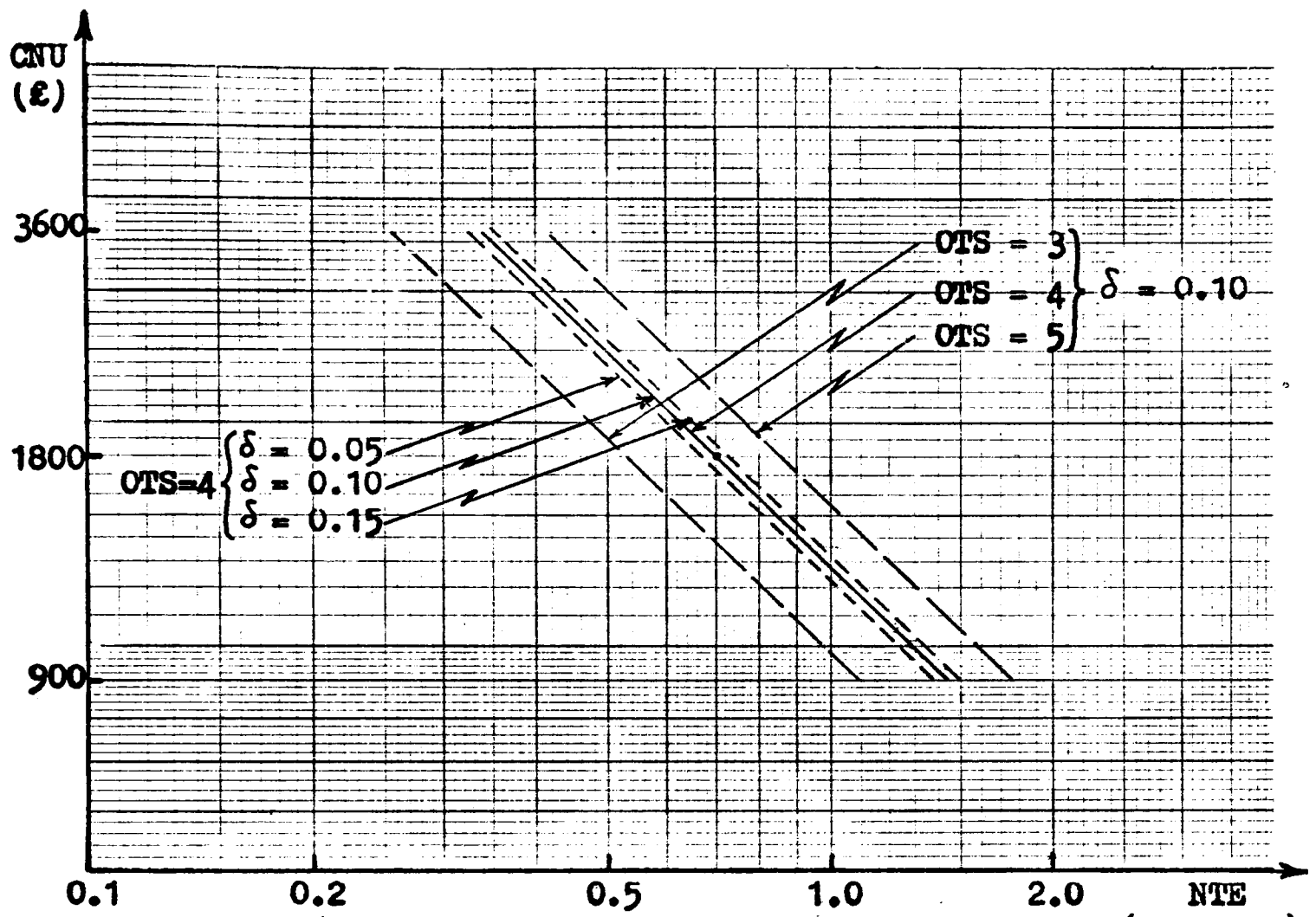
It is now possible to examine the sensitivity of these estimates to changes in parameter values. For simplicity, we shall only consider CNU, OTS and δ. Using the estimation procedure derived above for all manufacturing industries, the sensitivity of NTE to variations in CNU (from £900 to £3600), for several values of OTS (3, 4 and 5 working days) and of δ (0.05, 0.10 and 0.15), is shown in Figure 10.1. As expected with the relatively small contribution of Δ_1 to Δ, the influence of δ is far less than that of OTS.

It is noted from Figure 10.1 that the sensitivity curves are nearly linear on log-log paper and that their slope is almost exactly -1; this indicates that

$$NTE \approx \frac{\text{Constant}}{CNU} \qquad \ldots(10.11).$$

† This estimate is larger since the whole area under the corrected curve but above the cut-off is included, while the skimming approach gives a step-wise approximation to this area.

Figure 10.1: Sensitivity of NTE, for All Manufacturing Industries, to Variations in CNU for Several Values of OTS and δ.



It is obvious from equations 10.5, 10.6 and 10.10 that this (nearly) inverse relationship results from the correction factor X of equation 10.10 being negligibly small. This relationship is of some interest, since it suggests that reductions in the cost of national data network usage should lead a considerable increase in demand for terminals (expressed in TEs). It also suggests that the product of CNU and NTE is approximately constant; thus at any one time there is a relatively fixed amount that the manufacturing sector can afford to spend on data network usage.This result is hardly surprising, since it follows directly from the approach taken: using the quantitative models of Chapters 7 and 8, a total benefit is obtained for the manufacturing sector; this benefit gives the total amount which may be budgetted for national data network expenditure. This amount (which is a function of δ, OTS, and other parameters) is the constant of equation 10.11. Since this amount gives the total first order quantifiable benefit of national data network usage to the manufacturing sector,

its estimation is of considerable importance. Using the parameter values δ = 0.1 and OTS = 4 working days, equations 10.2, 10.10 and 10.11 give

$$\left\{\begin{array}{l}\text{Total First Order}\\ \text{Quantifiable Benefit to}\\ \text{the Manufacturing Sector}\end{array}\right\} \approx \text{£1,250 million} \qquad \ldots(10.12).$$

This total benefit is part of the £3,860 million overall total benefit (Section 9.6).

c. Production: The Non-manufacturing Census Industries

As noted in Section G.8, the non-manufacturing census industries are "mining and quarrying", "construction", and "gas, electricity and water". It is apparent that these industries will not benefit greatly from national data network usage; for example, how can mines, construction firms, gas works and water works increase their effective capacity utilization through network usage? Electricity generating stations might, however, be interconnected by a data network, so that peaks of demand could be transferred to spread the load. (In this connection, a recent computer simulation of the 1967 North American power black-out has indicated that there was a time interval of about ten minutes between the initial failure and the final breakdown. This suggests that a data network might be preferable to expensive excess reserve capacity.) However since there are only about 340 electricity generating stations (Board of Trade, 1969, p. 128/3), this application leads to relatively little demand.

It is also difficult to see how data network usage could enable stocks of finished goods to be reduced, since scheduling of work is fairly long-term. It might be felt that electricity and gas showrooms could benefit from a data network, but the average turnover per establishment was only about £6,000 in 1966 (Board of Trade, 1970, p. 1/32); this is far too small to support a data network terminal (equation 10.25).

Data network usage should, however, enable a non-manufacturing establishment to reduce its inventories of materials, stocks and fuel and to reduce its expenditure on communications (through the use of EBLs). Unfortunately, the only size distribution available is that of Table G.11 for S.I.C. Orders II' and XVII. Using the corresponding ratios of P/NO and PTTC/NO (taken from Table G.12) in

the equation

$$\Delta = \Delta_1 + \Delta_3$$

$$= (\text{PTTC} \times 0.83) + (\text{P} \times 0.0048) \qquad \ldots(10.13)$$

giving the total lump sum benefit Δ (from equations 7.5 and 8.34, with $\delta = 0.1$ and OTS = 4 working days), we obtain

$$\Delta \approx 0.00797 \times \text{NO} \qquad \ldots(10.14)$$

corresponding to equation 10.4. Following equation 10.5, and assuming that equations 10.6 and 10.7 apply, the cut-off net output in 1963 pounds is

$$\text{NO}_{\text{co}} \approx \text{£146,000 per year (in 1963 pounds)} \qquad \ldots(10.15).$$

The corrected curve of Figure G.5 indicates that about 2,400 establishments are of at least this size. If larger establishments have several TEs, the skimming approach (equation 10.9) suggests an estimated number of TEs of

$$\text{NTE} \approx 2{,}400 + 1000 + 345 + 168 + \ldots$$

$$\approx 4{,}470 \qquad \ldots(10.16).$$

Using the simpler method (equation 10.10) of assigning one TE to each £146,000 of net output attributable to the 2,400 largest establishments (Table G.11) gives the larger estimate

$$\text{NTE} \approx 5{,}470 \qquad \ldots(10.17).$$

Since an insignificantly small (Section 10.2.f) number of TEs is estimated for this sector, a sensitivity analysis is not really justified here.

d. Distribution: Retail Trade

Section G.9 suggests that, to a first approximation at least, the whole retail sector may be considered together. This subsection examines how a typical retail establishment might benefit from national data network usage. It is first noted that retailers are particularly concerned with obtaining and using the most up-to-date management information available, so that inventory levels may be kept to a minimal level. (This is particularly important in fashion areas of rapid change.)

The use of data networks and computers in distribution is a relatively recent phenomenon (National Computing Centre, 1968;

N.E.D.O. & N.C.C., 1968; Dalrymple & Thompson, 1969, pp. 328 ff). Nevertheless, the linking of retailers, wholesalers, depots, etc. with a data network is not far in the future; it is the benefits of this high level of data network usage which will be attributed to a national data network.

Since the function of retailing is to provide goods immediately, it is not expected that network usage would enable a typical retailer to reduce his customer order-handling time (COT) to obtain benefit Δ_4. He should, however, be able to reduce his procurement lead time and thus reduce stocks to gain the lump sum benefit Δ_3 (equation 8.34). To quantify this benefit, the choice of the time saving OTS is particularly important. As before, a value of about 4 working days is chosen. This choice is justified by considering a retail outlet which receives scheduled weekly deliveries and gives the order for the next week's delivery to the delivery man each week. Since replenishment orders should actually be made during the week, the average lead time is $1\frac{1}{2}$ weeks, with values spread between 1 and 2 weeks. With a data network, replenishment orders could be placed as required; the average lead time is now $\frac{1}{2}$ week, with a spread of 0 to 1 week. The procurement lead time is thus reduced by 1 week, or 6 working days. Since larger retail establishments probably have more frequent deliveries, a lower estimate of 4 working days provides a reasonable average.

Another benefit made available to the retailer† involves the use of direct credit transfers to banks (as in the so-called "cheque-less society" mentioned in Section 11.4), thus reducing the monetary "float" of uncleared cheques. Suppose that customers pay for a fraction β of the shop's turnover by cheques, which take an average of γ working days to clear. It is further assumed that the benefit received is distributed 50:50 between customer and retailer. Then, from equation 8.54, the lump sum benefit received is Δ_5.

$$\Delta_5 \approx 0.004 \times \frac{\beta \times \gamma}{2} \times TO \qquad \ldots(10.18)$$

where TO is the annual turnover.

Assuming the parameter values

$$\begin{aligned} \beta &= 0.5 \\ \gamma &= 4 \end{aligned} \qquad \ldots(10.19)$$

† This benefit is not considered for manufacturers and wholesalers, since terms of trade govern their dealings.

gives

$$\Delta_5 = 0.004 \times TO \qquad \ldots(10.20).$$

With the above two benefits, a retailer should also receive the benefit Δ_1 of reduced communication expenses, giving the total lump sum benefit

$$\Delta = \Delta_1 + \Delta_3 + \Delta_5$$

$$= (PTTC \times 0.83) + (P \times 0.0048) + (0.004 \times TO) \qquad \ldots(10.21)$$

using equations 7.5, 8.34 and 10.20. Using the ratios PTTC/TO and P/TO (equation G.15 and Table G.14),

$$\Delta \approx 0.0115 \times TO \qquad \ldots(10.22).$$

This equation relates the size of the retail establishment (expressed in terms of turnover) with the lump sum benefit Δ.

Equating Δ to CNU (equation 10.2) gives the cut-off turnover (TO_{co}).

$$TO_{co} = \frac{CNU}{\Delta/TO} = \frac{1800}{0.0115} \approx \text{£156,000 per year (in 1970 pounds)} \qquad \ldots(10.23)$$

All retail establishments of at least this size should be expected to join the national data network. To determine this number of establishments, equation 10.23 must be converted to 1966 pounds so that the size distributions of Figure G.7 may be used. From Table G.15 and equation G.12 it is estimated that

$$\frac{(\text{Turnover})_{1966}}{(\text{Turnover})_{1970}} \approx 0.86 \qquad \ldots(10.24).$$

Since similar assumptions to those given in Section 10.2.b concerning establishment sizes may also be made for the retail sector, equation 10.23 becomes

$$TO_{co} \approx \text{£134,000 per year (in 1966 pounds)} \qquad \ldots(10.25).$$

From the plotted curve for total retail trade in Figure G.7, it is seen that about 6,800 establishments are of at least this size. Assuming that one TE is economically justified by each £134,000 of turnover (and this corresponds to approximately one TE for every 26 people employed (Board of Trade, 1970, p. 1/36)), the skimming approach of equation 10.9 applied to Figure G.7 gives the series

$$NTE = 6,800 + 3,100 + 1,700 + 1,160 + \ldots \qquad \ldots(10.26),$$

while the simpler approach of equation 10.10 gives the estimate

$$NTE \approx \frac{(11,451 - X) \times 10^6}{TO_{co}} \approx \frac{2,771 \times 10^6}{134,000} \approx 20,700 \qquad \ldots(10.27)$$

using Table G.13. Here the correction factor X is definitely not negligible.

Since this estimate is relatively small (Section 10.2.f), a full sensitivity analysis (involving varying OTS, β, γ and δ) is not included here. The sensitivity of NTE to changes in CNU is, however, indicated in Figure 10.2.

e. Distribution: Wholesale Trades

This subsection deals with the other half of the distributive sector: wholesale trades. As indicated in Section G.10, the availability of size distributions requires that wholesale business units be examined in two categories: "businesses operating mainly on a commission basis" and "businesses trading with and without stock".

For the former category of businesses, the only first order benefit likely to be received from national data network usage is the reduction of communication expenses. From equations 7.5 and G.16, this benefit is

$$\Delta_1 = 0.83 \times PTTC \approx 0.00407 \times REC \qquad \ldots(10.28).$$

This equation relates the size of a wholesale business unit (expressed in terms of annual total receipts REC) with the total lump sum benefit. Equating this benefit with CNU (equation 10.2) gives the cut-off receipts (REC_{co}).

$$REC_{co} \approx \begin{array}{l} £442,000 \text{ per year} \\ \text{(in 1970 pounds)} \end{array} \qquad \ldots(10.29).$$

To convert this to 1965 pounds (so that the size distribution of Figure G.8 may be used), it is assumed that

$$\left.\frac{(\text{Receipts})_{1965}}{(\text{Receipts})_{1970}}\right|_{\text{Wholesale}} = \left.\frac{(\text{Turnover})_{1965}}{(\text{Turnover})_{1970}}\right|_{\text{Retail}} \approx 0.83 \qquad \ldots(10.30)$$

using Table G.15 and equation G.12. Thus equation 10.29 becomes

$$REC_{co} \approx \text{£366,000 per year (in 1965 pounds)} \quad ...(10.31).$$

The "commission basis" size distribution (Figure G.8) suggests that only about 29 business units could justify data network usage.

Turning to the second category of businesses, it is apparent that the benefit Δ_1 will still be available. In addition, a lump sum benefit Δ_3 should be received as data network usage enables the procurement lead time for purchases to be reduced (by 4 working days' OTS) so that the average level of stocks may be reduced. Using equations 8.34, 10.28 and G.17, the total lump sum benefit Δ for business units trading with and without stock is

$$\Delta = \Delta_1 + \Delta_3$$

$$= 0.00827 \times REC \quad ...(10.32).$$

Following equations 10.29 to 10.31, the cut-off receipts REC_{co} are

$$REC_{co} \approx \text{£218,000 per year (in 1970 pounds)}$$

$$\approx \text{£179,000 per year (in 1965 pounds)} \quad ...(10.33).$$

Figure G.8 indicates that some 9,300 business units in this category would benefit from network usage. Assuming that one TE corresponds to every £179,000 in receipts for these establishments (and this implies about one TE for every 10 people employed (Board of Trade Journal, 1968)), then the skimming approach of equation 10.9 gives the series

$$NTE = 9,300 + 5,100 + 3,500 + 2,580 + ... \quad ...(10.34),$$

while the simpler approach of equation 10.10 gives the estimate

$$NTE \approx \frac{(13,908 - X) \times 10^6}{REC_{co}} \approx \frac{12,600 \times 10^6}{179,000} \approx 70,400 \quad ...(10.35)$$

using Table G.16. (The correction factor X is fairly small here.)

As in previous subsections, a full sensitivity analysis is not made here, although the sensitivity of NTE to changes in CNU is shown in Figure 10.2.

f. Production and Distribution: A Summary

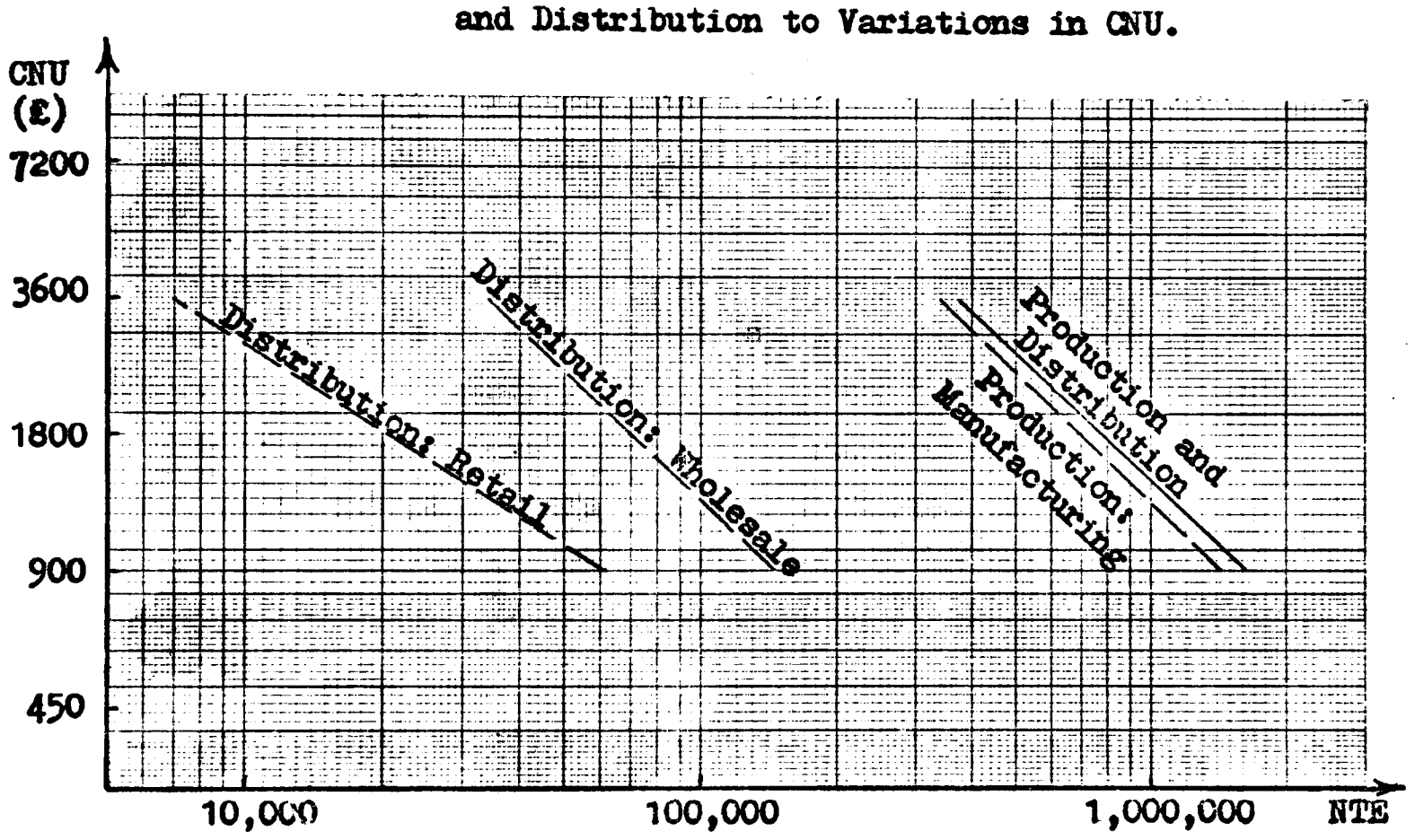
The results of the previous four subsections are now totalled to give an estimated number of terminal equivalents (NTE) for the

production (manufacturing and non-manufacturing) and distribution (wholesale and retail) sectors. A point estimate based upon the originally considered parameter values is

$$NTE \approx 790{,}000 \qquad \ldots(10.36).$$

The sensitivity of this to variations in the cost of network usage (CNU) parameter is indicated in Figure 10.2. The approximately inverse

Figure 10.2: Sensitivity of Estimates of NTE for Production and Distribution to Variations in CNU.



relationship of equation 10.11 still holds; this suggests (Section 10.2.b) that the total first order quantifiable benefit to the production and distribution sectors would be

$$\left\{\begin{matrix}\text{Total First Order} \\ \text{Quantifiable Benefit}\end{matrix}\right\} \approx £1{,}420 \text{ million} \qquad \ldots(10.37).$$

This would form part of the overall total benefit of £3,860 million.

It might at first appear that there is a gross discrepancy between these two estimates of total benefit, but this results from the fact that the £3,860 million refers to the total social benefit, to customers and suppliers throughout the economy, of national data network usage, while the £1,420 million only refers to suppliers

in the production and distribution sectors. In fact, it may be shown that the approach of Chapter 9 applied to these two sectors alone, with an OTS of 4 working days, estimates the benefit to suppliers at about £1,400 million; this corresponds closely with the result of equation 10.37.

It must be emphasized that the estimates of NTE made in this chapter are limit lines which would be approached at market saturation; these estimates are, moreover, only first approximations. This is particularly true since the actual number of terminal equivalents would never even reach these limit lines. This follows from the implicit assumption that all those with whom an establishment (considered as a potential data network subscriber) deals are already data network subscribers. But since some small establishments would never join the network, corrections are needed to both the total lump sum benefit Δ received and to the limiting NTE estimates. It is, however, expected that these corrections would be quite small, judging from the often-quoted principle of concentration of the form: "80% of our business is with 20% of our customers". The actual value of the correction factor may be derived using the approach of Section 10.4, where an iterative procedure produces an S-curve describing the build-up of the market. A comparison of the saturation level of this S-curve with the NTE estimate derived using the methodology of this section gives the correction factor; it is expected that this correction will be small, of the order of 10% (Section 10.4.c).

It is also noteworthy that the approach of this chapter (and indeed of this whole thesis) is predominantly theoretical; since appropriate parameter values are simply not available, intuitive estimates have had to be made. While these have been confirmed in some instances by empirical data, many parameter values are only first approximations; thus NTE estimates can only be first approximations as well.

g. Other Sectors of the British Economy

The theoretical approach of this section, based upon quantifiable models and establishment size distributions, obviously requires that suitable statistics exist for any sector of the economy to be examined. Unfortunately, however, few British statistics exist except for the production and distribution sectors. It is thus not possible to apply the approach of this section to other sectors to obtain

NTE estimates.

Since an NTE estimate for the whole economy is required in Section 10.5, an attempt must be made to assess the data network demand for other sectors. One approach involves using the (computer-oriented) market research sector forecasts of SCICON (1969), which indicate that some 162,000 TEs of the total 1983 forecast of 490,000 TEs would be for the production and distribution sectors; this leaves some 328,000 TEs forecast for the rest of the economy. Taking the saturation limit to be about 350,000 TEs (for 1970 firm sizes - see Section 10.3) for these remaining sectors and making a 10% correction to equation 10.36 gives the estimate for the whole British economy of

$$NTE_{total} \approx 1{,}060{,}000 \qquad \ldots(10.38).$$

(This estimate is somewhat larger than that of 995,000 TEs which is obtained by applying the 1.4 factor (of Section 9.4.c) to the 10%-corrected value from equation 10.36.) It is found that the application to equation 10.38 (without the 10% correction) of the approach used to derive equation 10.12 gives an estimated total benefit to all suppliers of the same order as that of equation 9.21 (with an OTS of 4 working days).

10.3 The Growth of Saturation Levels

The use of the CNU value of equation 10.2 indicates that the estimates of NTE made so far refer to the 1970 sizes of British establishments. Now the size of a typical establishment is increasing over time (Section 10.2.b); indeed, the use of equations such as equation 10.6 suggests that the distribution of establishment sizes may easily be made time-dependent by multiplying output levels (turnovers, or other measures of size) by a parameter describing growth over time. Since the cost discussions of Chapters 4 and 5 are entirely in 1970 pounds, it is reasonable to continue to use this constant monetary unit; the effect of inflation is thus removed from consideration.

If it is assumed that the growth of establishment sizes, measured in 1970 pounds, follows the real growth of the G.D.P. (at 1963 factor cost, say), then the size of an establishment in year Y may be related to its 1970 size (using equation G.10).

$$(\text{Size})_Y = (\text{Size})_{1970} \times \exp.(0.0262 \times (Y-1970)) \qquad \ldots(10.39)$$

(in 1970 pounds)

And since total lump sum benefits calculated in Section 10.2 are expressed as linear functions of establishment sizes, these benefits also grow at this real rate. (It is noted that only first order quantifiable benefits are considered here; the inclusion of further benefits should increase the rate of growth to be determined.)

While benefits will obviously grow over time, it is more difficult to describe the future of costs. It is first noted that technological improvements have enabled (American) data communication costs (i.e. of data transmission and terminals) to decrease by about 2% p.a. (Zeidler, Lipinski, Moll, Shapiro, Kent & Wensley, 1969, p.12); this slow rate of cost reduction might be considerably increased with the mass production of equipment which would result as a data network grew to the size suggested by equation 10.38. In addition to these direct cost reductions, there will certainly be effective cost reductions as the cost of computing (the complement of data communication, according to Section 7.2) falls: Zeidler *et al.* (1969, pp. 18 and 30-31) indicate that computer software costs have been decreasing by about 25% p.a., and computer hardware costs have been decreasing even faster. Such future cost reductions should encourage and stimulate data network usage.

Countering these trends of cost reduction is the fact that the cost of adding a subscriber to the data network will increase as the number of subscribers already using the network increases (since some equipment must be added in proportion to the number of possible interconnections of subscribers, rather than merely in proportion to the number of subscribers). In addition, it may be expected that (as with nearly all complex technological projects) the total cost of implementing the national data network will exceed the estimates of Section 4.4.

While an accurate analysis of future cost trends is really required, the first approximation may be made that the opposing trends roughly cancel each other out, so that CNU remains as given in equation 10.2. With costs remaining constant, and with benefits increasing, the NTE saturation levels will obviously grow over time.

To illustrate this growth, calculations will be made for the whole manufacturing sector for the years 1975, 1980 and 1985. From equation 10.5, the cut-off net output for year Y is, in 1970 pounds,

$$(NO_{co})_Y \approx \text{£}23{,}100 \text{ per year (in 1970 pounds)} \qquad \ldots(10.40).$$

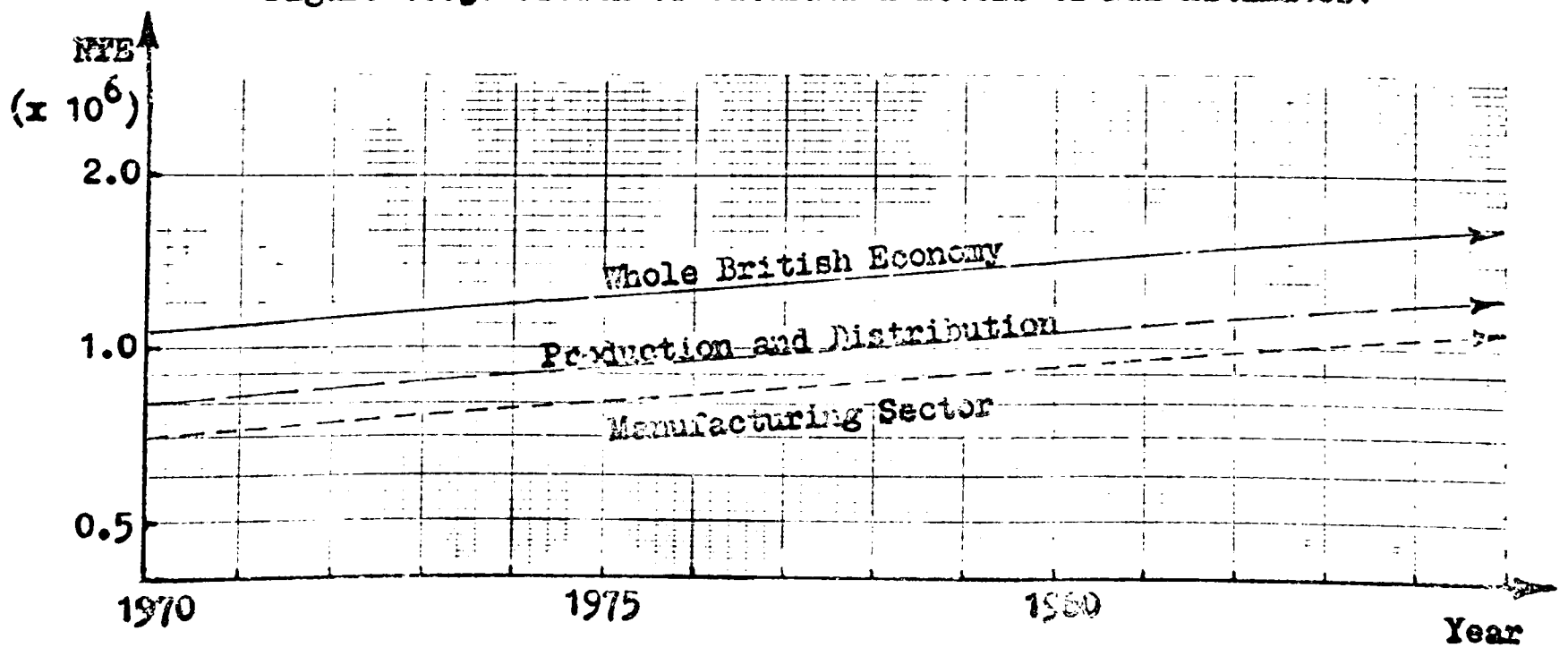
To convert this estimate to 1963 pounds (so that it may be applied directly to Figure G.4.b), equations 10.7 and 10.39 are used, giving the $(NO_{co})_Y$ values, in 1963 pounds, in the second column of Table 10.2.

Table 10.2 : Growth of NTE Saturation Levels Over Time for the Whole Manufacturing Sector.

Year Y	Cut-off Net Output in 1963 pounds (£ p.a.) $(NO_{co})_Y$	Estimated Number of Establish-ments #	Estimated Number of Terminal Equiva-lents NTE
1970	14,900	53,000	693,000
1975	13,070	57,000	794,000
1980	11,460	61,000	910,000
1985	10,060	65,000	1,042,000

Following the approaches used to derive equations 10.8 and 10.10, the results of the final two columns of Table 10.2 are obtained. The NTE estimates of saturation levels are plotted in Figure 10.3; also shown are the corresponding growth lines for "production and distribution" (starting from the 1970 estimate of equation 10.36) and for the whole British economy (starting from the 1970 estimate of equation 10.38).

Figure 10.3: Growth of Saturation Levels of NTE Estimates.



10.4 A Theory of the Build-up of Demand

a. Introduction

Although the results of Sections 10.2 and 10.3 are of considerable value in suggesting the magnitude of the eventual market for national data communications, it is obvious that they only tell how much demand there will be, without reference to when this demand will occur. But for planning purposes, it may be argued that the "when" is even more important than the "how much", since timing is of paramount importance in considering the introduction of a data network. It is thus necessary to forecast the future development of this service; as suggested in Section 1.1, this is difficult, since it involves assessing the possible demand for a future service of unknown characteristics.

The approach made in Section 10.5 involves curve-fitting using an S-type curve. Thus any forecasts obtained are "surprise-free"; this is also implicit in the use of first order benefits. As noted in Sections 3.2 and 3.3, this forecasting approach requires that the "height", "width" and "shape" of the S-curve be known. Now the "height" of the S-curve is obviously given by the total saturation level of Figure 10.3. But since densities of TEs are preferred to absolute numbers (Section 3.3), so that growth elements can be considered separately, the "height" will be taken as the NTE_{total} estimate of equation 10.38. (The use of this estimate implies that parameter values - CNU, OTS, δ, etc. - are assumed to remain constant.) And if the "shape" of the S-curve is known, then the "width" may be determined from the initial rate of growth. If it is assumed that the growth of national data network traffic will be the same as the current rate of demand growth for Datel services (and this is implied by Figure 4.1), then the "width" may be estimated by fitting an S-curve of the appropriate shape and height to the current part of the fitted curve in Figure 4.1.

It is apparent that only the "shape" of the S-curve of future demand remains to be determined. A possible curve might be the logistic curve of equation 3.1. But since this curve is derived from highly over-simplified assumptions, a far more realistic (and thus far more complex) expression is required to describe the build-up of demand for national data telecommunication facilities over time.

From Figure 3.1 it is noted that the benefit to any individual user of the data network is a function of the others in his "community of interest" who are also users. There is thus a positive feedback effect in the "benefit loop": as more subscribers join the network, benefits increase, so more potential subscribers are encouraged to join. (This positive feedback produces the early, roughly exponential growth of the S-curve; this growth is, however, limited by various factors such as the cut-off establishment size, the "absorption-rate constraint" (Section 10.4.d), etc.) In the following subsection, a comparative statics approach is made to give a step-wise approximation, on theoretical grounds, to the actual dynamic situation; this analysis enables an understood demand curve to be derived for the number of TEs which will be on the data network.

b. Derivation of Theory

From Section 10.2 it is noted that the total lump sum (first order) benefit available to the k th establishment (out of a total of I) in sector i, as a result of national data network usage, can be written in the generalized form Δ_i^k:

$$\Delta_i^k = C_i \times T_i^k \qquad \ldots(10.41)$$

where C_i is a generalized benefit coefficient, and

T_i^k is an appropriate measure of annual transactions (such as net output, turnover, or receipts) which indicates the size of establishment k.

This benefit may be subdivided into the benefits Δ_{ij}^k available from transactions with each sector j, at the annual rate T_{ij}^k.

$$\Delta_{ij}^k = C_i \times T_{ij}^k \qquad \ldots(10.42)$$

With N sectors in the (closed) economic system considered, these benefits may be summed to give the benefit Δ_i^k.

$$\Delta_i^k = \sum_{j=1}^{N} \Delta_{ij}^k \qquad \ldots(10.43)$$

The total benefit Δ_{ij} to sector i available from all transactions (at the annual rate T_{ij}) with sector j is obtained by summing over I establishments.

$$\Delta_{ij} = \sum_{k=1}^{I} \Delta_{ij}^{k} = C_i \times T_{ij} \qquad \ldots(10.44)$$

The total benefit Δ_i available to sector i from all of its transactions (at the annual rate T_i) is obtained by summing over N sectors.

$$\Delta_i = \sum_{j=1}^{N} \Delta_{ij} = C_i \times T_i \qquad \ldots(10.45)$$

While these equations assume that all establishments with which establishment k deals will be on the data network, this will obviously not be the case. A correction is required (Sections 10.2.f and 10.4.a), and this correction actually gives the transient build-up of the network.

The effect of sector j having only $n_j(t)$ establishments (out of J) on the data network at some time t is now considered. If $*T_{ij}^{k}(t)$ gives the annual transactions between establishment k in sector i and these $n_j(t)$ establishments, equation 10.42 takes the time-dependent form

$$\Delta_{ij}^{k}(t) = C_i \times *T_{ij}^{k}(t) \qquad \ldots(10.46).$$

The time-dependence of this lump sum benefit does not include the effect of growth of the economy over time; the derivation of this subsection relates to densities (Section 3.2). Since T_{ij}^{k} gives the total annual transactions that establishment k of sector i has with all of sector j,

$$*T_{ij}^{k}(t) = T_{ij}^{k} \times *T_{ij}(t) / T_{ij} \qquad \ldots(10.47)$$

where $*T_{ij}(t)$ is the annual transactions rate between sector i and the $n_j(t)$ establishments of sector j at time t. The total of these annual transactions between sector i and the $n_j(t)$ establishments of all sectors j at time t is $*T_i(t)$, where

$$*T_i(t) = \sum_{j=1}^{N} *T_{ij}(t) \qquad \ldots(10.48).$$

It is assumed (equation 10.47) that an establishment's transactions with sectors are proportional to its relative size within its own sector. Thus a time-independent size distribution parameter d_i^k may be defined for establishment k in sector i as

$$d_i^k = \frac{T_{ij}^{k}}{T_{ij}} = \frac{T_i^k}{T_i} \qquad \ldots(10.49).$$

Using equations 10.43 and 10.46 to 10.49, the total lump sum benefit available to establishment k in sector i at time t is

$$\Delta_i^k(t) = C_i \times d_i^k \times {}^*T_i(t) \qquad \ldots(10.50).$$

Suppose (following Section 10.1) that the (time-independent) cost of network usage, CNU, is taken as the lump sum benefit required to justify one national data network terminal equivalent (TE) economically. Then if

$$\Delta_i^k(t) \geq CNU \qquad \ldots(10.51),$$

establishment k can justify having at least one TE; in general, if

$$\Delta_i^k(t) \geq n \times CNU \qquad \ldots(10.52),$$

then the establishment can justify n TEs. Taking n to be an integer index (which has values 1,2,3 ... as required), cut-off establishment sizes ${}_nCO_i(t)$ may be derived for sector i at time t, such that all establishments of at least size ${}_nCO_i(t)$ can justify at least n TEs. Since these cut-off sizes correspond to the annual transactions rate T_i^k, it follows from equations 10.49, 10.50 and 10.52 that

$${}_nCO_i(t) = \frac{n \times CNU \times T_i}{C_i \times {}^*T_i(t)} \qquad \ldots(10.53).$$

The number ${}_n\#_i(t)$ of establishments in sector i which are at least as large (in terms of annual transactions) as this cut-off size may be determined from a sector i size distribution (cf the form of Figure G.7). The estimated number of TEs economically justified for sector i at time t, $NTE_i(t)$, is thus obtained as

$$NTE_i(t) = {}_1\#_i(t) + {}_2\#_i(t) + \ldots = \sum_{n=1} {}_n\#_i(t) \qquad \ldots(10.54).$$

(This equation corresponds to the skimming approach of equation 10.9.) The estimated total number of TEs justified at time t for the whole economy, NTE(t), is obtained by summing over the N sectors.

$$NTE(t) = \sum_{i=1}^{N} NTE_i(t) \qquad \ldots(10.55)$$

To obtain a step-wise approximation to the continuous curve of build-up of demand, calculations using equation 10.53 are made at time intervals of dt (where this interval is unspecified at this stage). This discrete approach requires that equation 10.53 be rewritten

in the lagged form

$$ {}_{n}CO_{i}(t) = \frac{n \times CNU \times T_{i}}{C_{i} \times {}^{*}T_{i}(t-dt)} \qquad \ldots(10.56). $$

For the initial time t=0, the starting condition is imposed that each sector has one TE installed. (This, or a similar condition, is required to "seed" the system so that the build-up of demand may commence; obviously if there are initially no TEs, equation 10.56 will not allow any to be justified.) Calculations are then made at times dt, 2dt, 3dt, etc. using the determination of ${}^{*}T_{ij}(t-dt)$, of ${}^{*}T_{i}(t-dt)$, of ${}_{n}CO_{i}(t)$, of ${}_{n}\#_{i}(t)$, and of $NTE_{i}(t)$ in an iterative loop. This enables the time series NTE(t), which gives the expected build-up of demand for national data network TEs over time, to be determined. Since this build-up starts at a very low value (where the system is "seeded") and proceeds to a saturation level (Section 10.2), it is expected that a plot of NTE(t) over time should give some form of S-curve.

The actual "width" (defined in some manner) of this S-curve depends directly upon the choice of the time interval dt. Since a continuous growth of demand is modelled by a discrete approximation, the estimation of dt is difficult (Section 10.4.a). This is particularly so since dt is a parameter which may be controlled to some extent by the Post Office: efforts by the Post Office Marketing branch to educate potential users about the benefits of the data network should enable dt to be reduced, so that the build-up of demand would occur more rapidly.

The build-up of demand and its satisfaction have been assumed to proceed without any external constraints being felt; this over-simplification will be dealt with in Section 10.4.d.

c. Application of Theory to a Simple Three-Sector System

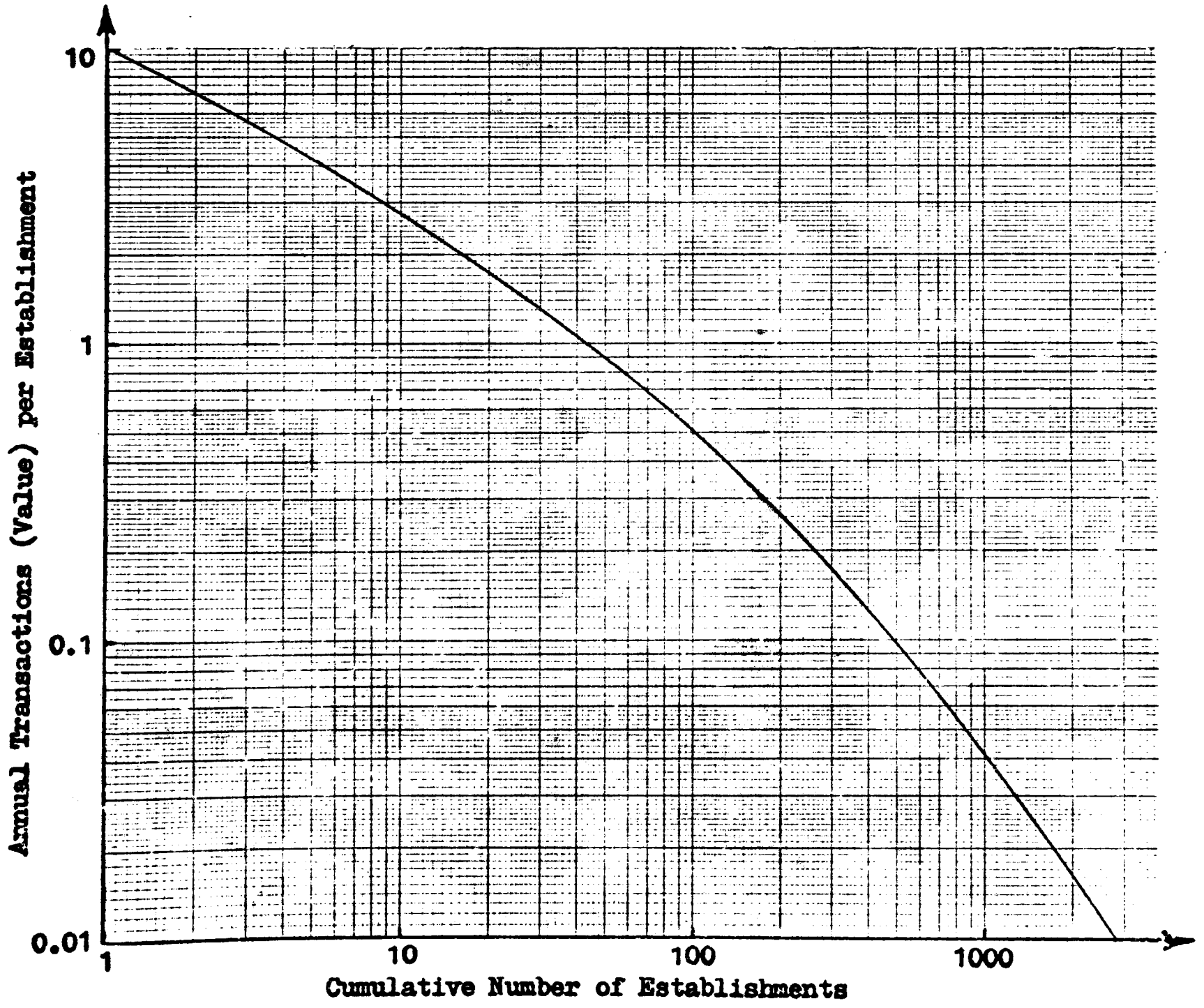
The theoretical approach derived above is now applied to the simple (and manageable) case of a closed economy with three similar sectors. Each sector is assumed to have the size distribution of establishments given in Table 10.3 below. (The unit of transactions might, for example, be considered as millions of pounds of net output.)

Table 10.3 : Size Distribution of Establishments in a Sector.

Transaction Range	Number of Establishments	Average Transactions per Establishment	Total Transactions
<0.01	1,300	0.0060	7.8
0.01-0.02	1,000	0.0136	13.6
0.02-0.05	820	0.0295	24.2
0.05-0.1	390	0.0675	26.3
0.1-0.2	230	0.135	31.1
0.2-0.5	160	0.29	46.4
0.5-1.0	56	0.67	37.5
1-2	28	1.31	36.7
2-5	12	2.75	33.0
> 5	4	7.1	28.4
TOTAL	4,000		285.0

This distribution (based upon Figure G.4) is plotted in Figure 10.4.

Figure 10.4: Size Distribution of Establishments in a Sector.



Inter-sectoral transactions are obtainable from the simple input-output matrix of Table 10.4.

Table 10.4 : Three-Sector Input-Output Matrix.

Sales by Sector \ Purchases by Sector	1	2	3	Total
1	95	95	95	285
2	95	95	95	285
3	95	95	95	285
Total	285	285	285	855

For this simple matrix,

$$T_{ij} = 95$$

and

$$T_i = 285 \qquad \ldots(10.57)$$

for all sectors†; for a more complex system, transaction coefficients (which indicate any sector's "community of interest") could be approximated as the average of the (different) input-output coefficients X_{ij} and X_{ji}.

The parameters remaining to be quantified are C_i and CNU. Following equations 10.4 and 10.2 respectively, these are given the values

$$C_i = 0.07$$

and

$$CNU = 0.0018 \text{ transaction units} \qquad \ldots(10.58).$$

Using these values, equation 10.56 becomes

$$_nCO_i(t) = \frac{n \times 7.33}{*T_i(t-dt)} \qquad \ldots(10.59).$$

At time t=0, the system is "seeded" by having the largest establishment in each sector join the network. Since these establishments each have annual transactions of 10 (Figure 10.4), the cut-off transaction rate at the end of the first time interval is

$$_nCO_i(dt) = n \times 0.733 \qquad \ldots(10.60).$$

† Since the three sectors are identical here, the approach of this subsection is applicable to any multi-sector system with similar sectors.

Using Figure 10.4, the skimming approach of equation 10.54 gives

$$NTE_i(dt) = 65 + 26 + 14 + 9 + \ldots \approx 140 \qquad \ldots(10.61).$$

Alternatively, using the approach of equation 10.10 (by which one TE is assumed to be justified for each amount ${}_1CO_i(dt) = 0.733$ of the total annual transactions of the ${}_1\#_i(dt) = 65$ largest establishments in sector i), the estimate is

$$NTE_i(dt) \approx \frac{112.2}{0.733} = 153 \qquad \ldots(10.62).$$

(This latter equation form is preferred for the following calculations used to obtain the series $NTE_i(t)$.) Taking ${}^*T_i(dt) = 112.2$, equation 10.59 gives

$${}_nCO_i(2dt) = n \times 0.0653 \qquad \ldots(10.63)$$

so that

$${}_1\#_i(2dt) \approx 705 \qquad \ldots(10.64)$$

and thus

$$NTE_i(2dt) \approx \frac{227.6}{0.0653} = 3{,}480 \qquad \ldots(10.65).$$

Continuing in this fashion, and using the fact that the number of establishments at time t and the total number of TEs at time t are given by

$$\#(t) = 3 \times {}_1\#_i(t)$$

and

$$NTE(t) = 3 \times NTE_i(t) \qquad \ldots(10.66)$$

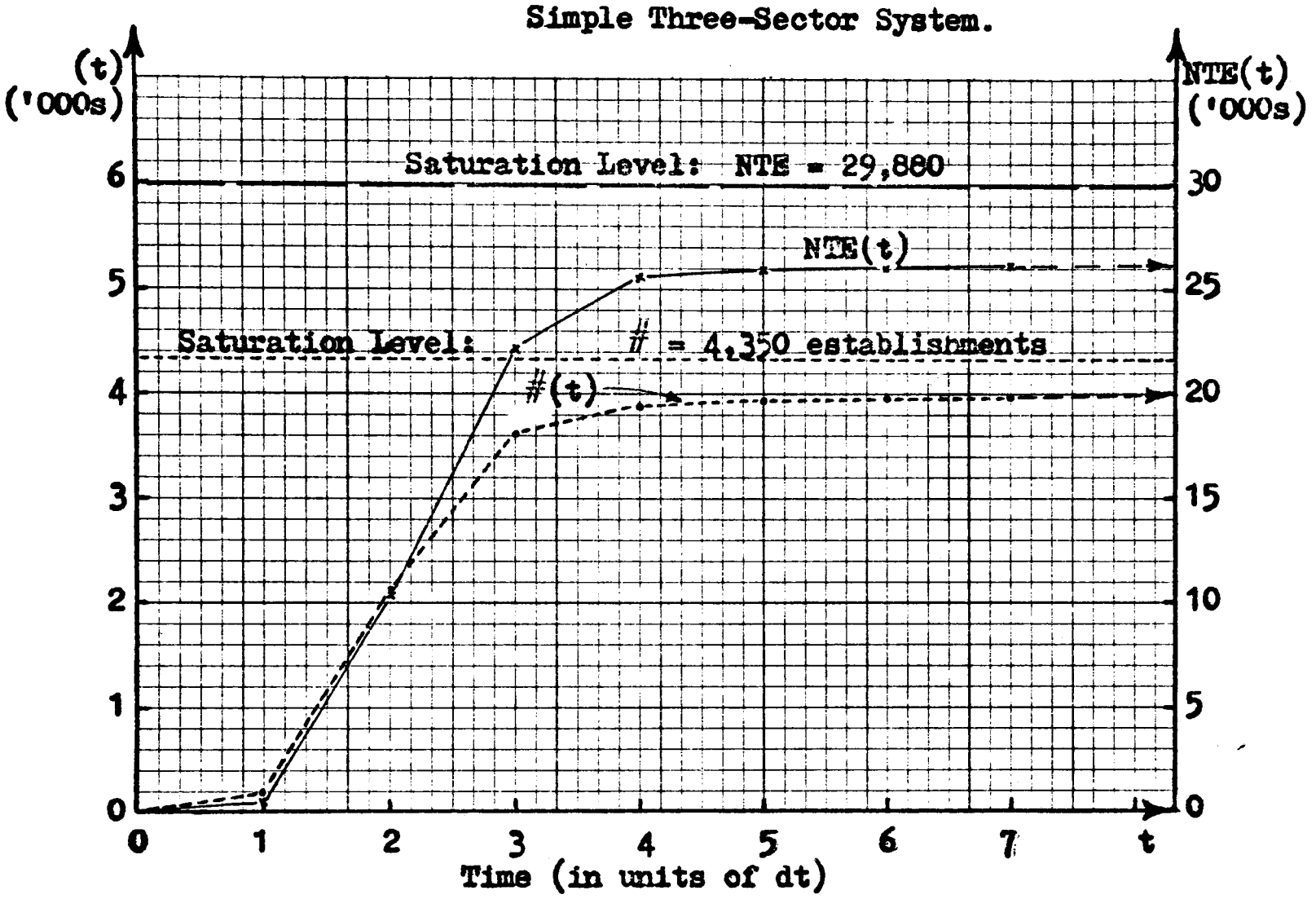
(since the three sectors of the system are identical), we obtain the build-up of the data network for our simple system given in Table 10.5.

Table 10.5 : Build-up of Data Network for a Simple Three-Sector System.

Time t	Estimated Number of Establishments #(t)	Estimated Number of Terminal Equivalents NTE (t)
0	3	3
dt	195	459
2dt	2,115	10,440
3dt	3,660	22,250
4dt	3,900	25,710
5dt	3,960	26,040
6dt	3,975	26,130
7dt	3,981	26,145
⋮	⋮	⋮

These results are plotted in Figure 10.5; also plotted are the corresponding saturation levels now calculated following Section 10.2.

Figure 10.5: Build-up of Data Network for a Simple Three-Sector System.



The cut-off transaction rate is CO_i, where

$$CO_i = \frac{CNU}{C_i} = 0.0257 \qquad ...(10.67).$$

From Figure 10.4, the total number $\#_i$ of sector i establishments which could justify data network usage is

$$\#_i \approx 1,450 \qquad ...(10.68),$$

while the approach of equation 10.10 gives the estimated number of terminal equivalents NTE_i as

$$NTE_i \approx \frac{256.2}{0.0257} = 9,960 \qquad ...(10.69).$$

The corresponding saturation levels for the whole system are # and NTE, where

$$\# = 3 \times \#_i \approx 4,350$$
$$NTE = 3 \times NTE_i \approx 29,880 \qquad ...(10.70).$$

It is observed from Figure 10.5 that the S-curves are saturating about 8% and 12% below these saturation levels; thus a correction of the order of 10% would have to be made to the values of equation 10.70 to make these acceptable as real saturation levels.

The build-up of our simple model is extremely rapid, reaching within a percent of the actual saturation level after five time intervals. In the following subsection, the model is modified by constraints to slow down this very rapid growth and to make the system somewhat more realistic.

d. Constraints and Modifications

The first constraint introduced is a "supply-rate constraint" which limits the rate at which TEs can be supplied by the telecommunication Administration: it is arbitrarily assumed that the number of additional TEs supplied in any time interval cannot exceed $1\frac{1}{2}$ times the number supplied in the previous time interval. Since the system is "seeded" at time t=0, this constraint is taken to operate from the end of the first time interval. Thus

$$NTE'(t) \leq 1.5 \times NTE'(t-dt)$$
$$\text{for } t \geq dt \qquad \ldots(10.71)$$

where NTE'(t) is the increase in the number of TEs during the time interval from t to t+dt. This first difference is defined by

$$NTE'(t) \equiv NTE(t+dt) - NTE(t) \qquad \ldots(10.72).$$

This supply-rate constraint relates to the limited capacity of suppliers to the telecommunication Administration; it does not include limitations of supply which might occur if the Administration was unprepared for the future growth of demand or if unexpected demand were to develop.

This constraint is taken to operate concurrently with an "absorption-rate constraint" which limits the rate at which an establishment can absorb TEs into its structure: it is arbitrarily assumed that only one new TE can be absorbed by any establishment in any time interval. Used with the skimming approach of equation 10.54, this second constraint takes the form

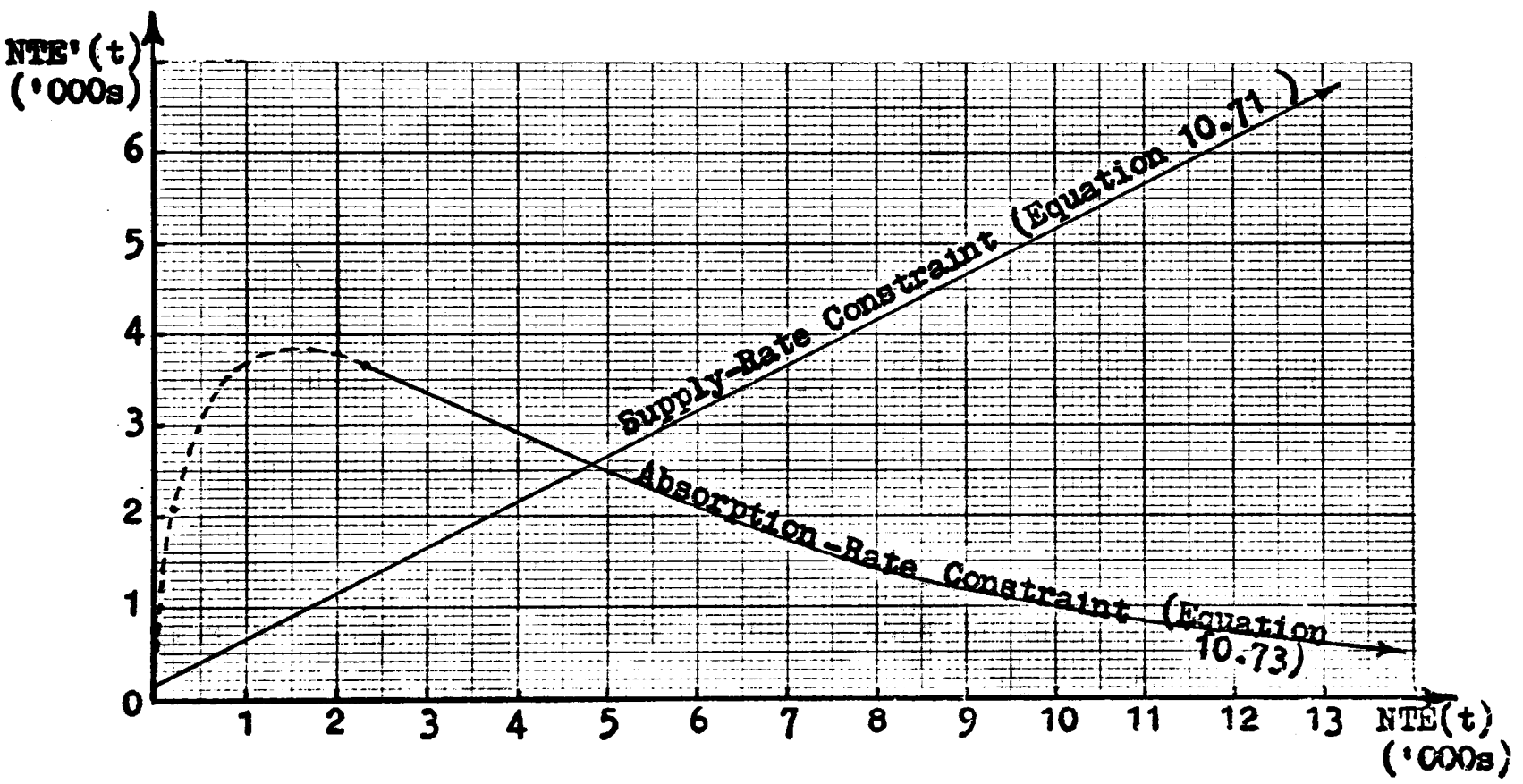
$$n\#_i(t) \leq {}_{n-1}\#_i(t-dt) \qquad \ldots.(10.73).$$

This absorption-rate constraint indicates that an establishment will not immediately (upon joining the data network) have the economically

justified number of TEs, as was implicitly assumed in the previous subsection. (This constraint may also be taken to include the fact that the initial growth of the network will be slower than might otherwise be expected, since establishments will be relatively slow to appreciate the full benefits of data network usage.)

The effect of these two constraints upon the simple three-sector system modelled in the previous subsection is indicated in Figure 10.6: the boundary curves are obtained by plotting appropriately calculated values of the first difference NTE'(t) against NTE(t).

Figure 10.6: Constraints on the Build-up of a Data Network.



It is observed from Figure 10.6 that growth will initally be supply-limited and will later be restricted by the absorption-rate constraint. This is indicated by Table 10.6, which describes the build-up of data network usage under the influence of the two constraints considered above; the NTE(t) figures from this table are plotted in Figure 10.7 below.

From Figures 10.6 and 10.7, the point of inflection is

$$\begin{aligned} t &= 6.3 \text{ dt} \\ NTE(t) &= 4{,}800 \end{aligned} \qquad \ldots(10.74).$$

Table 10.6 : Build-up of Data Network for a Simple Three-Sector System with Two Constraints Operating.

Time t	Estimated Number of Terminal Equivalents NTE(t)	First Difference NTE'(t)	
0	3	195	1.
dt	198	293	1.
2dt	491	439	1.
3dt	930	658	1.
4dt	1,588	987	1.
5dt	2,575	1,481	1.
6dt	4,056	2,221	1.
7dt	6,277	2,000	2.
8dt	8,280	1,360	2.
9dt	9,640	1,070	2.
10dt	10,710	900	2.
11dt	11,610	760	2.
12dt	12,370	670	2.
13dt	13,040	580	2.
14dt	13,620	510	2.
15dt	14,130	450	2.
16dt	14,580	400	2.
17dt	14,980	370	2.
18dt	15,350		
⋮	⋮	⋮	

Notes: 1. Subject to supply-rate constraint.
2. Subject to absorption-rate constraint.

The S-curve of Table 10.6 is now compared with other S-curves used in telecommunication forecasting (Section 3.2) by fitting these to this point of inflection. Using equations 3.3, 3.4 and 10.74, the appropriate negative exponential S-curve is

$$NTE(t) = 35{,}500 \times e^{-12.6\ dt/t} \qquad \ldots(10.75).$$

This equation is plotted in Figure 10.7 as a dashed curve; the fit is reasonable to the curve of Table 10.6. Also plotted (as a dotted curve) is a logistic curve. Using equations 3.2 and 10.74, and fitting equation 3.1 to the t = 3dt value of

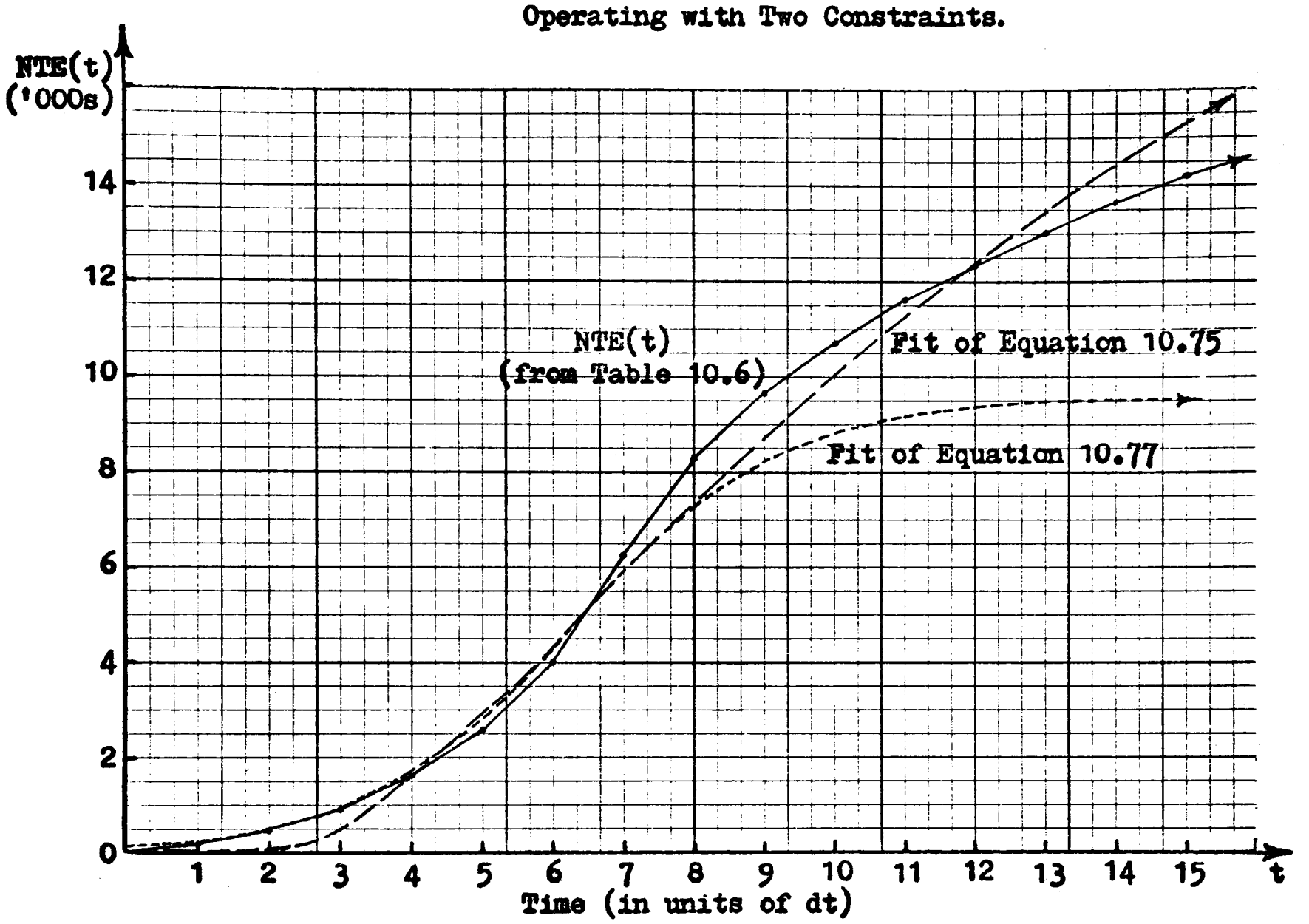
$$NTE(3dt) = 930 \qquad \ldots(10.76),$$

gives the logistic curve

$$NTE(t) = \frac{9{,}600}{1 + e^{0.677(6.3 - t/dt)}} \qquad \ldots(10.77).$$

The fit of this equation to the curve of Table 10.6 is only acceptable for low t values; this is expected from the low saturation level

Figure 10.7: Build-up of Data Network for Simple System Operating with Two Constraints.



of 9,600 TEs.

The suggested build-up of Table 10.6 is based upon calculations for what is obviously a highly over-simplified system. For actual forecasting to be carried out, a far more realistic system should be modelled; possible refinements include the extension of the system to many sectors, the use of a more realistic input-output matrix, and the use of more realistic constraints. Further modifications of the model would involve attributing only a fraction of an establishment's total transactions to any one TE, including Post Office Marketing efforts (which reduce dt), and including lags involved in augmenting the network's capital plant.

While such lags might make the system slightly oscillatory, further oscillatory influences may also be noted. For example, the rate of build-up has been assumed to depend upon the (level of) total transactions attributable to establishments on the network at any

time; constraints have limited this rate.† A more complex model would allow rates as well as levels to influence the build-up of demand. Thus an establishment might increase its rate of build-up of TEs if a competitor is rapidly building up a data transmission system; this is a positive interaction. Alternatively, a negative interaction might result when establishments slow down their rate of build-up through excess caution instilled by seeing others "have their fingers burnt". If all such interactions are positive (negative), the rate of build-up will be amplified (attenuated); if some interactions are positive and others are negative, oscillations in network build-up might be expected.

10.5 Market Growth Over Time

While the previous section has been more concerned with developing a theoretical approach than with deriving an actual S-curve "shape" for the build-up of a data network, it is of interest to fit the curve of Table 10.6 to the available data (Section 10.4.a), giving a forecast of total market growth over time. The use of this curve to estimate the future transient approach to the limit line (Section 10.3) of network usage gives only a first approximation; this is particularly noted from the sensitivity of S-curve shapes to changes in parameter values and in assumptions made.

To fit this curve to the 1970 "height" of equation 10.38, it is noted that the actual saturation limit of this curve is

$$NTE_{system} \approx 19{,}000 \qquad \ldots(10.78).$$

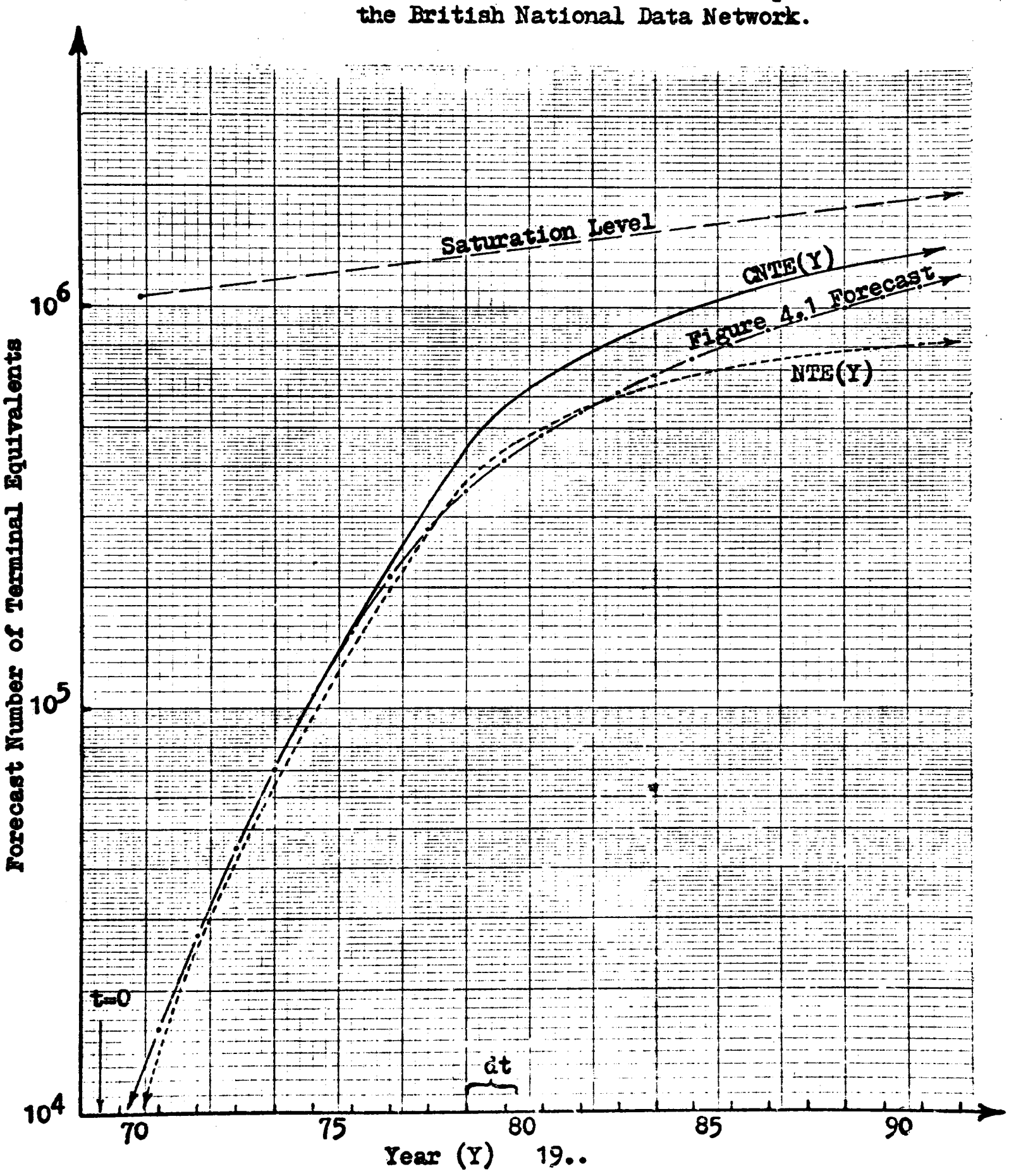
(This is obtained by plotting Table 10.6 on semi-log paper and extrapolating.) Thus a scaling factor of about 56X must be used on the figures of Table 10.6 to make them applicable to the whole British economy. It now remains to fit the scaled S-curve which results to the current rate of growth for data transmission facilities (i.e. to the "width" parameter). To achieve this, the curve of Figure 4.1 is first converted to terminal equivalents, using the conversion factor (derived from equations 5.4 and 10.1)

$$\left\{\begin{array}{l}\text{Number of}\\ \text{TEs forecast}\end{array}\right\} = 1.378 \times \left\{\begin{array}{l}\text{Number of}\\ \text{terminals forecast}\end{array}\right\} \qquad \ldots(10.79).$$

† Indeed, the constraints used have almost completely masked the original theoretical basis of Section 10.4.b; the build-up of Table 10.6 depends almost entirely upon constraint parameters (equations 10.71 and 10.73).

The use of this factor shifts the curve of Figure 4.1 to its new level plotted in Figure 10.8.

Figure 10.8: Forecasts of the Possible Build-up of the British National Data Network.



The scaled S-curve is now fitted approximately (the reason for this will shortly become apparent) to this plotted curve, by scaling the dt time interval as

$$dt \approx 1\frac{1}{3} \text{ years} \qquad \ldots(10.80)$$

and by choosing the initial point

$$t = 0 \quad \text{midway through 1969} \qquad \ldots(10.81).$$

The resulting curve is plotted in Figure 10.8, by dotted points, as the estimated number of terminal equivalents in year Y, NTE(Y). The distinct break in the curve at year 1979 corresponds to the inflection point where the absorption-rate constraint replaces the supply-rate constraint.

But since the forecast NTE(Y) refers to densities (Section 10.4.a), the growth factor of Section 10.3 must be included, giving the corrected estimated number of TEs in year Y, CNTE(Y), as

$$CNTE(Y) = GF(Y) \times NTE(Y) \qquad \ldots(10.82)$$

where GF(Y) is the appropriate growth factor derived from the saturation level plotted in Figure 10.8 (from Figure 10.3). The corresponding corrected forecasts are plotted by a solid curve in Figure 10.8; it is noted that the fit to the Figure 4.1 forecast is particularly good for the near future period 1972-1975. It is also noted that CNTE(Y) suggests a considerably greater demand for the 1980's than that forecast in Table 4.3.

It must be remembered that the CNTE(Y) forecasts derived here are only first approximations. The use of the trend extrapolation or curve-fitting forecasting technique means that any results obtained are "surprise-free" (Section 10.4.a); this is not very realistic in the rapidly changing field of telecommunications. Moreover, both the trend forecast of Figure 4.1 and the shape of the S-curve derived in Section 10.4 involve considerable uncertainty; a more accurate forecast would involve the derivation of an S-curve for a far more realistic (and complex) system than that considered above.

While the forecasts derived above are only approximate, it is interesting to see how they might be incorporated in a general Industrial Dynamics simulation model (Section C.1) of the development of the national data network. This might best be achieved through the use of the XUDR(I-1) component (equation 5.1), which closes both the cost and benefit feedback loops in the simple model of Figure 3.1.

10.6 Conclusion

This chapter has developed a general theory of demand for a national data network. While actual forecasts have been made, the emphasis throughout is on providing a methodology for determining how demand could reasonably be expected to grow in the future. With

the modifications and improvements suggested, it should be possible to make a very accurate assessment of demand; this would be of considerable value to all branches of the Post Office concerned with the future of the data network.

CHAPTER 11 : QUALITATIVE ASSESSMENT OF SOME POSSIBLE SOCIAL CONSEQUENCES OF A NATIONAL DATA NETWORK

11.1 Introduction

As noted in Section 7.2, it is not really possible to examine a national data network in isolation, since its usage would be closely linked with that of its complementing technology - computing. Indeed these two industries (digital data communications and computers) are not merely complementary: they are mutually indispensible. The computer requires the existence of a national data network for it to have widespread coverage, and the data network needs computer traffic for its operation to be economical. Since the computer industry has been advancing (and reducing costs) more rapidly than the data transmission industry (Zeidler *et al.*, 1969), there is a danger that society will not gain its maximum benefit unless advances in the latter industry can be speeded up.

It is an enormous task to attempt to consider the social consequences of computers generally; several technological forecasting studies have, however, probed possible future applications of and implications of the so-called "computer utility" (Barnett & Associates, 1967; Gruenberger, 1968). This chapter attempts a brief qualitative study of the future of the national data network. (As mentioned in Sections 7.1 and 9.6, the domestic sector is not explicitly considered; consequences are considered of business applications of the network alone.) Although many of the future consequences which will be mentioned are as much computer-based as data network-based, they will all be directly attributable to the data network; none of the chains of consequences considered would be realizable in the absence of a national data network.

11.2 An Approach to Determining Possible Social Consequences

In Section 11.3 a systematic catalogue (as exhaustive as possible) of some of the possibilities made real by a national data network is presented in the structured form of flow diagrams or causative chains† derived using "intuitive technological forecasting" (Jantsch, 1967). The approach taken involves including all technically

† This approach is comparable to the use of "SOON charts" to indicate Sequences Of Opportunities and Negatives (Ayres, 1969).

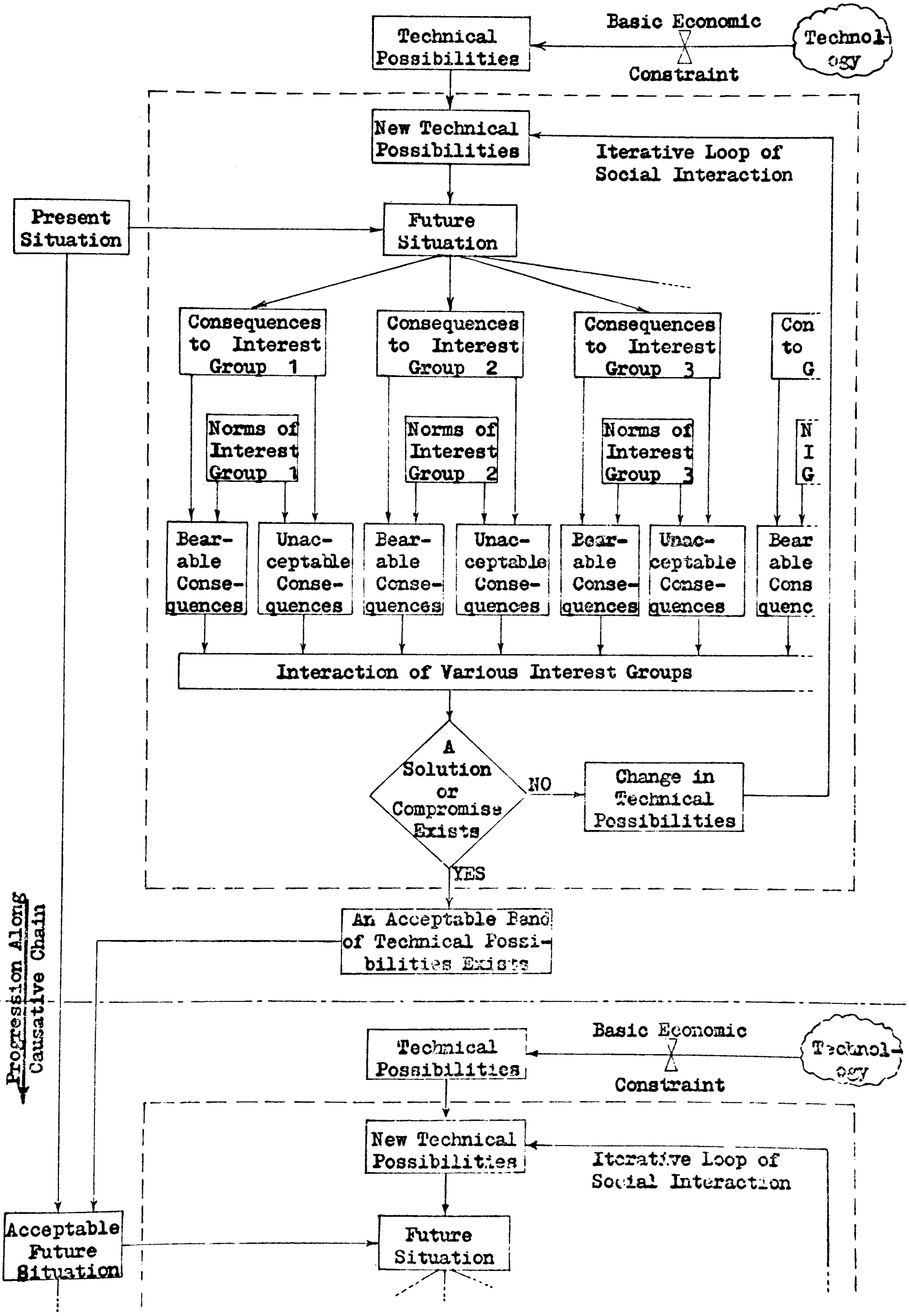
feasible ideas; the extent of usage and application of these will depend upon economic and social factors.

Economic factors may be considered fairly straightforwardly: since almost anything is technically feasible if one is willing to spend enough on it, economic factors can be taken to constrain the technical feasibility of a possibility. For our purposes, technical feasibility and economic feasibility are thus assumed to be virtually synonomous. The consideration of social factors is rather more difficult. The easiest approach is to include these factors implicitly in any technological forecasts made, as in Helmer's (1966) Delphi technique. Forecasts of future social developments may also be made in parallel with technological forecasts (Sulc, 1969).

Since the interaction between social factors and technical possibilities is dynamic, these should really be considered explicitly and in conjunction with each other. The approach of this chapter considers *how* various things may happen in the future, and *how* decisions would be made in the future. Since future decisions will result from vigorous interaction between different groups of people, it is necessary to determine who would find various technically-derived changes desirable, and what powers would push for these changes. This consideration of interactions follows causative chains of possibilities as far as possible; these chains should provide a fairly well-balanced scenario of possible future consequences.

We first examine how future interactions between various interested parties (or interest groups) might provide decisions about acceptable bands of technical possibilities; Figure 11.1 suggests how such a band might be determined for any step along a causative chain. A set of technical possibilities results from the working of a basic economic constraint upon the "pool" of technology. By interacting with the present situation, these possibilities produce an extrapolated future situation which induces various consequences in the interest groups. Depending upon the norms or criteria of these groups, some consequences may be labelled as bearable and some as unacceptable. The various interest groups then interact, with weightings on bearable consequences determined by the strength of each interest (or pressure) group. If a compromise solution can be obtained, an acceptable technical possibility has been determined; if a solution does not exist within the bounds provided by unacceptable consequences, then the above procedure is repeated for a new set of technical pos-

Figure 11.1: Determining Acceptable Bands of Technical Possibilities.



sibilities. By a process of iteration over the loop of social interaction (which for simplicity has been assumed to extend over only one step in a causative chain), it is possible to determine a band of technical possibilities which give socially acceptable or bearable consequences.

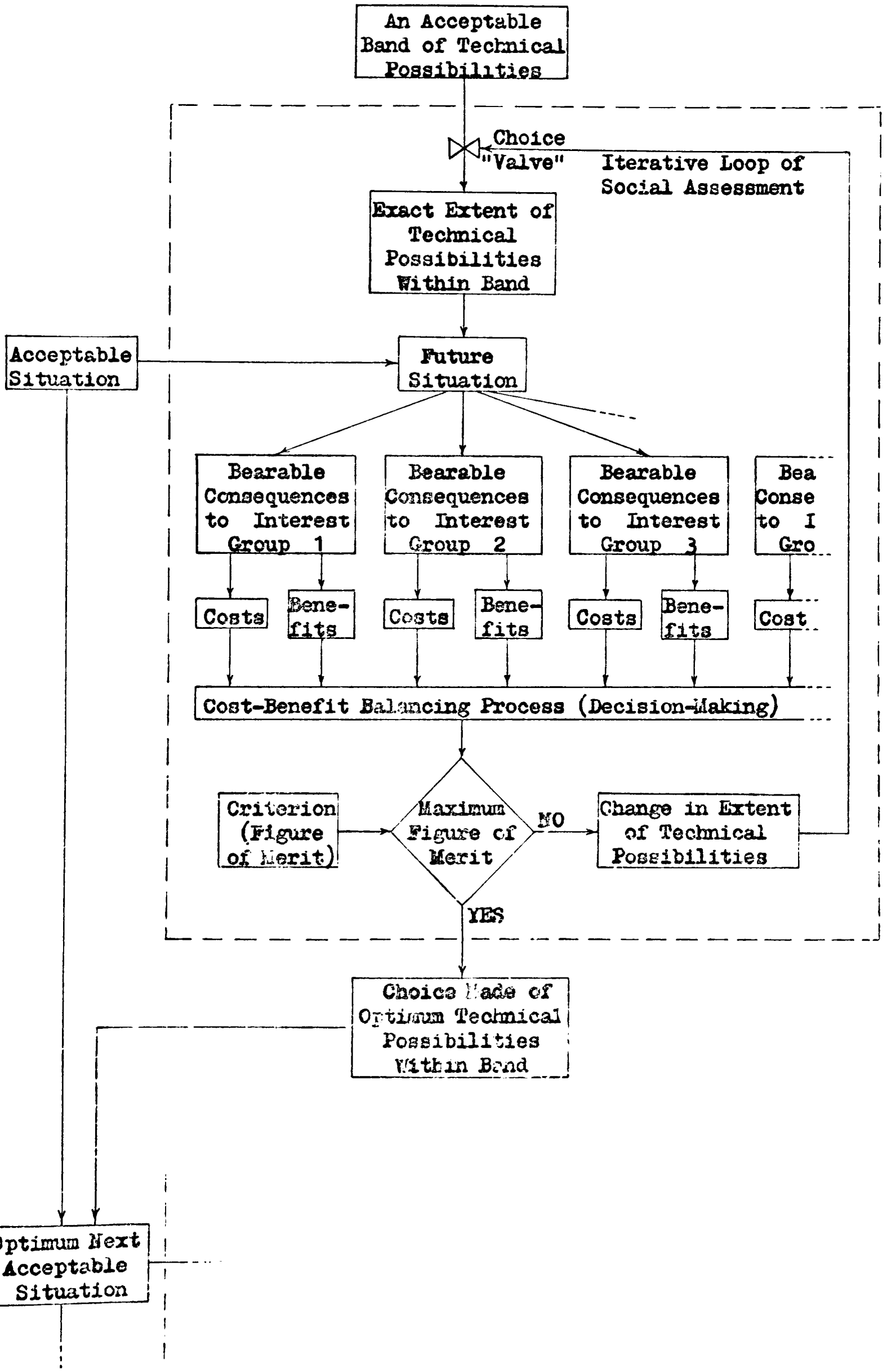
A region of acceptable possibilities might now be considered to have been created in hyperspace. The position (or description) of the possibility which will actually occur may be determined by assigning vectors to the bearable consequences of each interest group; the vigorous interaction and pressure activity of these groups could be represented by a vector "conflict" in hyperspace, where the resultant gives the compromise solution. The compromise technical possibilities thus chosen may well be far from socially optimal; the manner in which a social assessment might operate (in some cost-benefit sense) to determine the socially optimal technical possibilities is indicated in Figure 11.2.

A particular extent of technical possibilities is first chosen from within the acceptable band; the future situation which would result is then examined to see what would be the costs and benefits of the bearable consequences to each interest group. These costs and benefits are balanced (Section 2.2) and a "figure of merit", according to some cost-benefit (or other) criterion, is then maximized using the iterative loop of social assessment. Thus an optimum choice of technical possibilities may be made from within the acceptable band. (This cost-benefit optimizing approach may obviously be generalized to the more conceptual approach of Appendix A.)

Since this process may be used to move from one optimum situation to the next, an approach similar to that of dynamic programming (Bellman, 1957) might be used to determine the sequence of technical possibilities which would link an overall socially optimum future situation (determined by normative technological forecasting) with the present situation.

Returning to the considerations of Figure 11.1, it is apparent that the actual choice of the social norms of each interest group is of particular importance. Since these norms are partly time-independent and partly time- (or situation-) dependent, their description is difficult; for simplicity, only time-independent factors will be examined here. Since interest groups are composed of individual people, the pressures they exert and the norms or criteria by which they judge possible future consequences are best examined using

Figure 11.2: Determining Cost-Benefit Optimal Technical Possibilities.



a behavioural approach. Because of the fact that an individual may fulfil several roles in society, there will be considerable overlap of interest group membership. Consider, for example, the following possible categorization of individuals into interest groups:

Interest Group 1: Man qua individual person.
Interest Group 2: Man qua technologist.
Interest Group 3: Man qua manager.
Interest Group 4: Man qua ruler.
etc.

Norms for each of these interest groups may now be suggested. For Interest Group 1, where man is considered as a psychological animal existing in society, norms would be based upon individual needs and wants, as outlined by the theory of motivation's "need hierarchy" (O'Shaughnessy, 1966, pp.72-124). The consequences to Interest Group 1 of any technical possibility involve its human implications; these are of paramount importance since this Group includes the whole populace.

The norms of Interest Group 2 are simpler: its members want to push technology forward, thus increasing its impact (which they take to be beneficial) upon society. As members of Interest Group 1, technologists thus hope to increase their prestige and standing.

The description of the norms of Interest Group 3 is more difficult, since a behavioural theory (such as that of Cyert & March, 1963) really describes the interaction of Interest Groups 1 and 3. (See also Parkinson, 1958.) These norms are thus taken to describe institutional pressures of maintaining the *status quo* or of improving a firm's competitive position.

The norms of Interest Group 4 may be taken to be government policies; membership of Interest Groups 1 and 4 leads to bureaucratic activity (Parkinson, 1960).

It is now possible to indicate how the interaction of various interest groups might occur. Technologists (as Interest Group 2 members) might push for extreme technological changes which would be supported by managers (as Interest Group 3 members) as long as the results seemed attractive. Interest Group 1 members might oppose these changes as being too radical and as having far-reaching consequences. Then government (as personified by Interest Group 4 members) might adjudicate to balance the desires for economic progress and growth with the reluctance of the labour force to accept radical changes.

11.3 Possible Future Consequences of a National Data Network

This section lists some of the possibilities, both in the near and in the more distant future, which are made real by a national data network. Possible consequences are presented in the form of causative chains for three general areas in which such a network would be highly influential: in reducing the constraints of time, distance, and physical being (Section 7.1). These three constraints are of course very highly interrelated; indeed it could be argued that only two of these constraints are independent. Nevertheless, the effects of reducing each of these constraints will be examined separately (in Figures 11.3 to 11.5); many cross-overs are noted.

Each of these three causative chains commences with an organization of general technical possibilities into three categories, according to the type of communication channel which is involved. These channel types: "man-man", "man-machine" (and *vice versa*), and "machine-machine" are illustrated by the following forms of usage which relate to the present and to the near future:

Man-man:
- (telephone)
- telegraph
- Telex (Datel 100; Service† T)
- facsimile (Datel 2400, "Electrowriter", and Wideband; Services D and E)
- video links ("Confravision" and other closed circuit video)
- viewphone

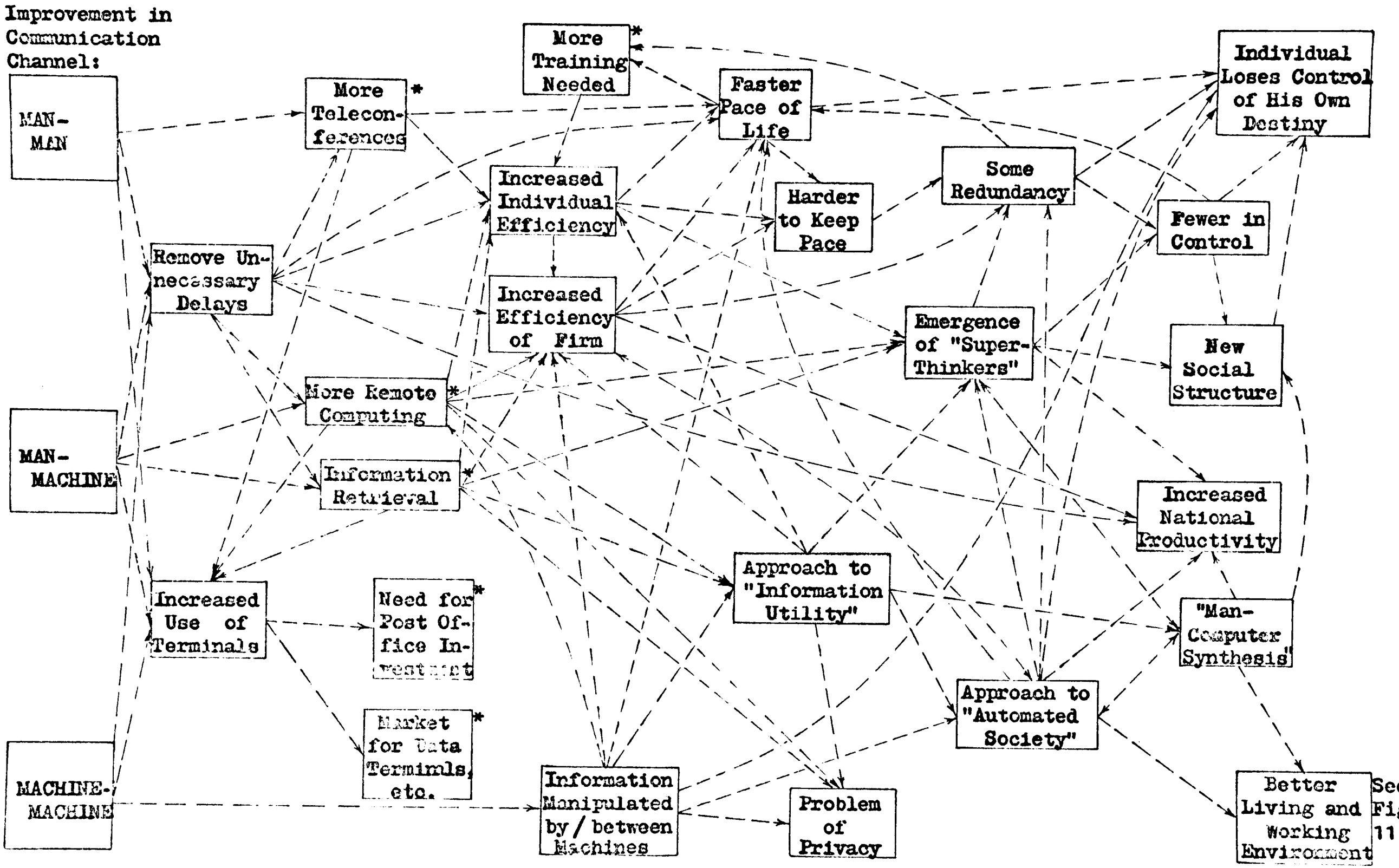
Man-machine:
- bureaux and remote access to computers (Datel 200; Service B)
- data collection and enquiry (Datel 600: Service A)

Machine-machine:
- telemetry and data collection (old Datel 300; Service C)
- high-speed (Wideband; Service E)
- inter-computer and processor to processor (Service "6").

The introduction of a national data network may be expected to lead to considerable improvements in each of these types of channel. Using these improvements as starting points, Figures 11.3 to 11.5 list various possible (first and second order) social consequences in each of the three areas of constraint reduction; taken together, these Figures provide a limited scenario of a possible future.

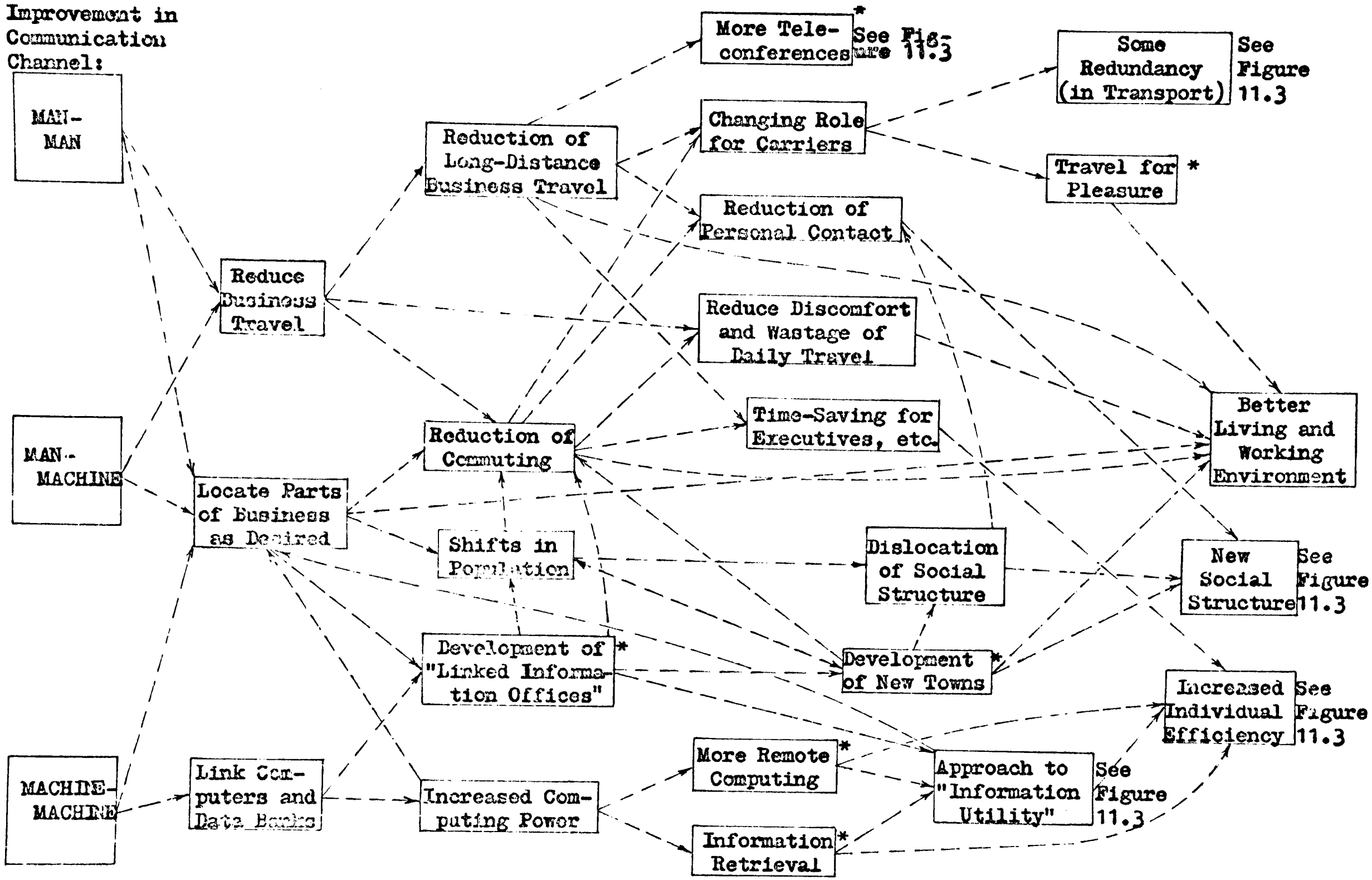
† The services refer to those of Table 4.1.

Figure 11.3: Reduction of the Time Constraint.



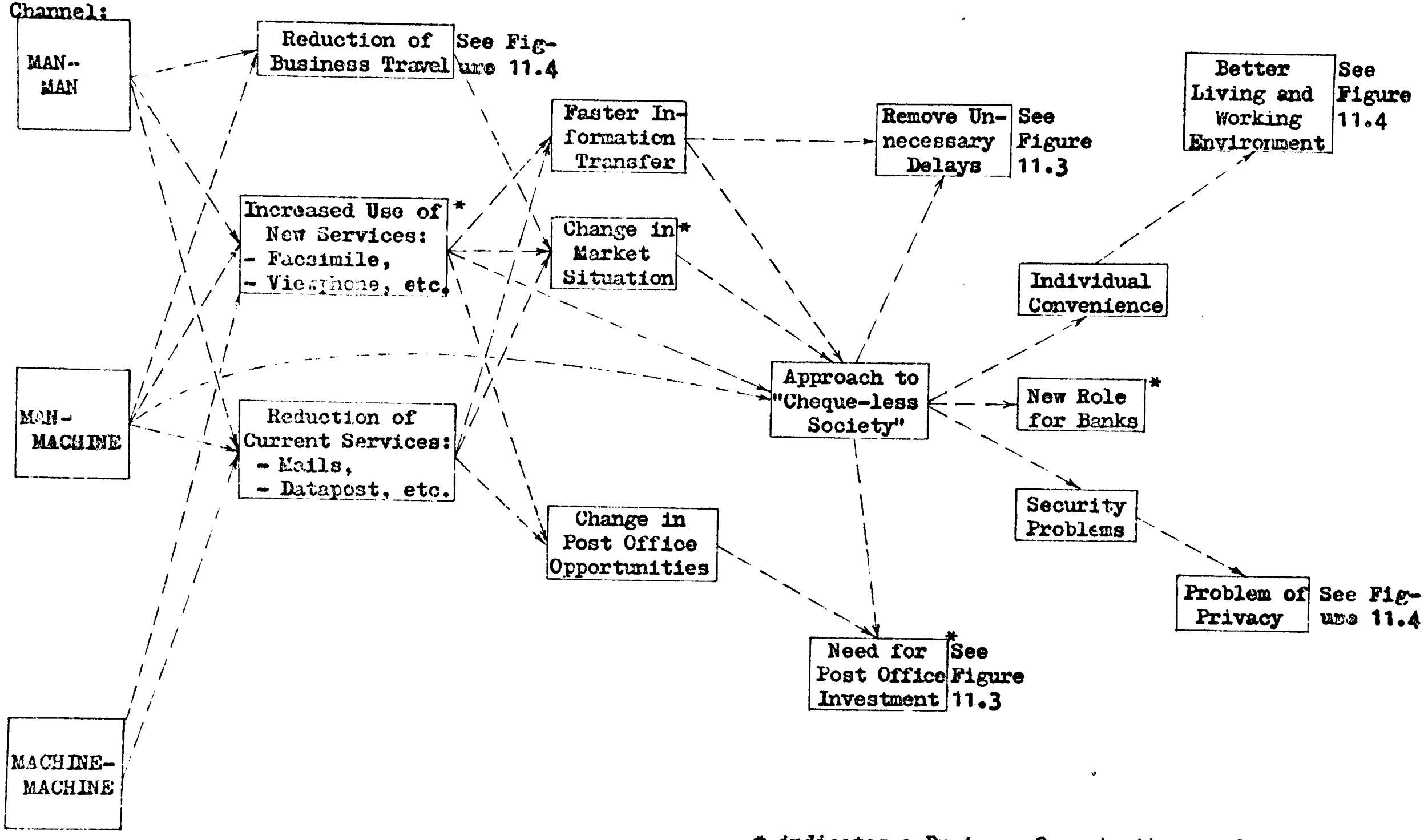
* indicates a Business Opportunity now foreseen.

Figure 11.4: Reduction of the Distance Constraint.



* indicates a Business Opportunity now foreseen.

Figure 11.5: Reduction in the Physical Constraint.



* indicates a Business Opportunity now foreseen.

It is interesting to note that this approach (involving the consideration of types of communication channel) is recommended by Wiener, who suggests (1954)

> "that society can only be understood through a study of the messages and the communication facilities which belong to it; and that in the future, development of these messages and communication facilities, messages between man and machines, between machines and man, and between machine and machine, are destined to play an ever-increasing part."

11.4 Conclusion

This chapter attempts to provide a structure within which social and economic consequences of a national data network may be examined; this structure could be used to organize the extremely ill-structured literature of the subject. Thus various published predictions of the future may be evaluated, in the social value analysis sense, by examining their repercussions on society; among such predictions are "the cheque-less society" (Head, 1966; Sackman, 1967, p.556); the "information utility", which would include information banks linked by a computer grid (Barnett *et al.*, 1967; Gruenberger, 1968; Zani & Zani 1969); "man-computer synthesis" (Licklider, 1965; Sackman, 1967, p.37; Licklider & Taylor, 1968); "arbitrage" and computerized smoothing of market fluctuations (Keefer, 1969b); the replacement of transportation by communication (Clare, 1964; Jeppsson, 1966; Handel, 1967); the problem of privacy (Armer, 1968; Stone & Warner, 1969; Hall, 1969); etc.

These second order predictions, and those suggested in Figures 11.3 to 11.5, indicate that the introduction of a national data network will have a tremendous impact upon society, since this will be as revolutionary a change as was the advent of automation or computerization. (An idea of the extent of this impact is indicated by Appendix H, which assesses the macro-economic importance of information-handling from the points of view of both employment and national cost.) Since the network will introduce a fundamental change in the infrastructure of society, it is essential that great caution be exercised to minimize the adverse social changes which might result. It is, however, felt that the overall net results of the introduction of the network will be highly beneficial to society.

CHAPTER 12 : CONCLUSION

12.1 A New Approach

This thesis provides a new approach to both the forecasting of telecommunication development and to the assessment of its consequences, with particular regard to the consideration of a national data network. The newness of the approach is noted by a comparison with the only other comprehensive data network forecasting study made to date: the SCICON (1969) report. Recognising the uncertainties involved (due to the newness of the technology, the wide variety of applications, the relatively small number of users and the very rapid growth rate, etc.), SCICON approached the forecasting problem by seven different routes:

- statistical trend projection
- technological forecasting
- finance related forecasts
- activity forecasts
- sector forecasts
- computer related forecasts
- mathematical method

The first of these must, of course, be used in any forecasting approach to link the present to the forecast future. The next three "routes" were discarded by SCICON as impracticable; the final three "routes" formed the basis of SCICON's report.

SCICON's main emphasis was upon the sector forecasts, which were obtained by market research techniques; while their results are of particular value in the short-term, their long run value is more uncertain since "users have great difficulty in giving meaningful estimates of future applications" (Post Office Telecommunications, 1969). The results obtained by all three "routes" are reasonably compatible; this is not altogether surprising, since the approaches used were almost entirely computer-oriented. SCICON's final point estimates are given in Table 4.3.

It is immediately apparent that this thesis ties in well with the SCICON report, since it attempts to forecast by the three discarded "routes". Our approach involves modelling the applications of a data network in the most general sense; thus future activities are explicitly considered. An assessment of benefits (initially described in terms of constraint reduction) then follows; this gives the amount that an establishment can budget for data network usage,

making the forecasting approach finance related. Chapter 11 is obviously a form of exploratory technological forecasting which attempts to trace out future consequences of activities made possible by a data network.

The forecasting approach used here has, moreover, a certain theoretical appeal since it models the underlying value of data network usage and the possible mechanism of network build-up, rather than just forecasting the results. By attempting to "see into the minds" of decision-makers (Section 10.1), this approach tries to determine the underlying ("implicit") demand rather than merely the expressed ("explicit") demand (Section 4.1). Since quantitative models are used throughout this thesis, the sensitivity of results to parameter (and to model) changes may easily be determined. Thus the results obtained are considerably more useful than are the point estimates of Table 4.3.

Since our forecasting of future demand for data transmission facilities is based upon their value to users (Section 3.3), it becomes possible to carry out a social value analysis (Section 2.4) of the proposed general national data network (Section 4.4). While a comprehensive social value analysis of the whole dynamic future of the data network has not been made, many of the component parts of such an analysis have been provided. The choice between Datel services and a new digital network has been examined in some detail (Chapter 6); models of measurable costs and benefits have been developed and used (Chapters 5, 7, 8, 9 and 10), and a qualitative methodology for including possible social consequences is given (Chapter 11). These components do enable a preliminary social value analysis to be made (Sections 9.7 and 12.2).

These components are thus useful in decision-making. Indeed, in providing a new approach to forecasting and assessing the future of a national data network, this whole thesis provides a decision-making tool which should be of considerable value to all those concerned with the network.

12.2 The Future of a National Data Network in Britain

Since the contribution of this thesis is primarily its provision of a new decision-making tool, the approach and methodology are emphasized; the forecasts derived are really estimates, and many of them are only first approximations. In the absence of better forecasts (particularly of benefits), however, these must suffice; a

summary follows.

The size of the national data network is expected to follow the CNTE(Y) curve of Figure 10.8. While this growth is similar to that forecast by the fitted trend line of Figure 4.1 until 1975, the network size is expected to exceed this latter forecast thereafter. It is now forecast that there will be one million terminal equivalents by 1985, and that there will be one million terminals by 1991 (Figure 10.8 and equation 10.79). These (business sector) forecasts assume, of course, that the Post Office (and its suppliers) will be able to satisfy the demand for network facilities. The final saturation level of the business market is over one million terminal equivalents for the 1970 British economy (equation 10.38); this is expected to grow as indicated by Figure 10.8.

While cost estimates for the network are given in Section 4.4, a more meaningful cost figure is that the present value of the total direct cost of the whole investment project is some £260 million (equation 5.26) in 1970 pounds. Although this figure is high, it is considerably less than what it would cost to carry the forecast data traffic by the Datel services (Chapter 6).

The direct benefits of the national data network far exceed the direct costs. The Post Office is expected to receive a benefit whose overall net present value is some £120 million (equation 5.27); this amount is, however, dwarfed by the total (first order quantifiable) benefit whose present value is of the order of £4,000 million! This benefit, which should grow over time (at the rate given in Figure 10.3), corresponds to an increase in the G.D.P. of some 6% (Section 9.6).

These estimates suggest that the national data network investment project should be overwhelmingly beneficial from an economic point of view. Chapter 11 considers some social consequences and concludes that the net results of the network will be highly beneficial to society. Thus a preliminary social value analysis "absolutely" recommends this project (Section 9.7).

12.3 Further Research Areas

The obvious next step would involve carrying out a full social value analysis of the national data network; this analysis would be based upon a large computerized simulation model (Section C.1) which would enable the full dynamic consequences of possible future

developments to be examined. (This model should also enable the social value and marketability of various facilities which might be offered by a national data network to be assessed.) Such a comprehensive and dynamic model has not been used in this thesis for several reasons. Since many parameters are as yet unknown, considerable research work will be required to define and quantify them. And since most of the results which are now known are (Post Office) confidential, they could not be used in this thesis. With very little data available, this thesis has concentrated upon developing a methodology which could be used in social value analysis. This methodology may be considered to form a theory of telecommunication forecasting and assessment; empirical evidence will be required to prove or disprove it.

It is also expected that the theoretical basis of this thesis may be generalized to give a new approach to social value analysis, as suggested in Appendix A. Further research is needed to assess the potential of this approach and to attempt its application.

APPENDIX A: A NEW APPROACH TO SOCIAL VALUE ANALYSIS

It is obviously useful to be able to quantify social consequences in terms of quantities which can be superposed and added linearly; for example, an important thesis of Chapters 7, 8 and 9 is that many benefits may be considered in terms of the overall time saving involved, so that time provides a universal measure. It seems intuitively reasonable to assume that there might exist other measures or quantities by which social consequences could be assessed; these would form the co-ordinates or dimensions of a hyperspace which at this point must remain conceptual. (This approach is a generalization of the discussion of Section 11.2.)

Suppose now that it was possible to choose a set of co-ordinate quantities which was suitable and sufficient for social assessment. Then any particular project contemplated would have a certain shape in hyperspace. Assessment and decision-making might now involve choosing a suitable shape from among various possibilities. And while this new approach could not make it possible to evade decisions, it might simplify decision-making by suggesting what was a suitable or acceptable shape in hyperspace. For here historical information from past cases could be categorized: it would be hoped that projects which were "successful" would have shapes of one type (location, and inclination) in hyperspace, while wrongly undertaken projects would have sufficiently different shapes. If such were the case, a new and valuable tool for social value analysis would have been created.

While the approach suggested here would provide only a very crude attempt to systematize decision-making, it would still be a great improvement over cost-benefit analysis as usually practised. A cost-benefit analysis tries to reduce all costs and benefits to a single monetary scale by which they are measured; any features of a project which cannot be so reduced are neglected or must be considered separately, often as implicit constraints (Section 2.2). The new approach now suggested recognizes the fact that many features of a project are really incommensurable; it attempts to find an acceptable solution using what is really a multi-dimensional optimization† approach. While this optimization is carried out in hyperspace, the cost-benefit form of optimization is really only achieved in a single dimension.

† This simultaneous optimization in multiple dimensions is made possible by the effective trade-offs between dimensions which are provided by interest group interaction (Section 11.2).

APPENDIX B : SURVEY OF DATEL SERVICES

All communication facilities for data transmission provided by the British Post Office are known as "Datel" (a contraction of "Data and Telecommunication") services. These services are a combination of a particular type of line and, where necessary, a modem (modulator-demodulator) unit to provide a customer with a data transmission facility for a stated speed range. Table B.1 gives a summary of some of the important and relevant characteristics of Datel services (Post Office, 1968c; Post Office Telecommunications, 1969).

This appendix is particularly concerned with Datel tariffs. In general, public line tariffs involve a nominal rental for the line (for example, the £24 p.a. telephone network rental for a business exchange line) plus a charge dependent upon usage. Private lines have a fixed annual rental; this is cheaper than a public line if one is sending a very large volume of data traffic (for many hours per day), particularly if this transmission is not within a local STD area. Estimates are now made of typical annual costs per terminal for public Datel usage; these provide a standard by which tariffs for a general national data network (Section 5.3) may be evaluated.

The annual charge for the basic public Telex terminal with a teleprinter is £160 (Neilson, 1968); to this amount must be added the daily running expenses in 1p (2.4d) units, where the amount of time available for a unit depends on the distance between Telex centres. An estimate of the annual transmission charge for a typical Telex user may be made by comparing the total number of inland Telex units used (Post Office, 1969a) with the number of Telex terminals in operation (Post Office, 1969b) at the same time, giving an average annual usage of 11,000 Telex units costing £92 p.a. at the old 2d unit charge, or £110 p.a. at the new 1p unit charge. Since a comparison of total inland Telex income (Post Office, 1969a) with the number of terminals suggests an average Telex cost of £292 p.a. at the old unit charge, the average rental paid for terminal equipment is about £200 p.a.; it is assumed that the rental could be reduced by about £50 p.a. with a national data network.

For Datel 200, a public network subscriber rents a Post Office Modem No.2 at £100 p.a.; in addition, he pays £24 p.a. for a business exchange connection, plus STD charges. Now the ITT sales

Table B.1 : A Summary of Some Characteristics of the Datel Services.

Datel Service	Facility	Signal Path	Maximum Transmission Rate (b/s)	Tariff or Charge Basis	Modem	Application of Service	Remarks
100	Telex	Switched Public Telex Network	50	Telex	None	Telex	
	Telegraph	Private Wire	50	Tariff H	None	Telegraph	
			100	Tariff J			
200	Telephone	Public Network	200	STD	P.O. Modem No.2 @ £100 p.a.	Bureau and broadcast	P.O. Modem No.2 provides simultaneous two-way transmission
		Private Wire		Tariff S1	See Note		
600	Telephone	Public Network	600	STD	P.O. Modem No.1 @ £100 p.a.	Bank enquiry and distribution; Data collection	P.O. Modem No. 1 can have a 75 b/s return channel simultaneous with data channel
		Private Wire	1,200	Tariffs S1,S2, and S3.	See Note		
2400	Telephone	Public Network (Standby)	1,200	STD	P.O. Modem No.7 @ £200 p.a.	Coded facsimile; Magnetic tape	P.O. Modem No.7 has various models available providing optional facilities
		Private Wire (Specially equalised)	2,400	Tariff T	See Note		
Wide-band	Special Links		48,000 240,000	Special, from about £3000 p.a.	P.O. Modems No.8 and No.9 @ ~ £900 p.a.	Uncoded facsimile, High speed use	

Note: With Private Wire, a customer can use private, but Post Office approved, equipment and modems.

literature for their R.T.S. Bureau suggests that a typical subscriber pays 5/- per day for STD charges; this corresponds to two hours per day of typical use in the local call area. (While this estimate was based upon the old 2d per 4 minute local call STD tariff, which was effective from 1 October 1968, a similar estimate is made for the new STD tariff of 6 minutes for 1p (2.4d) in the local area, effective from 1 July 1970.) This estimate corresponds to an annual STD cost of about £63. However, a recent Post Office survey (Piper, 1970) of a sample of computer bureau subscribers indicated that much higher STD charges (averaging about £500 p.a.) were actually paid, since many Datel 200 calls were made at STD trunk rates. Since this sample was probably biased towards large users, the estimate is made that typical STD charges come to about £200 p.a. Totalling these amounts, the annual Post Office charges for a typical Datel 200 subscribers are estimated as £324.

It is expected that annual charges for public network Datel 600 service are similar to these, especially since the modem rentals are identical. And similar transmission charges are also expected for public network Datel 2400 subscribers, whose Post Office Modem No. 7 has an annual rental of £200.

These estimates are summarized in Table B.2 which gives typical annual costs per terminal for public Datel usage; these exclude the costs of terminal usage, but include modem rentals, exchange line rentals, as well as the actual transmission costs.

Table B.2 : Typical Annual Costs per Terminal for Public Datel Usage.

Datel Service	Modem Rental (£ p.a.)	Exchange Line Rental (£ p.a.)	Transmission Charge (£ p.a.)	Total Costs (£ p.a.)
100	∿ 50†		∿ 110	∿ 160
200	100	24	∿ 200	∿ 324
600	100	24	∿ 200	∿ 324
2400	200	24	∿ 200	∿ 424

† This figure is attributed since, with a national data network, a Telex-type subscriber should save about this amount. (See text.)

APPENDIX C : COMPUTER SIMULATION

C.1 The Industrial Dynamics Approach

Industrial Dynamics (ID) involves the application of feedback concepts to social systems. It has a very wide range of application because of the common systems base in the structure of all social-economic-industrial-political organizations; ID relates this structure to its dynamic consequences (Forrester, 1961, 1968a, 1968b). One of the most striking aspects of an ID model is its complexity: the systems studied are typically high-order nonlinear systems with multiple and interrelated loops, and both positive and negative feedback (Nord, 1963; Packer, 1964; Robert, 1964). Because of this high degree of complexity, great difficulties are encountered in obtaining information to build an ID model and in validating a complete model. It is not therefore surprising that the whole Industrial Dynamics approach has come under severe criticism (Ansoff & Slevin, 1968). In spite of these criticisms, it is felt that an ID study could profitably be made in the field of telecommunications.

An ordinary ID study is usually predominantly concerned with the firm. Customers are not really considered, except as a "pool" of potential orders from which actual orders can come at a rate governed by the firm's quoted delivery time and unit price. The firm is considered to exist within a "given" environment; the ID approach involves adjusting various parameters of the firm to make its response to external changes both rapid and stable.

The effect of a change in the telecommunication structure may be considered at two levels. At the higher level, the effects on users of a change in the telecommunication services provided might be examined. While ID recognizes that a firm really observes and interacts with its environment *via* the information linkages with its customers, its suppliers, etc. by considering "information flow" as one of the six interconnecting networks comprising the basic ID system, the medium of transmission is assumed to be given. But if the Post Office changes the structure of telecommunication services, then the environment becomes changeable. These higher level considerations may be visualized within Forrester's framework of "meta-levels" (Forrester, 1968a; Davison, 1968). The ordinary "system", at the

firm or industry level, has a decider who makes a decisions based upon information received *via* feedback loops, etc. The next level up is that of the "meta-system", in which rules, upon which the decider within the system will base his decision, are chosen. At the next level is the "meta-meta-system", by which the environment is created; the rules of the meta-system are of course based upon the state of the environment.

The urban environment is now being studied by Forrester (1969). A study of the environmental changes due to a change in communications (whether it be an improvement in existing services or the introduction of a new service such as a national data network), and the resulting effect on inter-firm (and other) informational interactions within society, is similarly important. A partial approach to such a study has been made in Chapters 8 to 11.

At the lower level, the Post Office is considered to provide services of transferring information, so its "product" is the service of information transmission. An ID study carried out at this level would be of value in considering aspects of Post Office operation such as forecasting demand, marketing, and its interaction with private industrial suppliers of telecommunication equipment.

Linking together studies carried out at these two levels, a general ID simulation model covering various aspects of the national data network (as sketched in Figure 3.1) might be developed. For such a model to be realistic, enormous complexity would be needed. But this would be justified by the ways in which such a system model could be used: it would indicate financial aspects to the Post Office, to contractors and to users; it would indicate benefits to individual users and to the country as a whole, and it would indicate how the network might grow in terms of both numbers of subscribers and their usage.

C.2 The Simulation Language "KID"

While the above discussion examines how the subject matter of this thesis could be incorporated in a vast ID model, the main use made here of the ID methodology involves the simulation language of its compiler: DYNAMO (Pugh, 1963). Although Ansoff & Slevin (1968) are suspect of "the spectre of DYNAMO", its approach of computing levels from rates, then rates from levels, is felt to be valuable. However, a more flexible simulation language is required for various

reasons; a new FORTRAN-based simulation language "KID" provides this.

The DYNAMO format does not include decision points. Although the "flow controller" of DYNAMO is called an "action" or "decision" variable, it cannot redirect flow; it merely alters its rate. Thus Forrester's ID merely studies the dynamic behaviour of a static structure. With decision points (represented by FORTRAN IF-statements), KID makes it possible to consider the more complex problem of the dynamic behaviour of a dynamically changing structure.

KID is also more flexible than DYNAMO in allowing the use of initial values for rates as well as for levels, rather than merely allowing levels to have initial values. A simple analogy from mechanics is that DYNAMO simulates the position and velocity over time for an object starting from rest at some initial position; KID carries out a simulation in which the object may have a non-zero initial velocity as well. (This is achieved by having the simulation over time represented by a FORTRAN DO-loop with time I varying from 2 onwards; levels and rates are given initial values at time I=1.) The computer program computes the rates during time interval I-1, then obtains the levels at time I; the interdependence of one variable upon another is illustrated by the flow charts of Figures 5.1 and 5.2.

A further flexibility feature of KID is that, by using FORTRAN, it allows an almost unlimited number of equation formulations; DYNAMO, on the other hand, requires expressions to be written in one of a number of set "equation forms" (Pugh, 1963), thus restricting a program writer considerably. Names of parameters and variables are formed mnemonically, within FORTRAN's six letter allowed word-length, following the convention of integer and real types. The following additional rules apply to KID as used in Chapter 5: names beginning with CS refer to costs; names beginning with D give a number of data terminals, and names beginning with I refer to years. If the name ends in L, R, or C, then it refers to a level, a rate, or a constant respectively. If the second last letter (of a name of at least three letters) is I, then it refers to an individual Service; these Services are defined using the array subscript J. (Thus, for example, --- IR(I-1,J) is a rate.) These rules are illustrated by the list of parameter names given in Section GLOSSARY 2.

C.3 "Standard" Computer Program for Chapter 5

```
C       PHASING IN A NEW NATIONAL DATA NETWORK
C
C       DIMENSIONING STATEMENTS
        DIMENSION UDL(32), CUDR(31), XUDR(31), SUDR(31)
        DIMENSION UDIL(32,4), SUDIR(31,4), DNUDIR(31,4), DNUDIL(32,4)
        DIMENSION DATIL(32,4), DNDIR(31,4), DNDIL(32,4)
        DIMENSION DNTIR(31,4),DNTIL(32,4),DNTL(32),JDNTIL(32,4),JDNTL(32)
        DIMENSION REVIR(31,4), REVR(31), REVL(32), CSPNIR(31,4), CSPNR(31)
        DIMENSION CSCNIR(31,4), CSCNR(31), CSCNL(32), CSPNL(32)
        DIMENSION CSTRSR(31), CSXGR(31), CSTRSL(32), CSXGL(32), CAPACL(32)
        DIMENSION AIC(4), NIC(4), SIC(4), PNNIC(4), CNIC(4), IYRL(32)
        CALL XUOFF
C
C       INITIAL VALUES
        UDL(1) = 100.
        CUDR(1) = 130.
        CUDR(2) = 270.
        CUDR(3) = 500.
        CUDR(4) = 995.
        CUDR(5) = 1705.
        CUDR(6) = 3000.
        CUDR(7) = 5100.
        CUDR(8) = 8200.
        CUDR(9) = 13000.
        CUDR(10) = 19000.
        CUDR(11) = 26000.
        CUDR(12) = 34000.
        CUDR(13) = 42000.
        CUDR(14) = 48000.
        CUDR(15) = 50000.
        CUDR(16) = 51000.
        CUDR(17) = 50000.
        CUDR(18) = 49500.
        CUDR(19) = 49000.
        CUDR(20) = 48500.
        CUDR(21) = 48300.
        CUDR(22) = 48200.
        CUDR(23) = 48000.
        CUDR(24) = 48000.
        CUDR(25) = 48000.
        CUDR(26) = 48000.
        CUDR(27) = 48000.
        CUDR(28) = 48000.
        CUDR(29) = 48000.
        CUDR(30) = 48000.
        CUDR(31) = 48000.
        UDIL(1,1) = 59.3
        UDIL(1,2) = 32.2
        UDIL(1,3) =  5.4
        UDIL(1,4) =  3.1
        DATIL(1,1) = 59.3
        DATIL(1,2) = 32.2
        DATIL(1,3) =  5.4
        DATIL(1,4) =  3.1
        DNUDIL(1,1) = 0.
        DNUDIL(1,2) = 0.
        DNUDIL(1,3) = 0.
        DNUDIL(1,4) = 0.
        DNDIL(1,1) = 0
```

```
      DNDIL(1,2) = 0.
      DNDIL(1,3) = 0.
      DNDIL(1,4) = 0.
      CAPACL(1) = 0.0
      DNTIL(1,1) = 0.
      DNTIL(1,2) = 0.
      DNTIL(1,3) = 0.
      DNTIL(1,4) = 0.
      DNTL(1) = 0.
      IYRL(1) = 1964
      REVL(1) = 0.0
      CSTRSL(1) = 0.0
      CSCNL(1) = 0.0
      CSPNL(1) = 0.0
      CSXGL(1) = 0.0
C
C     PARAMETER VALUES (OR CONSTANTS)
C     IC IS YEAR OF GO-AHEAD FOR STARTING WORK ON NATIONAL DATA NETWORK
      IC = 7
C     ISC IS YEAR OF START OF OPERATION OF NATIONAL DATA NETWORK
C     ISC IS INTEGER VARIABLE IN THE RANGE ABOVE (IC+2)
      ISC = 12
C     IDIFC GIVES NUMBER OF YEARS OF CAPITAL EXPENDITURE FROM IC TO ISC
      IDIFC = ISC - IC - 1
C     PBC IS NUMBER OF YEARS FOR PAYBACK
      PBC = 10.
      IPBC = PBC
C     ROI IS RATE OF INTEREST OR RETURN ON CAPITAL INVESTMENT
      ROI = 0.100
C     ROICM IS COMPOUNDING MULTIPLIER; ROICMH IS " FOR HALF YEAR
      ROICM = 1.0 + ROI
      ROICMH = 1.0 + ROI/2
      FDC = ( ROI )/(((ROICM)**(PBC))-1)
      FDITC = FDC + ROI
      AIC(1) = 690 * FDITC
      AIC(2) =1030 * FDITC
      AIC(3) =2660 * FDITC
      AIC(4) =3100 * FDITC
C     NIC(J) DESCRIBES S-CURVE FOR SERVICE J TRANSFERS
      NIC(1) = 4
      NIC(2) = 7
      NIC(3) = 7
      NIC(4) = 10
C     SIC(J) DESCRIBES S-CURVE FOR SERVICE J BUILD-UP
      SIC(1) = 0.9
      SIC(2) = 0.8
      SIC(3) = 0.8
      SIC(4) = 0.7
C     PNNIC(J) GIVES PENALTY COST FOR SERVICE J TRANSFER
      PNNIC(1) = -250.
      PNNIC(2) = 300.
      PNNIC(3) = 300.
      PNNIC(4) = 0.
C     CNIC(J) GIVES CONNECTING COST PER SERVICE J TERMINAL
      CNIC(1) = 172.5
      CNIC(2) = 257.5
      CNIC(3) = 515.
      CNIC(4) = 775.
C     GRLNC GIVES THE GROWTH LIMIT OF THE NEW DATA NETWORK
      GRLNC = 60000.
C     CSXTRC GIVES THE CAPITAL COST FOR 25000 TERMINALS EXTRA CAPACITY
```

```
      CSXTPC = 15460000.
C
C     LOOP FOR TIME I
      DO 24 I=2,32
      XUDR(I-1)=0.
      SUDR(I-1)=CUDR(I-1)+XUDR(I-1)
      UDL(I) = UDL(I-1) + SUDR(I-1)
C     DEFINE UDIL(I,J) AND SUDIR(I-1,J)
      UDIL(I,1) = 0.593 * UDL(I)
      UDIL(I,2) = 0.322 * UDL(I)
      UDIL(I,3) = 0.054 * UDL(I)
      UDIL(I,4) = 0.031 * UDL(I)
      SUDIR(I-1,1)=0.593 * SUDR(I-1)
      SUDIR(I-1,2)=0.322 * SUDR(I-1)
      SUDIR(I-1,3)=0.054 * SUDR(I-1)
      SUDIR(I-1,4)=0.031 * SUDR(I-1)
C     LOOP FOR SERVICE J TERMINALS AT TIME I.
      DO 16 J=1,4
C     BUILD-UP OF USAGE OF SERVICE J TERMINALS IN NEW DATA NETWORK
      IF ( ISC-I) 4,3,3
    3 DATIL(I,J) = UDIL(I,J)
      DNDIL(I,J) = 0.
      GO TO 7
    4 CONTINUE
      IF ( ISC + NIC(J) - I ) 5,5,6
    5 DATIL(I,J) = 0.
      DNDIL(I,J) = UDIL( ISC,J)
      GO TO 7
    6 CONTINUE
      DNDIL(I,J) = (UDIL( ISC,J))*((1-COS((3.1416*(I-ISC))/(NIC(J))))/2)
      DATIL(I,J) = UDIL( ISC,J)-DNDIL(I,J)
    7 CONTINUE
      DNDIR(I-1,J) = DNDIL(I,J) -DNDIL(I-1,J)
      IF ((I-1) .LT. ( ISC)) DNUDIR(I-1,J) = 0.
      IF ((I-1) .EQ. ( ISC)) DNUDIR(I-1,J) = SIC(J)* SUDIR( ISC,J)
      IF ((I-1) .EQ.(ISC+1)) DNUDIR(I-1,J) = SUDIR(ISC+1,J)
      IF ((I-1) .EQ.(ISC+2)) DNUDIR(I-1,J) = SUDIR(ISC+2,J)+ (1-SIC(J))*
     1(SUDIR( ISC,J))
      IF ((I-1) .GT.(ISC+2)) DNUDIR(I-1,J) = SUDIR(I-1,J)
      DNUDIL(I,J) = DNUDIL(I-1,J) + DNUDIR(I-1,J)
      DNTIR(I-1,J) = DNDIR(I-1,J) + DNUDIR(I-1,J)
      DNTIL(I,J) = DNDIL(I,J) + DNUDIL(I,J)
      JDNTIL(I,J) = DNTIL(I,J)
C     ANNUAL SERVICE J REVENUE FROM NEW DATA NETWORK
      REVIR(I-1,J) =AIC(J)*(DNTIL(I-1,J) + (DNTIR(I-1,J))/2)
C     COST PENALTY FOR SERVICE J TRANSFERS FROM DATEL
      IF ( DNDIR(I-1,J) .EQ. 0 ) GO TO 10
      SUM = 0.
      KS = IC
   71 KS = KS + 1
      SUM = SUM + SUDIR(KS,J)
      IF ( ISC - KS - 1 ) 72,72,71
   72 CONTINUE
      IF ( DNTIL(I,J) . LE. SUM ) GO TO 10
      M = I
      IF ( M-IPBC ) 8,8,9
    8 M = IPBC + 1
    9 CONTINUE
      IF ( DATIL(M-IPBC,J) - DNDIL(I-1,J) - DNDIR(I-1,J) ) 11,10,10
   10 CSPNIR(I-1,J) = 0.
      GO TO 15
```

```
   11 K = M
   12 K = K+1
      IF ((K-IPBC) .GT. I) GO TO 10
      IF ( DATIL(K-IPBC,J) - DNDIL(I-1,J) - DNDIR(I-1,J) ) 13,14,14
   13 GO TO 12
   14 CSPNIR(I-1,J) = (K-I)*(PNNIC(J))*(DNDIR(I-1,J))/IPBC
   15 CONTINUE
C     COST FOR CONNECTING SERVICE J TERMINALS TO NEW DATA NETWORK
   16 CSCNIR(I-1,J) = CNIC(J) * DNTIR(I-1,J)
C     ALL-TERMINAL CONSIDERATIONS
      REVR(I-1)=REVIR(I-1,1)+REVIR(I-1,2)+REVIR(I-1,3)+REVIR(I-1,4)
      CSPNR(I-1)=CSPNIR(I-1,1)+CSPNIR(I-1,2)+CSPNIR(I-1,3)+CSPNIR(I-1,4)
      DNTL(I)=DNTIL(I,1)+DNTIL(I,2)+DNTIL(I,3)+DNTIL(I,4)
      JDNTL(I) = DNTL(I)
      CSCNR(I-1)=CSCNIR(I-1,1)+CSCNIR(I-1,2)+CSCNIR(I-1,3)+CSCNIR(I-1,4)
C     COST FOR GROWTH OF NEW DATA NETWORK
      IF (GRLMC-DNTL(I-1)) 18,18,17
   17 CSXGR(I-1)=0.
      GO TO 23
   18 GRLMC = GRLMC + 25000.
      IF (GRLMC-DNTL(I-1)) 20,20,19
   19 CSXGR(I-1) = CSXTRC
      GO TO 23
   20 GRLMC = GRLMC + 25000.
      IF (GRLMC-DNTL(I-1)) 22,22,21
   21 CSXGR(I-1) = 2 * CSXTRC
      GO TO 23
   22 GRLMC = GRLMC + 25000.
      CSXGR(I-1) = 3 * CSXTRC
   23 CONTINUE
C     TRANSIENT GIVING INCLUSIVE CAPITAL COST
      IF ((I-1).LT.6) CSTRSR(I-1)=0.
      IF ((I-1).EQ.6) CSTRSR(I-1)=500000.
      IF (((I-1).GT.6).AND.((I-1).LT.IC)) CSTRSR(I-1)=0.
      IF ((I-1).EQ.IC) CSTRSR(I-1)=1000000.
      IF (((I-1).GT.IC).AND.((I-1).LT.ISC)) CSTRSR(I-1)=37500000./IDIFC
      IF ((I-1).GE. ISC  ) CSTRSR(I-1)=0.
C
C     CAPITAL ACCOUNT OF THE NEW DATA NETWORK
      REVL(I) = ROICM * REVL(I-1) + ROICMH * REVR(I-1)
      CSTRSL(I) = ROICM * CSTRSL(I-1)+ ROICMH * CSTRSR(I-1)
      CSCNL(I) = ROICM * CSCNL(I-1) + ROICMH * CSCNR(I-1)
      CSPNL(I) = ROICM * CSPNL(I-1) + ROICMH * CSPNR(I-1)
      CSXGL(I) = ROICM * CSXGL(I-1) + ROICMH * CSXGR(I-1)
      CAPACL(I) = REVL(I) - CSTRSL(I) - CSCNL(I) - CSPNL(I) - CSXGL(I)
   24 IYRL(I) = (1963 +I)
       CALL PDUMP (IC, CAPACL(32), 4, IC, CAPACL(32), 5)
   25 FORMAT (38H1PHASING IN A NEW DIGITAL DATA NETWORK//6H YEAR ,9H
     1DNTL ,14H      CAPACL    ,8H  DNT1L ,8H  DNT2L ,7H DNT3L ,7H DNT4L ,
     214H        REVL    ,13H     CSTRSL    ,13H      CSCNL    ,13H      CSPNL
     3   ,13H       CSXGL   //)
      WRITE (3,25)
      DO 27 I=6,32
   26 FORMAT (' ',I4,2X,I7,2X,F12.1,2X,I6,2X,I6,2X,I5,2X,I5,2X,F12.1,2X,
     1F11.1,2X,F11.1,2X,F11.1,2X,F12.1)
      WRITE (3,26) IYRL(I),JDNTL(I),CAPACL(I),JDNTIL(I,1),JDNTIL(I,2),JD
     1NTIL(I,3),JDNTIL(I,4),REVL(I),CSTRSL(I),CSCNL(I),CSPNL(I),CSXGL(I)
   27 CONTINUE
      STOP
      END
```

APPENDIX D : THE DATRAN PROPOSAL

On 25 November, 1969, DATRAN (the Data Transmission Co.) proposed a $375 million American national data transmission network in a filing to the Federal Communications Commission (Telecommunications, 1969). This network would provide a "door-to-door" digital data transmission service with a connection time of under three seconds; this compares favourably with the 20 seconds normally required by present systems. The new system is designed to provide interconnection capability with either T.D.M. (its own mode of transmission) or analogue modes of transmission; it would interface with computers, teleprinter-type machines, and digital Xerographic-type machines.

The planned rate schedules (Table D.1) would base charges on seconds, so that a user's data transmission costs would be about half what they now are. (In addition to these transmission charges there would be a $25 connection charge, and a $15 per month rental for a "digital communications console".) The number of "data units" (D.U.) included in the monthly "floor" charges make the basic charge 0.5 ¢/D.U.; for further usage, a charge of 5 ¢/D.U. would be made.

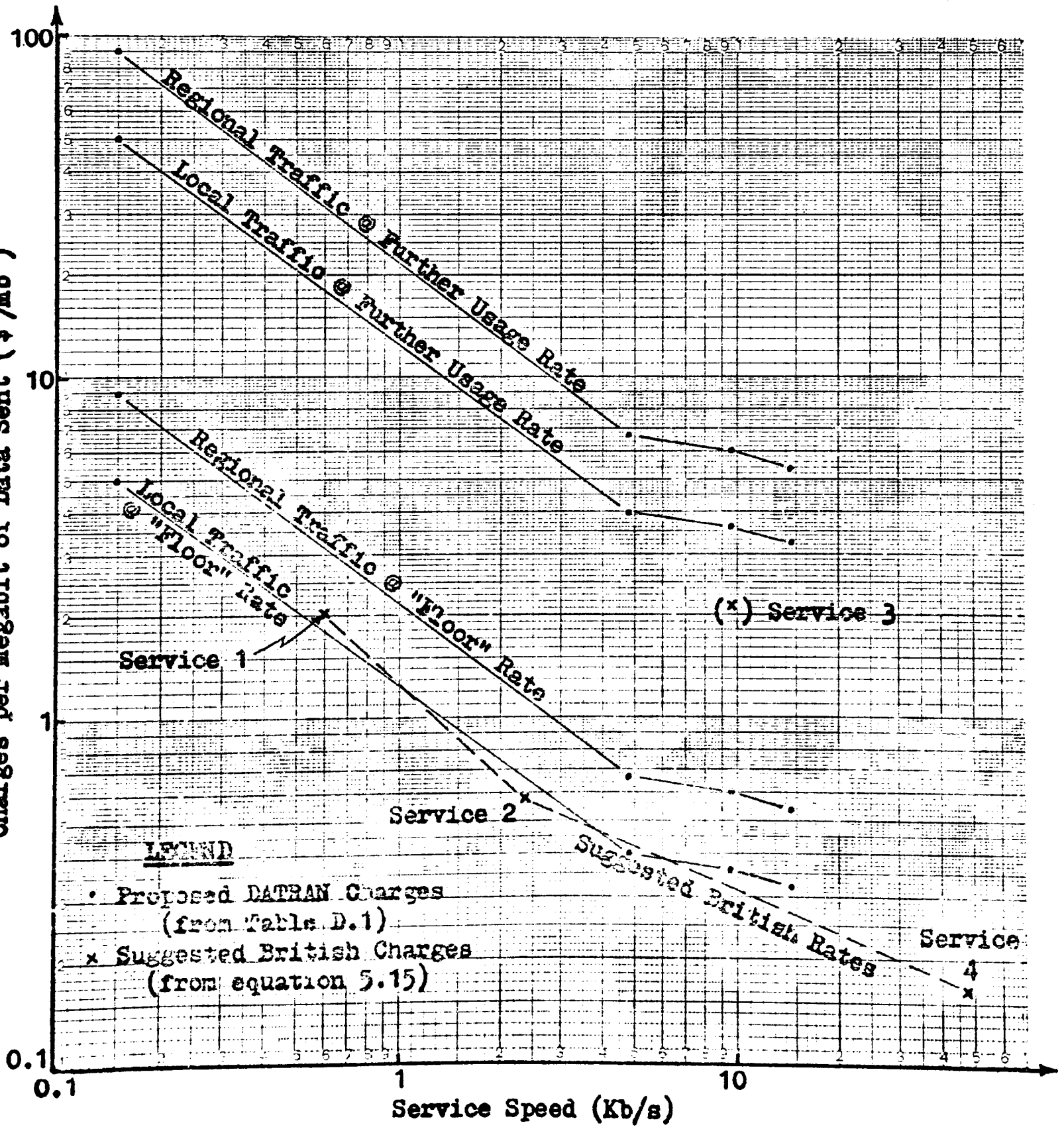
Table D.1 : Proposed DATRAN Transmission Rate Schedule.

Service Speed	Monthly "Floor" Charge	Data Units Included in "Floor" Charge	Charges per Minute		Charges per Megabit of Data Sent			
			Local Traffic	Regional Traffic	At "Floor" Rate of 0.5 ¢/D.U.		At Further Usage Rate of 5¢/D.U.	
					Local Traffic	Regional Traffic	Local Traffic	Regional Traffic
(b/s)	($/ Month)	(D.U.)	(D.U. /min)	(D.U. /min)	($/Mb)	($/Mb)	($/Mb)	($/Mb)
150	20	4,000	9	16	5.00	8.90	50.00	89.00
4.8K	25	5,000	23	39	0.40	0.68	4.00	6.80
9.6K	30	6,000	42	70	0.36	0.61	3.60	6.10
14.4K	40	8,000	56	94	0.32	0.54	3.20	5.40

These proposed data transmission rates may be compared with the tariff-only charges of equations 5.15 (which do pay their way, according to Section 5.6), using the current exchange rate of

$2.40/£; this comparison is shown in Figure D.1. With the exception of the rather out-of-line (according to Section 5.3) Service 3 charge, it is observed that the suggested British tariff-only charges are comparable to the DATRAN "floor" rate charges for local traffic. Since DATRAN's other charges far exceed the suggested British charges (which are distance-independent averages), it follows that DATRAN stands to make considerable profits; this is confirmed by DATRAN, which estimates a market of $185 million in annual revenues for the initial system a few years after it goes into operation!

Figure D.1: A Comparison of Suggested British Charges with Proposed DATRAN Charges.



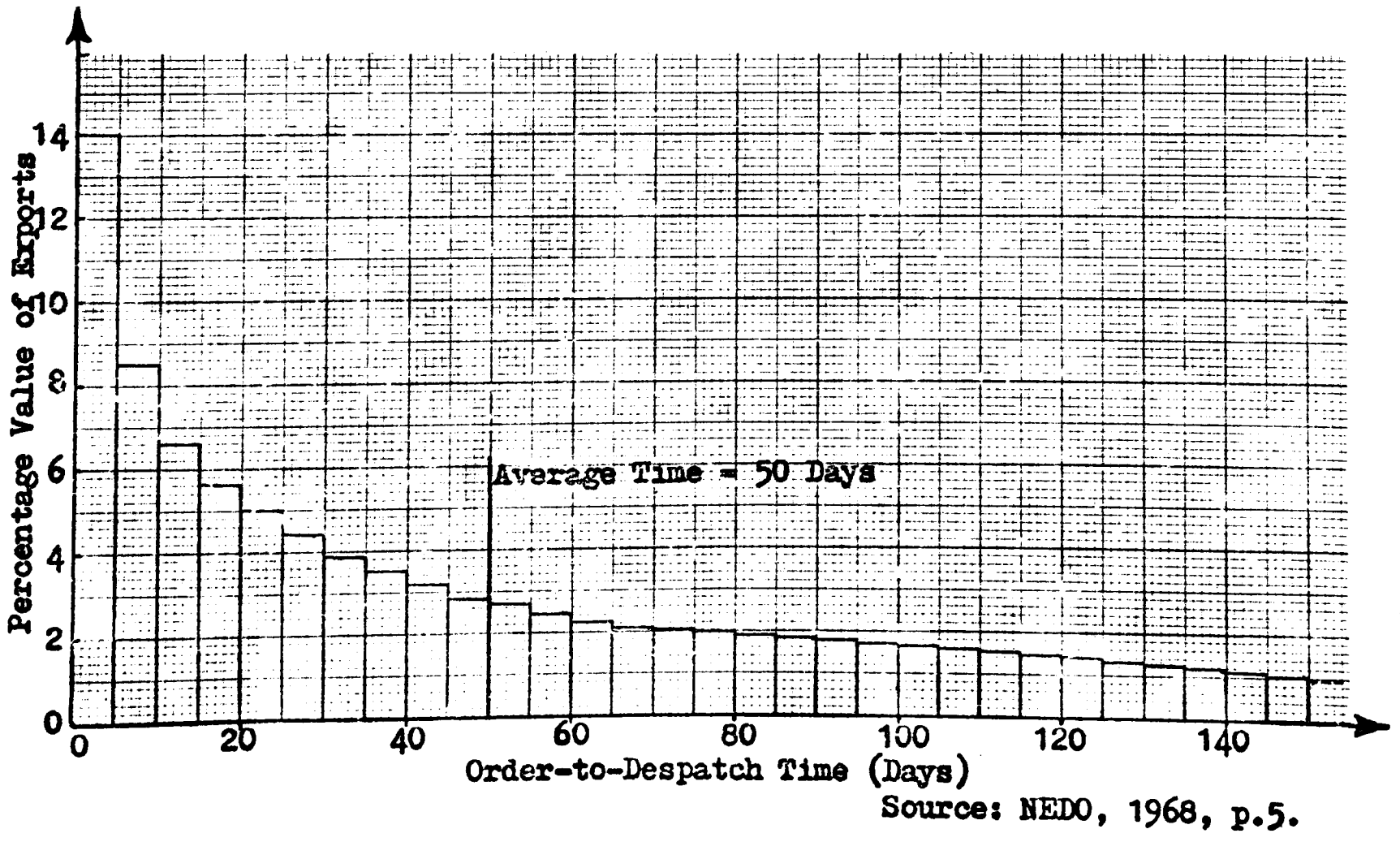
APPENDIX E : ORDER-TO-DESPATCH TIMES IN BRITISH INDUSTRY

E.1 Introduction

A special study on British exports to Europe was recently carried out by the Metra Consulting Group for the Movement of Exports EDC (N.E.D.O., 1968). The data collected by Metra gives distributions of the total delivery time (between receipt of an order by an exporter and the arrival of the goods at the importer's premises), whose average was 60 days, and of its two components: the order-to-despatch time, whose average was 50 days (Figure E.1), and the transport time (excluding goods sent by air), whose average was 10 days. The similar relative shapes of these component distributions confirm that, in general, the transport time represents only a small proportion of total delivery time. While the overall average order-to-despatch time was 50 days, this average varied considerably with the commodity group, ranging from the lowest value of 22 days for "food and drink" to the highest value of 72 days for "heavy machinery".

A high variability in order-to-despatch times is thus suggested; indeed, there are often considerable differences even for

Figure E.1: Distribution of Order-to-Despatch Times for All British Exports to Europe.



Source: NEDO, 1968, p.5.

similar goods exported by one company from one production plant. These differences certainly contribute to the poor record of British exporters in meeting promised delivery dates: only 50% of goods were despatched by the promised date; almost 25% of goods were sent more than 10 days late, and 8% left over a month late.

In view of the length of order-to-despatch times and the proportion of promised despatch dates which are not met, there is little doubt that exporting firms have considerable scope for improvement. It is particularly important that excess delays (Section 7.3) be reduced or eliminated; the approach of Chapters 8, 9 and 10 may be used to quantify some of the benefits which might result from the corresponding time saving. This appendix estimates a possible time saving from the magnitude of the common "internal communication" (IC) excess delay shown in Figure 7.1.

E.2 Order-to-Despatch Time Component Distributions

An attempt is now made to break down distributions of the form of Figure E.1 into two possible component distributions. It is first assumed (following Section 8.2.a) that exported goods may be subdivided into two groups: those which are manufactured to order and those which - as stock items - are merely removed from inventory. It is next assumed that there exist distributions of the time required for each of these two operations: the X-distribution (with mean $\overline{X}$) describes the order-to-despatch times for goods manufactured to order; the Y-distribution (with mean $\overline{Y}$) describes the times required to despatch goods from inventory. These two order-to-despatch time distributions are further assumed to apply throughout the British economy. It is finally assumed that these two distributions may be combined together to give the order-to-despatch time distributions for various commodity groups (as mentioned in Section E.1); the weightings are taken from the fractions of manufacturing industry which produce goods to order ($\overline{\alpha}$) derived in Section G.1, with the "heavy machinery" commodity group taken to be a typical "durable goods" industry and with the "food and drink" commodity group taken to be a typical "nondurable goods" industry.

Using the $\overline{\alpha}$ values of Section G.1, this strong set of assumptions gives three equations of the form:

$$\overline{\alpha}_A \cdot X + (1 - \overline{\alpha}_A) \cdot Y = \text{(Overall order-to-despatch distribution of Figure E.1)}$$

etc. ...(E.1).

It may be shown that the averages of these weighted distributions can be obtained by weighting the averages of the component (X and Y) distributions. Thus

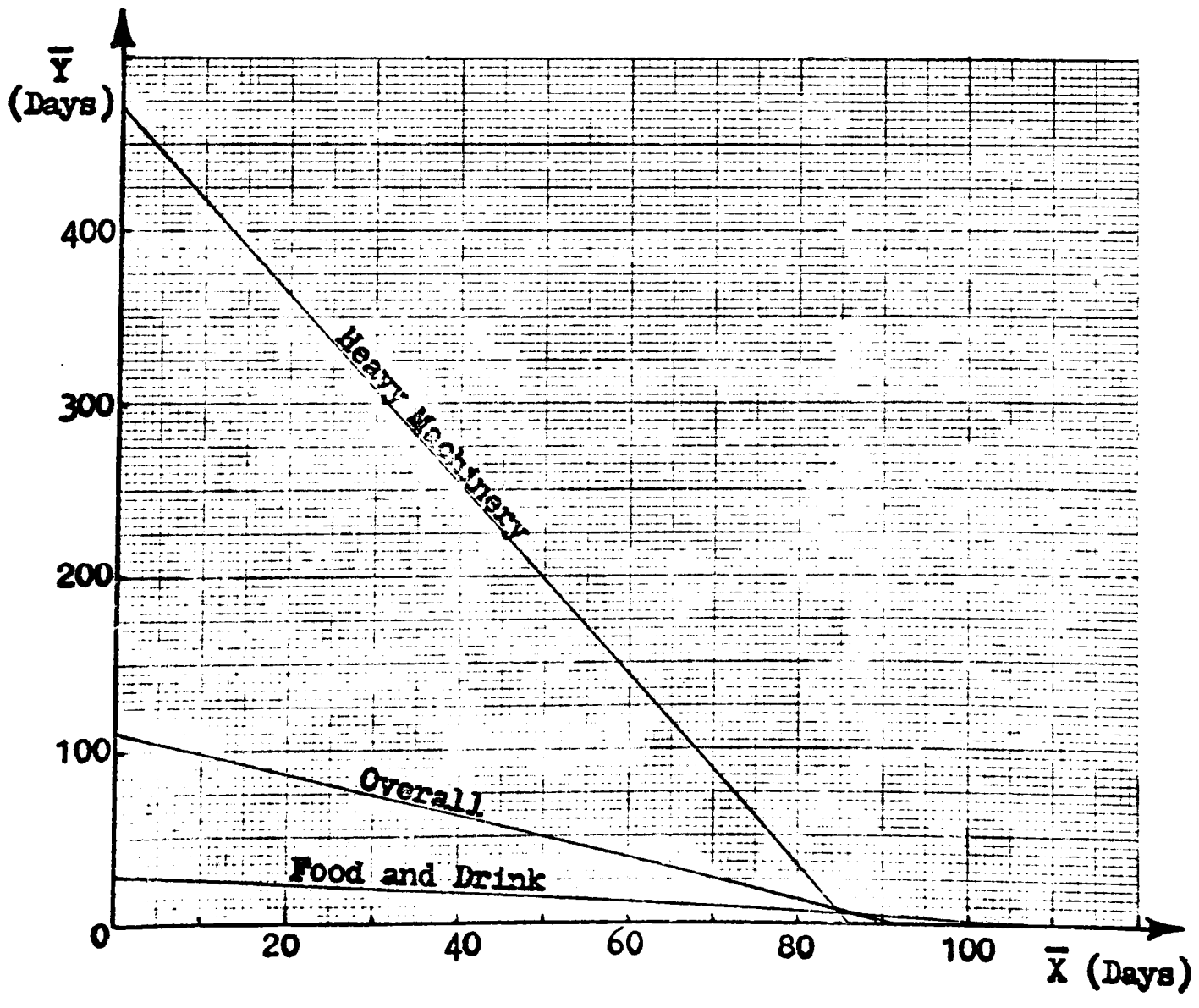
$$\bar{\alpha}_A \cdot \bar{X} + (1 - \bar{\alpha}_A) \cdot \bar{Y} = 50 \pm 0.5$$
$$\bar{\alpha}_D \cdot \bar{X} + (1 - \bar{\alpha}_D) \cdot \bar{Y} = 72 \pm 0.5$$
$$\bar{\alpha}_N \cdot \bar{X} + (1 - \bar{\alpha}_N) \cdot \bar{Y} = 22 \pm 0.5 \qquad \ldots(E.2).$$

Using the $\bar{\alpha}$-values of equations G.4, these three equations in two unknowns are solved graphically in Figure E.2; a fairly high level of consistency is noted. The estimated solution is

$$\bar{X} = 84 \pm 2 \text{ days}$$
$$\bar{Y} = 7.5 \pm 2 \text{ days} \qquad \ldots(E.3).$$

It should also be possible to use equations E.1 and Metra's distributions (N.E.D.O., 1968) to obtain the component X- and Y- distributions. Unfortunately, however, this cannot be completely achieved within a set of constraints designed to incorporate the above assumptions

Figure E.2: The Solution of Three Equations in Two Unknowns.



and other suitable requirements (such as that X- and Y- distributions should be fairly regular in form). Nevertheless, it is felt that the consistent averages of equations E.3 are of some significance.

For example, $\overline{X}$ may be taken as an estimate of the British "temporal buffer length", TBL; this term is defined in Section 8.3. Taking 30 days to a month, the British TBL is estimated as

$$TBL_{British} \approx (2.8 \pm 0.1) \text{ months} \qquad \ldots(E.4).$$

This value lies well within the range of American TBL values computed using the American statistical data of Table G.1 with the equation (from equation 8.6):

$$TBL \approx \frac{UO_A}{S_W} = \frac{UO_D + UO_N}{S_W} \qquad \ldots(E.5)$$

where the right-hand parameters are defined in Section G.1. In fact, a mean value for the past eight years is

$$\overline{TBL}_{American} \approx (2.9 \pm 0.1) \text{ months} \qquad \ldots(E.6).$$

The $\overline{X}$ value of equations E.3 thus appears to be fairly realistic; the significance of the Y value is considered below.

E.3 The "Internal Communications" Excess Delay

The $\overline{Y}$ value in the vicinity of $7\frac{1}{2}$ days is particularly important since it provides an estimate of the average time required for dealing with an order for goods already in stock. This time includes the times required for clerical and packing operations; also included is the internal communications excess delay (ICXD). It is expected that ICXD would form a considerable proportion of $\overline{Y}$.

A large part of this excess delay should be removable with more efficient operations (resulting from the use of management consultants, computerization, etc.) and with the faster procedures which would result from the use of a national data network; it is assumed that the reduction of ICXD made possible by national data network usage is about 3 working days (where there are 250 working days per year of 365 days).

Since ICXD would be a part of almost any overall operation carried out by an establishment (according to Figure 7.1), it follows that this reduction in ICXD (or this overall time saving) could result from national data network usage in many operational environments.

APPENDIX F : THE M/D/1 : (∞/FIFO) MODEL FROM QUEUING THEORY

The simplest type of establishment which might be modelled by a queuing theory model is a firm which manufactures products at a constant rate μ (per unit of time = unity) to meet orders which arrive randomly with an average rate λ. An appropriate model to determine the average queue length of unfilled orders is classified, using the Kendall notation for queuing processes, by:

$$M/D/1 : (\infty/FIFO)$$

The parameters here indicate the following (Lee, 1966):

M Arrivals are random and are governed by a Poisson process.
D There is a constant service time of $1/\mu$.
1 There is only one service-channel: the plant.
∞ There is no limit to the permissible length of the queue.
FIFO Orders are met strictly in the order of their arrival.

The application of this model to the operation of a firm is obviously a great over-simplication, which requires that products being manufactured are relatively homogeneous and that products are manufactured in batches equal in size to the amount of work in the service-channel (the "work in progress") at any time. Nevertheless, it is of value to examine some of the properties of this model.

Particularly interesting is the equation giving the average queue length. Counting the contents of the service-channel as one unit, this average queue length is $\bar{m}$.

$$\bar{m} = \frac{(\lambda/\mu)^2}{2\,(1 - \lambda/\mu)} = \lambda\,\bar{W} \qquad ...(F.1)$$

where $\bar{W}$ is the average queuing-time of an arrival (Sasieni, Yaspan & Friedman, 1959, p. 143). Taking the "manufacturing intensity" (or capacity utilization) to be related to the "traffic intensity" λ/μ (≤ 1), it follows that a positive relationship exists between capacity utilization and the average queue length: increasing this average length corresponds to an increase in capacity utilization (Thomas *et al.*, 1970, Figure 2).

While this general conclusion is of considerable interest, it only applies to a specific and very simple model of a firm. To model the actual operations of a real firm, a far more complex queuing theory (or other operations analysis type of) model would be required; the solution of such a model would be extremely difficult. It is, however, expected that a positive relationship would also be found between the average queue length and the capacity utilization.

APPENDIX G : STATISTICAL DATA

G.1 The Fraction of Manufacturing Industry which Manufactures Goods to Order

In Section 8.3 and in Appendix E the fraction of manufacturing industry which manufactures goods to order is required. Since the appropriate statistics are not available for the United Kingdom, American statistics for the years 1962 to 1969 are used to obtain Table G.1 (U.S. Bureau of the Census, 1968; U.S. Department of Commerce, 1970).

A few terms must first be defined. The "durable goods" industries include stone, clay and glass, primary metals, fabricated metal products, machinery, transportation equipment, and instruments and related parts; the "nondurable goods" industries include food, tobacco, textiles, paper, chemicals, petroleum and coal, and rubber and plastics. The "unfilled orders" (UO) and "finished goods inventory" (FG) figures are three-monthly (or "quarterly") averages of seasonally adjusted end-of-month values. The "shipments" (S) figures are also three-monthly averages of seasonally adjusted monthly values of manufacturing shipments (or sales). The subscripts used are:

D = Durable goods industry
N = Nondurable goods industries
A = All manufacturing industries
W = Weighted average ...(G.1).

It is now assumed that the ratio of UO to (UO + FG) provides an estimate for each of durable and nondurable goods industries of the fraction of the industry which manufactures goods to order, α. Thus

$$\alpha_D = \frac{UO_D}{UO_D + FG_D}$$

$$\alpha_N = \frac{UO_N}{UO_N + FG_N} \qquad ...(G.2).$$

It is also assumed that the relative values of manufacturing shipments of these industries provide a measure of the relative weightings to be used in averaging α_D and α_N to obtain the overall fraction α_A.

Table G.1: Three-Monthly ("Quarterly") Averages of Seasonally Adjusted Monthly Figures for American Manufacturing Industries; Calculations.

Year	Q	DURABLE GOODS INDUSTRIES				NONDURABLE GOODS INDUSTRIES				ALL MANUF. INDUSTRIES		
		Unfilled Orders UO_D $\$x10^9$	Finished Goods Inv. FG_D $\$x10^9$	$\alpha_D = \frac{UO_D}{UO_D+FG_D}$ Ratio	Shipments S_D $\$x10^9$/ month	Unfilled Orders UO_N $\$x10^3$	Finished Goods Inv. FG_N $\$x10^9$	$\alpha_N = \frac{UO_N}{UO_N+FG_N}$ Ratio	Shipments S_N $\$x10^9$/ month	$S_W = \alpha_D \times S_D + \alpha_N \times S_N$ $\$x10^9$/ month	$S_A = S_D+S_N$ $\$x10^9$/ month	$\alpha_A = \frac{S_W}{S_A}$ Ratio
1962	I	45.7	9.18	0.832	17.1	3.24	9.80	0.249	15.9	18.2	33.0	0.552
	II	44.5	9.32	0.827	17.1	3.18	9.92	0.243	15.9	18.0	33.0	0.545
	III	43.6	9.50	0.821	17.1	3.11	10.2	0.234	16.0	17.8	33.1	0.538
	IV	43.9	9.55	0.822	17.2	2.96	10.4	0.221	16.2	17.7	33.4	0.530
1963	I	46.3	9.66	0.828	17.5	2.65	10.3	0.204	16.4	17.8	33.9	0.525
	II	48.2	9.70	0.832	18.2	2.71	10.3	0.208	16.7	18.6	34.9	0.534
	III	48.1	9.75	0.831	18.5	2.78	10.5	0.209	16.9	18.9	35.4	0.534
	IV	48.2	9.76	0.831	18.8	2.92	10.7	0.215	17.1	19.3	35.9	0.538
1964	I	48.9	9.87	0.832	19.1	2.85	10.9	0.206	17.3	19.5	36.4	0.536
	II	50.7	9.97	0.835	19.5	2.75	11.0	0.199	17.6	19.8	37.1	0.534
	III	53.2	10.0	0.843	19.8	2.75	11.0	0.199	17.8	20.2	37.6	0.538
	IV	55.2	10.2	0.844	19.9	2.84	11.2	0.203	18.1	20.5	38.0	0.540
1965	I	57.6	10.3	0.850	21.4	2.86	11.3	0.201	18.3	21.9	39.7	0.552
	II	59.4	10.4	0.851	21.8	2.94	11.3	0.207	18.7	22.3	40.5	0.551
	III	61.0	10.5	0.853	22.5	3.05	11.4	0.210	18.9	23.2	41.4	0.561
	IV	63.8	10.7	0.858	23.2	3.18	11.6	0.215	19.3	24.0	42.5	0.565
1966	I	67.9	11.0	0.861	23.9	3.41	11.8	0.224	19.8	25.0	43.7	0.573
	II	72.2	11.2	0.865	24.5	3.55	12.1	0.226	20.2	25.8	44.7	0.578
	III	75.8	11.7	0.867	24.7	3.39	12.4	0.214	20.4	25.8	45.1	0.573
	IV	77.8	12.1	0.867	25.3	3.16	12.7	0.199	20.5	26.0	45.8	0.568
1967	I	76.8	12.6	0.859	24.5	2.98	13.0	0.186	20.5	24.9	45.0	0.554
	II	76.6	13.1	0.854	24.6	2.83	13.3	0.176	20.6	24.7	45.2	0.547
	III	77.9	13.3	0.854	25.1	2.92	13.3	0.180	20.7	25.2	45.8	0.551
	IV	79.5	13.3	0.858	25.6	3.05	13.4	0.185	21.2	25.9	46.8	0.554
1968	I	80.9	13.4	0.857	26.8	3.08	13.7	0.183	21.6	26.9	48.4	0.556
	II	81.7	13.5	0.859	27.3	3.05	14.1	0.177	22.5	27.4	49.8	0.551
	III	83.2	13.7	0.860	27.7	3.06	14.4	0.175	23.2	27.9	50.9	0.548
	IV	82.5	14.2	0.853	28.5	3.10	14.7	0.174	23.7	28.4	52.2	0.544
1969	I	84.9	14.7	0.852	29.6	3.07	14.7	0.172	23.5	29.3	53.1	0.552
	II	89.6	15.2	0.856	29.8	3.13	15.1	0.172	24.2	29.7	54.0	0.550
	III	89.3	15.7	0.850	31.1	3.05	15.2	0.167	24.6	30.6	55.7	0.550
	IV	86.5	16.1	0.844	31.0	3.05	15.3	0.166	25.1	30.6	56.1	0.545
Averages				0.847				0.200				0.549

$$\alpha_A = \frac{(\alpha_D \times S_D) + (\alpha_N \times S_N)}{S_D + S_N} = \frac{S_W}{S_A} \qquad \ldots(G.3).$$

where $S_W = (\alpha_D \times S_D) + (\alpha_N \times S_N)$ and

$S_A = S_D + S_N$

The overall average values taken from Table G.1 give the following estimated fractions of manufacturing industry which manufacture goods to order:

Durable goods	:	$\bar{\alpha}_D = 0.847 \pm 0.005$	
Nondurable goods	:	$\bar{\alpha}_N = 0.200 \pm 0.008$	
All manufacturing	:	$\bar{\alpha}_A = 0.549 \pm 0.005$	...(G.4).

It will be assumed that these averages, derived from American statistics, may also be applied to the United Kingdom; these are of course all long-term estimates.

G.2 Capacity Utilization and Absolute Buffer Length

To quantify working hypothesis H-1, statistical series are required of capacity utilization (CU) and of the absolute buffer length (ABL').

$$ABL' = \frac{UO}{WIP} \qquad \ldots(G.5)$$

where UO is the value of unfilled orders, and
WIP is the value of work in progress.

Table G.2 gives the appropriate American statistical series (U.S. Bureau of the Census, 1967; U.S. Department of Commerce, 1970) for the period from mid-1962 to the end of 1968. A plot of CU against ABL' is given in Figure G.3.

Table G.2: Capacity Utilization and Absolute Buffer Length for American Manufacturing Industries.

Year	Quarter	Three-Monthly ("Quarterly") Averages of Seasonally Adjusted Monthly Figures			Capacity Utilization
		Unfilled Orders UO ($\$x10^9$)	Work in Progress WIP ($\$x10^9$)	Absolute Buffer Length ABL'=UO/WIP (Ratio)	CU
1962	III	46.7	17.3	2.70	0.82
	IV	46.9	17.5	2.68	
1963	I	49.0	17.4	2.82	
	II	50.9	17.7	2.88	0.84
	III	50.9	17.8	2.86	
	IV	51.1	17.9	2.86	
1964	I	51.8	18.6	2.78	
	II	53.5	19.0	2.82	0.86
	III	56.0	19.2	2.92	
	IV	58.0	19.6	2.96	
1965	I	60.5	19.8	3.06	
	II	62.3	20.2	3.08	0.89
	III	64.1	21.1	3.04	
	IV	67.0	21.7	3.09	
1966	I	71.3	22.5	3.17	0.91
	II	75.8	23.5	3.23	0.91
	III	79.2	24.7	3.21	0.91
	IV	81.0	25.9	3.12	0.90
1967	I	79.8	27.0	2.96	0.87
	II	79.4	27.8	2.86	0.85
	III	80.8	28.3	2.86	0.84
	IV	82.6	28.9	2.85	0.848
1968	I	84.0	29.4	2.86	0.85
	II	84.8	30.0	2.83	0.848
	III	83.2	30.2	2.76	0.835
	IV	85.9	30.9	2.78	0.838

G.3 Industrial Expenditure on Communications

Table G.3 below indicates the amounts spent by various industries in the British economy on communications services for 1963. The column of "sales by the communications industry to ..." (SCI) is taken from the industry x industry flow matrix for 1963 (C.S.O., 1970, Table D); the column of "payments for postage, telephone, telegrammes and cables" (PTTC) is taken from the 1963 Census of Production (Board of Trade, 1969, pp.131/164 ff).

The SCI figures are observed to be somewhat greater than the PTTC figures for all industries except Construction (which is marked by an asterisk). The discrepancy between these sets of figures cannot, however, easily be removed, since the SCI figures have already undergone considerable preliminary adjustment to bring them close to the PTTC figures (C.S.O., 1970, p.18). Since the PTTC figures were directly obtained from Census data, they are preferred to the SCI figures which were indirectly estimated from input-output data. While either set of figures could be used in assessing the lump sum benefit Δ_1 (equation 7.5), the PTTC figures are used wherever possible.

Table G.3: Industrial Expenditure on Communications; United Kingdom, 1963.

Standard Industrial Classification (S.I.C.) Order	INDUSTRY			Sales by the Communications Industry to... SCI (£m)	Payments for Postage, Telephone, Telegrammes and Cables PTTC (£m)
I	Agriculture; Forestry and fishing			4.9	
II	Mining and quarrying			2.6	1.407
III	Food, drink and tobacco			7.5	6.809
IV	Chemicals and allied industries			7.8	6.944
V	Metal manufacturing			3.7	3.410
VI	Engineering and electrical goods			22.4	20.278
VII	Shipbuilding and marine engineering			0.8	0.695
VIII	Vehicles			6.7	5.974
IX	Metal goods not elsewhere specified			5.0	4.577
X	Textiles			4.8	4.533
XI	Leather, leather goods and fur			0.6	0.502
XII	Clothing and footwear			3.2	2.869
XIII	Bricks, pottery, glass, cement, etc.			3.5	2.738
XIV	Timber, furniture, etc.			2.6	2.510
XV	Paper, printing and publishing			14.1	12.739
XVI	Other manufacturing industries			3.6	3.308
III-XVI	All Manufacturing Industries			(86.3)	(77.886)
XVII	Construction			9.5*	10.545
XVIII	Gas, electricity and water			4.2	3.834
II-XVIII	All Census Industries			(102.6)	(93.672)
XIX	Transport			5.5	
	Communication			—	
XX	Distributive trades			114.0	
XXI-XXIII	Miscellaneous services			136.9	
	TOTAL INTERMEDIATE OUTPUT			(362.9)	
	Final Buyers	Current expenditure	Consumers	169.0	
			Public authorities	77.2	
		Gross domestic capital formation	Fixed	27.5	
			Stocks	—	
		Exports		17.4	
	TOTAL FINAL OUTPUT			(291.1)	
	TOTAL OUTPUT			654.0	

*See Text.

G.4 Manufacturing Capacity

The second column of Table G.4 below gives values for gross capital stock in plant and machinery, at 1963 replacement cost, for the British manufacturing sector (excluding textiles) (C.S.O., 1969a, p.77). The figure for each year is converted into current prices using the "price multiplier (1963 → current)" given in the third column of the table. These price multipliers are derived from statistics of gross domestic fixed capital formation in plant and machinery, at both 1963 and current prices (C.S.O., 1969a, p.67), and from statistics of gross domestic fixed capital formation for the manufacturing industry, at both 1963 and current prices (C.S.O., 1969a, p.68). The current price gross capital stock figures of column four are plotted in Figure G.1.

Figure G.1: Gross Capital Stock in Plant and Machinery for the British Manufacturing Sector.

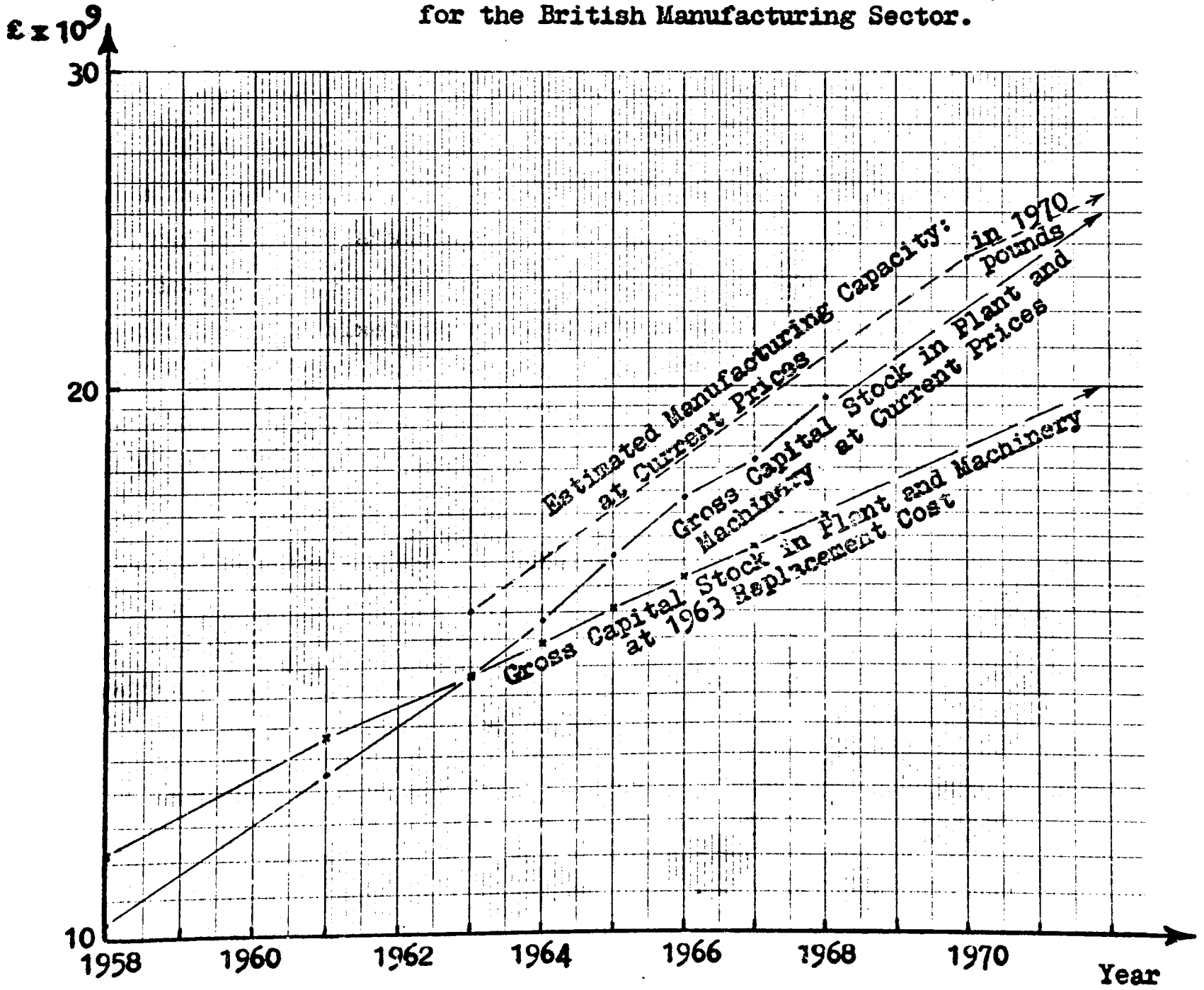


Table G.4: Gross Capital Stock in Plant and Machinery for the British Manufacturing Sector (excluding Textiles).

Year (Current)	Gross Capital Stock in Plant and Machinery, at 1963 Replacement Cost £x10^9	Price Multiplier (1963 → Current)	Gross Capital Stock in Plant and Machinery, at Current Prices £x10^9
1958	11.16	0.919	10.25
1961	12.81	0.957	12.26
1963	13.87	1.000	13.87
1964	14.45	1.022	14.77
1965	15.03	1.069	16.08
1966	15.66	1.112	17.41
1967	16.32	1.114	18.20
1968	16.96	1.161	19.69

The 1963 figure of £13.87 x 10^9 is broken down by industry in the third column of Table G.5 (C.S.O., 1969a, p.77). The aggregate figures for several industries are broken down to the estimates of the fifth column by assuming that the gross capital stock is roughly proportional to the total amounts spent by individual industries on gross domestic fixed capital formation in plant and machinery for the years 1953-1963 inclusive. These totals (C.S.O., 1964, Table 63; C.S.O., 1969a, Table 57) are given in the fourth column of Table G.5.

From Table G.5, the estimated total (including textiles) manufacturing capacity (Cap.) for 1963 is

$$\text{Cap.}(1963) \approx £15.0 \times 10^9 \qquad \ldots(G.6).$$

An extrapolation of this figure at the "current prices" rate of growth suggests a total manufacturing capacity for 1970 of

$$\text{Cap.}(1970) \approx £23.6 \times 10^9 \qquad \ldots(G.7).$$

Table G.5: Gross Capital Stock in Plant and Machinery for British Manufacturing Industries, 1963.

S.I.C. Order	INDUSTRY	Gross Capital Stock in Plant and Machinery (£m)	Total Gross Domestic Fixed Capital Formation in Plant and Machinery, 1953-1963 (£m)	Estimated Manufacturing Capacity (Cap.) (£m)
III	Food, drink and tobacco	1,240	631	1,240
IV	Chemicals and allied industries	2,590	1,297	2,590
V	Metal manufacturing	7,830	1,252	∿2,382
VI	Engineering and electrical goods		1,048	∿2,876
VII	Shipbuilding and marine engineering		79	∿ 217
VIII	Vehicles		602	∿1,657
IX	Metal goods not elsewhere specified		254	∿ 698
XIII	Bricks, pottery, glass, etc.	470	257	470
XIV	Timber, furniture, etc.	120	59	120
XV	Paper, printing and publishing	1,050	449	1,050
XI,XII	Leather, fur and clothing	570	81	∿ 164
XVI	Other manufacturing industries		200	∿ 406
	Total for all manufacturing excluding textiles:	13,870	6,209	13,870
X	Textiles		519	∿1,160
III-XVI	Total for all Manufacturing		6,728	∿15,030

G.5 The Gross Domestic Product and the Contribution of the Manufacturing Sector to It

Table G.6 below gives the British gross domestic product (G.D.P.) at 1963 factor cost (C.S.O., 1969a, Table 14) and at current factor cost (C.S.O. 1969, Table 1); the contribution of the manufacturing sector to the latter series (CMS) is also given (C.S.O. 1969a, Table 11).

These series are plotted in Figure G.2. It is noted that the "contribution" plot is roughly parallel to the "current cost G.D.P." plot; it is thus approximated that

$$CMS \approx 0.346 \times G.D.P. \qquad \ldots(G.8).$$

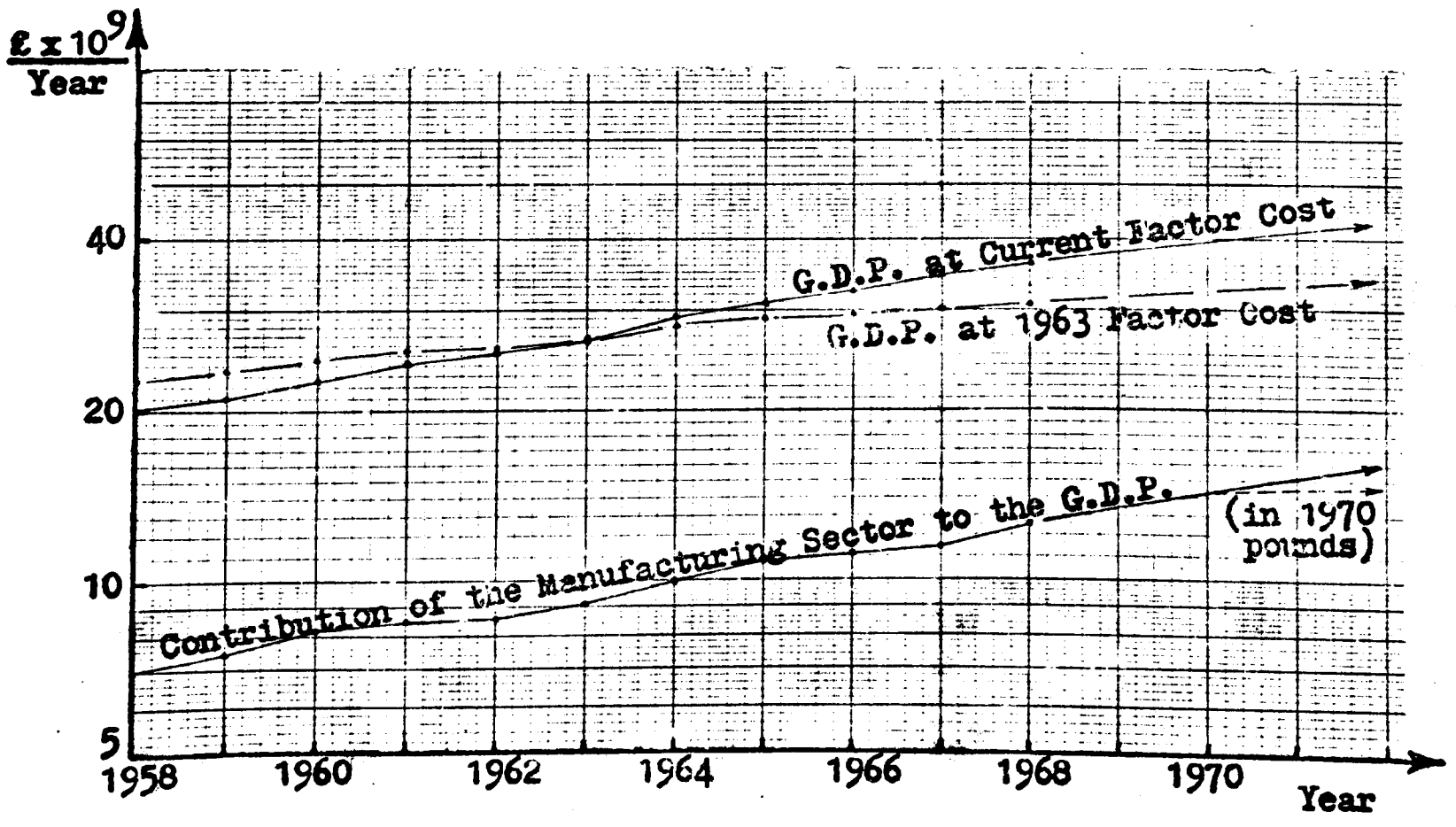
From Figure G.2 it is estimated that the 1970 contribution of the manufacturing sector to the G.D.P. is

$$CMS(1970) \approx £14.2 \times 10^{9}/\text{year} \qquad \ldots(G.9).$$

Table G.6: The Gross Domestic Product and the Contribution of the Manufacturing Sector to It.

Year	Gross Domestic Product		Contribution of the Manufacturing Sector to G.D.P., at Current Factor Cost MR £x10^9/year
	at 1963 Factor Cost G.D.P. £x10^9/year	at Current Factor Cost G.D.P. £x10^9/year	
1958	22.701	20.115	7.006
1959	23.476	21.151	7.470
1960	24.613	22.563	8.198
1961	25.492	24.139	8.454
1962	25.763	25.230	8.568
1963	26.826	26.826	9.068
1964	28.226	28.966	10.010
1965	28.948	30.895	10.825
1966	29.500	32.590	11.106
1967	29.992	34.386	11.488
1968	30.854	36.267	12.527

Figure G.2: The Gross Domestic Product (G.D.P.) and the Contribution of the Manufacturing Sector to It.



The extrapolation of this figure to a future year Y, at the "1963 factor cost" rate of growth, gives the future CMS(Y) in (constant) 1970 pounds,

$$CMS(Y) = CMS(1970) \times \exp.(0.0262 \times (Y-1970)) \quad ...(G.10).$$

Since the contributions of individual manufacturing industries to the G.D.P. are not available, the rates of growth of individual industries are not directly obtainable. An estimate of these rates of growth (in current prices) up to 1970 may be made using the estimate "wages and salaries" in each industry. (C.S.O., 1969a, Table 18). These series are plotted in Figure G.3. For growth beyond 1970, the rate of equation G.10 is appropriate.

G.6 Stocks in Inventory

To use Section 8.3's equations in Section 9.4.b, statistics relating to stocks of materials, stores and fuel (MS&F) and of finished goods (FG) are required, while work in progress (WIP) statistics are not needed. Table G.7 below gives the book value of all stocks (except work in progress) in Britain (C.S.O., 1969a, p.78).

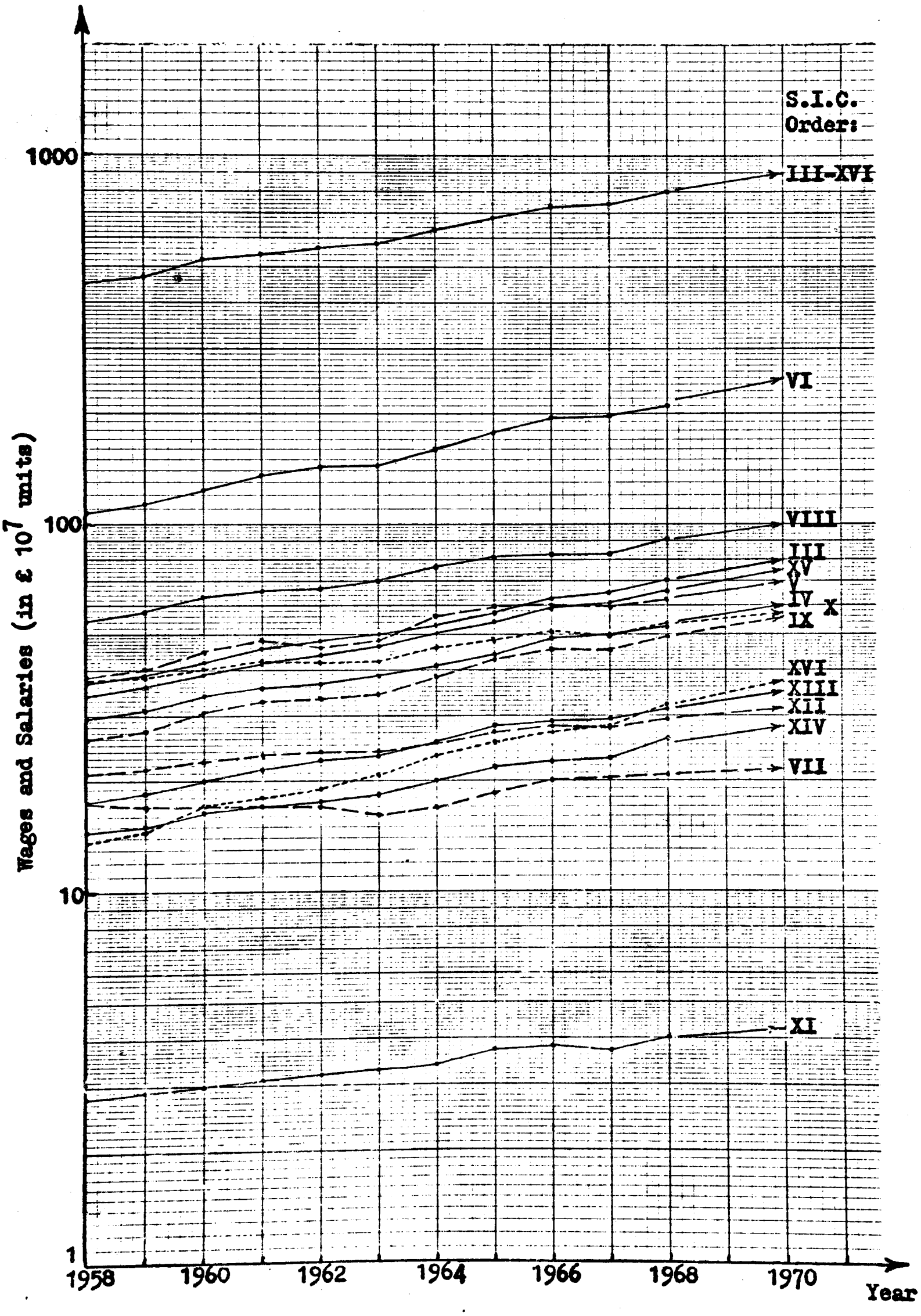
Table G.7: Book Value of All Stocks (Except Work in Progress) in Britain.

Year	Total End-of-year Level of Stocks (£ million)
1957	7,199
1958	7,272
1959	7,464
1960	8,015
1961	8,364
1962	8,511
1963	8,788
1964	9,473
1965	10,004
1966	10,424
1967	10,717
1968	11,446

The rate of growth is equal to about 4.9% per year, giving an estimate for the 1970 book value of all stocks (excluding work in progress) of

$$\text{Total Book Value (1970)} \approx £(12.6 \pm 0.2) \times 10^9 \quad ...(G.11).$$

Figure G.3: Wages and Salaries in Manufacturing Industries.



The totals of Table G.7 may be subdivided into stock levels for various industries. A subdivision for the end of 1968 is given in Table G.8.

Table G.8: Book Value of Stocks Held in Britain, End of 1968.

INDUSTRY	Book Value of Stocks (£ million)
Agriculture	1,334
Forestry	613
Mining and quarrying	176
Manufacturing, of which:	8,166
Materials and fuel	(2,731)
Work in progress	(3,223)
Finished products	(2,212)
Gas, electricity and water	225
Retail distribution	1,562
Wholesale distribution	1,434
Central government (Strategic)	114
Other industries	1,045
Total	14,669
Total excluding Work in progress	11,446

While manufacturing work in progress has obviously been removed in obtaining the totals of Table G.7, other work in progress has not explicitly been removed. An examination of Census statistics (Board of Trade, 1969) for mining and quarrying, construction, and gas, electricity and water indicates that just under 1% of the total stocks of these industries is devoted to work in progress. This correction, applied to Table G.8, has an almost negligible effect; equation G.11 remains unchanged.

A further breakdown of manufacturing inventories is given in Table G.10 in Section G.7 below.

G.7 Data on Manufacturing Industries

The 1963 Census of Production gives the following distribution of sizes of British manufacturing establishments (Board of Trade, 1969, Volume 131, Table 4).

Table G.9: Analysis of All Manufacturing Industries by Size of Establishment, 1963.

Average Number Employed in Each Establishment	Number of Establishments	Net Output During Year (£ million)	Average Net Output per Establishment During Year (£ thousand)
< 25	51,723	629	12.16
25 - 49	9,224	400	43.4
50 - 99	9,033	743	82.4
100 - 199	6,449	1,097	170.3
200 - 299	2,697	835	310.
300 - 399	1,450	649	448.
400 - 499	844	508	602.
500 - 749	1,083	890	821.
750 - 999	534	682	1,278.
1000 - 1499	520	965	1,856.
1500 - 1999	239	616	2,578.
2000 - 2499	135	474	3,510.
2500 - 2999	79	330	4,180.
3000 - 3999	79	442	5,600.
4000 - 4999	51	342	5,705.
5000 - 7499	45	404	8,980.
7500 - 9999	18	222	12,330.
> 10,000	23	480	20,850.
Satisfactory returns	84,226	10,709	
Unsatisfactory "	5,723	142	
TOTAL	89,949	10,851	

It is noted that unsatisfactory returns relate to an insignificant proportion of total net output.

The distribution of establishment sizes is shown by the plot of the average net outputs per establishment against the cumulative number of establishments which have at least that output. Figures G.4.a and G.4.b show this plot of the data of Table G.9, as well as the corresponding plots for the fourteen manufacturing industries (Board of Trade, 1969, Volume 131, Table 4). Unfortunately, however, the "total plot" of Figures G.4.a and G.4.b does not actually indicate the number of establishments which have net outputs above a certain size, since plotting average net outputs per establishment gives an over-estimate. The size distribution is corrected by shifting it to the left by an amount equal to B/2, where B is the number of establishments in any employment band; thus average values are taken

Figure G.4.a: Distribution by Size (of Net Output) of All Manufacturing Establishments, 1963. (Satisfactory Returns Only)

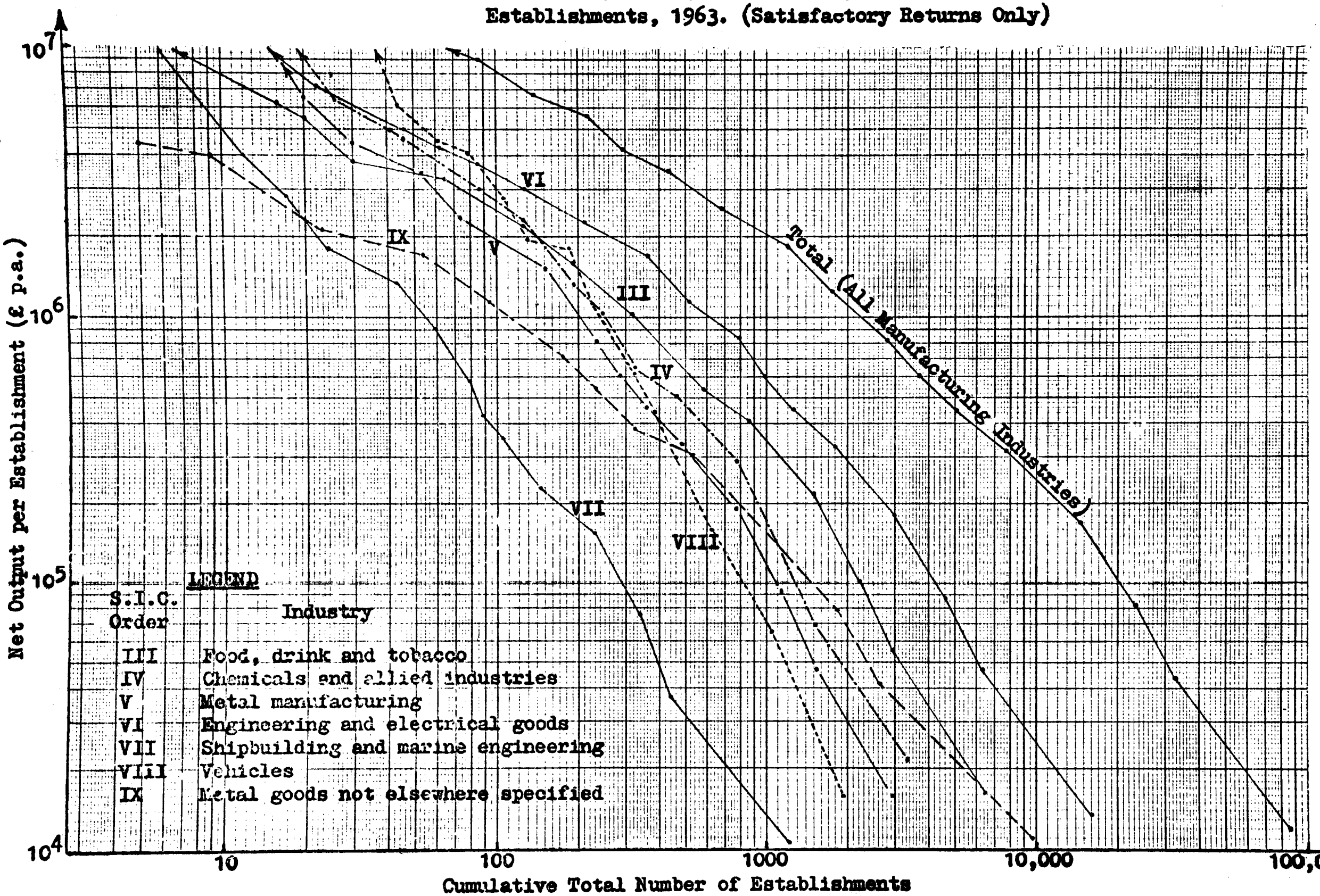


Figure G.4.b: Distribution by Size (of Net Output) of All Manufacturing Establishments, 1963. (Satisfactory Returns Only)

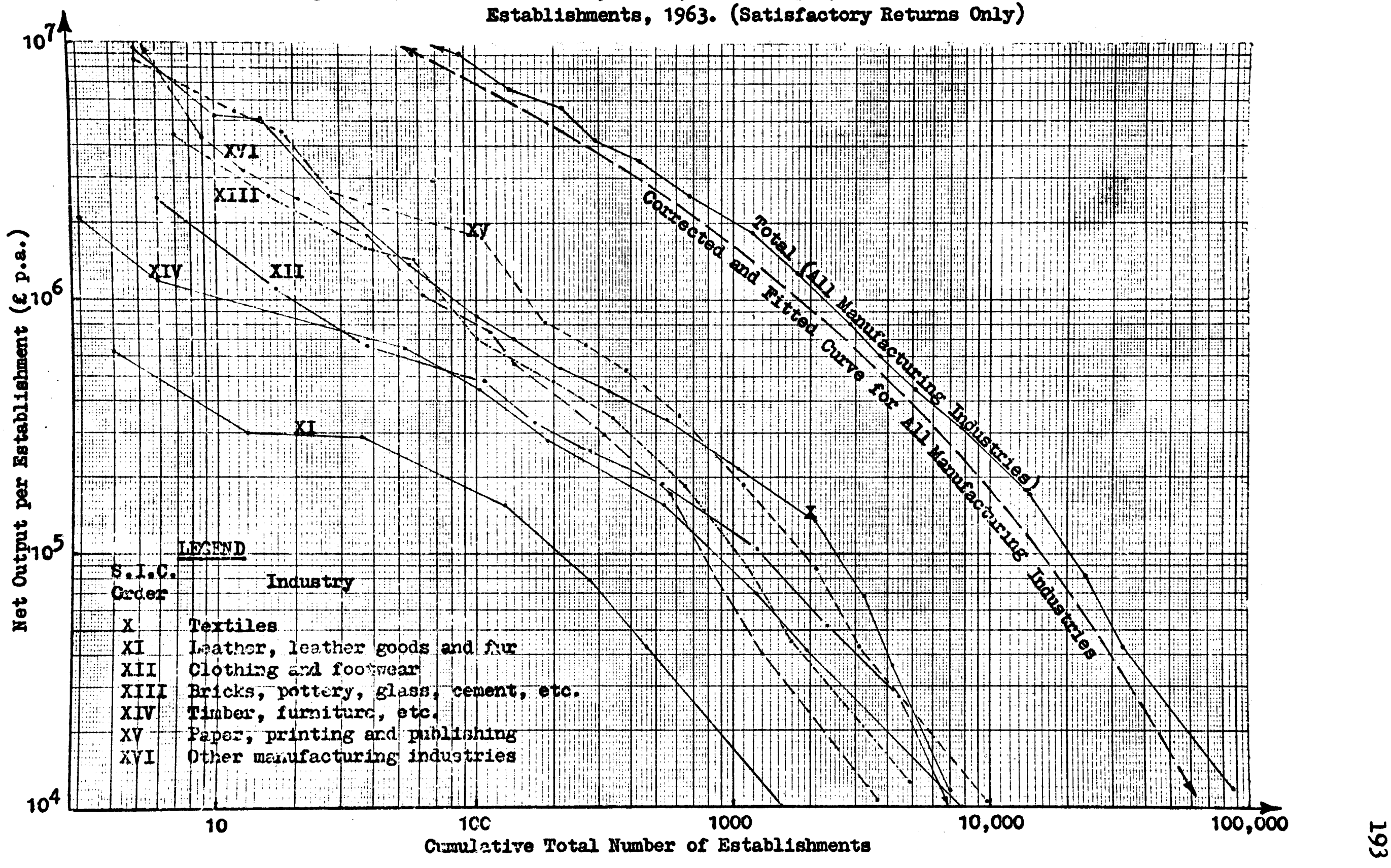


Table G.10: Data for Manufacturing Industries, 1963.

S.I.C. Order (See Table 10.2)	End-of-Year Stocks		Purchases	Goods Produced & Work done	Net Output	RATIOS			
	Materials, Stores & Fuel M,S&F (£m)	Finished Goods FG (£m)	P (£m)	GP&WD (£m)	NO (£m)	PTTC / NO x100 (Table G.3) (Ratio)	Cap / NO (Table G.5) (Ratio)	P / NO (Ratio)	GP&WD / NO (Ratio)
III	360	204	2,624	4,500	1,269	0.537	0.978	2.07	3.54
IV	192	194	1,830	2,763	1,058	0.658	2.45	1.73	2.59
V	226	98.5	1,695	2,498	830	0.411	2.87*	2.04	3.01
VI	441	287	2,135	4,439	2,507	0.809	1.15*	0.85	1.77
VII	17.7	1.93	165	418	215	0.324	1.01*	0.77	1.95
VIII	209	130	1,660	2,663	1,154	0.518	1.44*	1.44	2.31
IX	123	67.9	1,050	1,629	618	0.742	1.13*	1.70	2.64
X	208	165	1,304	2,079	804	0.565	1.45*	1.62	2.59
XI	16.9	11.9	114	165	59.3	0.846	0.372*	1.92	2.78
XII	76.6	52.8	462	835	382	0.752	0.372*	1.21	2.18
XIII	55.2	48.3	329	754	418	0.655	1.125	0.79	1.80
XIV	63.4	28.0	358	651	299	0.840	0.402	1.20	2.18
XV	111	75.3	724	1,629	846	1.509	1.24	0.86	1.93
XVI	58.9	67.5	426	775	392	0.845	1.04*	1.09	1.98
III-XVI	2,159 (Sum)	1,432 (Sum)	14,876 (Sum)	25,798 (Sum)	10,851 (Sum)	0.718 (Average)	1.38* (Average)	1.37 (Average)	2.38 (Average)

Note: * indicates estimates.

to be at the mid-points of the bands. (This correction procedure could be used in Section G.9 to derive Figure G.7 from Figure G.6.) A fitted curve to the corrected total points is shown in Figure G.4.b as a heavy dashed line.

Table G.10 summarizes various further data for manufacturing industries (Board of Trade, 1969, Volume 131). It is noted that "total purchases" (P) plus "total net output" (NO) approximates "total goods produced and work done" (GP&WD). Since the size distributions of Figures G.4.a and G.4.b are based upon net outputs, it is necessary to obtain conversion factors enabling the distributions to be expressed in terms of other parameters. These factors are given as ratios in Table G.10, using data from Tables G.3 and G.5.

G.8 Data on Non-manufacturing Census Industries

The "non-manufacturing census industries" are those considered in the 1963 Census of Production (Board of Trade, 1969) which are not devoted to manufacturing: these are S.I.C. Orders II (Mining and quarrying), XVII (Construction), and XVIII (Gas, electricity and water). Unfortunately, the only size distribution available is for "Mining and quarrying (other than coal mining) (which shall be called S.I.C. Order II') and Construction"; this distribution is given in Table G.11 below (Board of Trade, 1969, pp. 132/6-7).

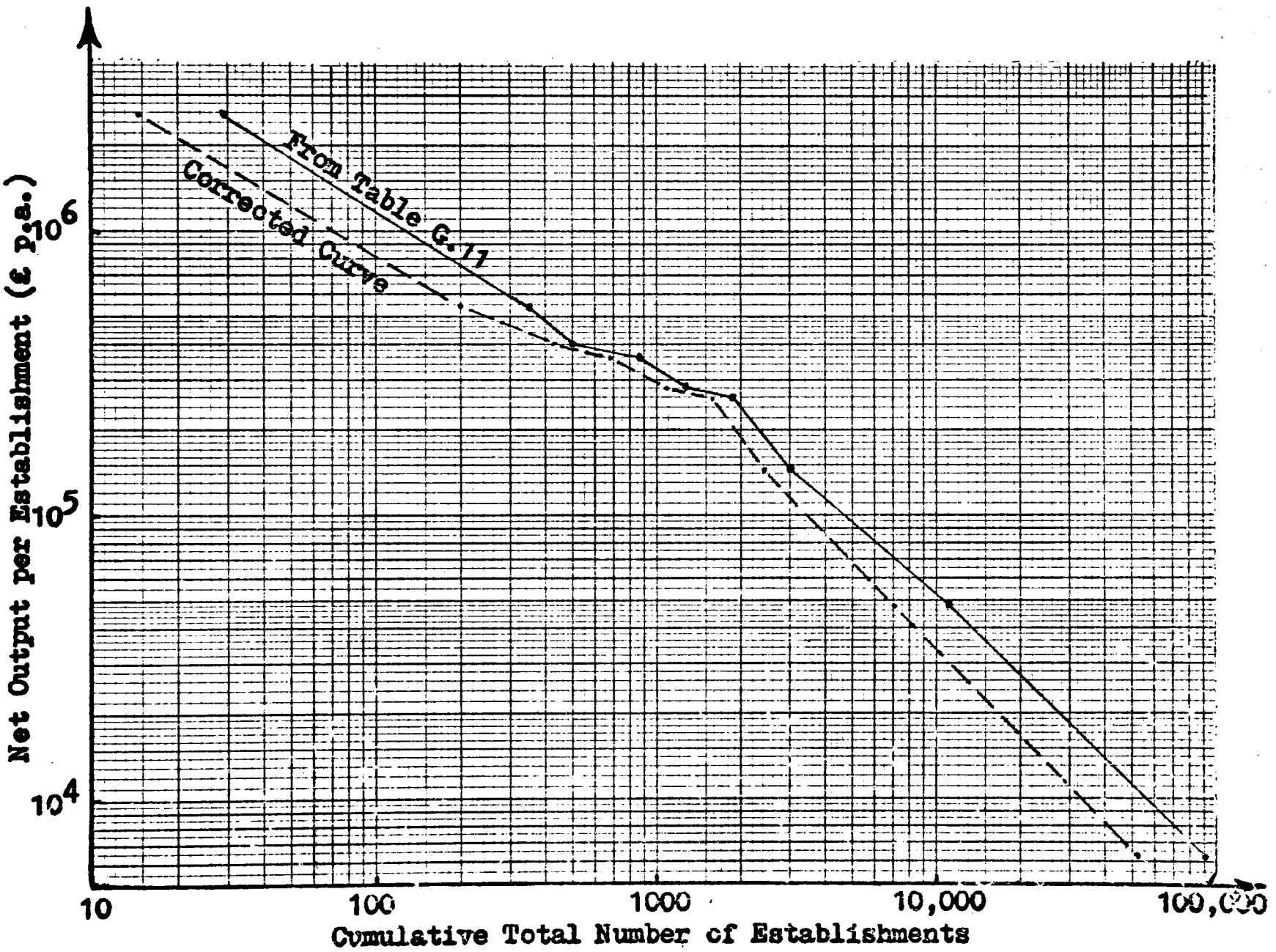
Table G.11: Analysis of Non-Manufacturing Industries (Orders II' and XVII) by Establishments, 1963.

Average Number Employed in Each Enterprise	Number of Establishments	Net Output During Year (£ million)	Average Net Output per Establishment During Year (£ thousand)
< 25	80,470	500	6.22
25 - 99	7,170	348	48.5
100 - 199	1,045	152	145.5
200 - 499	622	168	270.
500 - 999	356	129	* 362.
1000 - 1999	414	118	* 285.
2000 - 4999	322	174	540.
5000 - 9999	151	60	* 397.
<10,000	29	75	2,585.
TOTAL	90,579	1,723	

* row interchanges required here to give a smooth progression of net outputs per establishment.

The distribution of establishment sizes is given in Figure G.5 as a cumulative plot like Figures G.3 and G.4; also shown (as a dashed line) is the curve corrected using the methodology of Section G.9. It is noted that this distribution in far less regular than those for manufacturing industries.

Figure G.5: Distribution by Size (of Net Output) of Non-manufacturing Establishments, 1963.



Further data for Orders II' and XVII is given in Table G.12 below (Board of Trade, 1969, p.131/24, p.131/42, and Volume 131, Table 9).

Table G.12: Data for Orders II' and XVII, 1963.

S.I.C. Order (See Text.)	End-of-Year Stocks of Materials, Stores and Fuel M,S&F (£m)	Purchases P (£m)	Net Output NO (£m)	Payments for Postage, Telephone, Telegrammes and Cables PTTC (£m)	RATIOS $\frac{PTTC}{NO}$ x100	RATIOS $\frac{P}{NO}$
II'	7.1	47.0	117.0	0.426	0.364	0.402
XVII	128.4	1,269.2	1,819.3	10.545	0.580	0.698
II'+ XVII	135.5	1,316.2	1,936.3	10.971	0.567	0.680

G.9 Data on Retail Trade

The 1966 Census of Distribution and Other Services gives the following distribution of sizes (by turnover) of retail establishments (Board of Trade, 1970, p. 1/36).

Table G.13: Establishment Turnovers for Total Retail Trade, 1966.

Turnover Range (in £ thousand)	Number of Establishments	Turnover During Year (£ million)	Average Turnover per Establishment During Year (£ thousand)
<1	16,261	8.155	0.501
1 - 2	20,001	29.344	1.467
2 - 5	79,599	282.177	3.543
5 - 10	121,014	888.515	7.34
10 - 20	151,394	2,143.899	14.17
20 - 50	108,405	3,215,738	29.68
50 - 100	22,270	1,481.635	66.6
100 - 200	6,845	932.981	136.3
200 - 500	3,307	997.483	301.5
500 - 1,000	816	552.394	677.
1,000 - 2,000	327	438.665	1,342.
2,000 - 5,000	115	325.476	2,830.
5,000 - 10,000	15	95.402	6,360.
> 10,000	4	59.465	14,870.
Total: Simple estimates (Ratio estimates)	530,373 (504,412)	11,451.330 (11,131.816)	

While this table is based upon "simple estimates", "ratio estimates" are preferred since the ratio method reduces the sampling errors by

using supplementary information in addition to the sample, which merely provides the "simple estimates".

The distribution of establishment sizes is indicated by the plot in Figure G.6 of average turnovers per establishment against the cumulative total number of establishments, starting with the largest. Also shown in Figure G.6 are similar plots (Board of Trade, 1970, pp. 1/35 ff) for the seven subdivisions of retail trade indicated. Since Figure G.6 plots average turnovers, it overstates the number of retail establishments with turnovers above a certain size; these plots are corrected in Figure G.7 where the lower ends of turnover ranges are plotted against the cumulative total number of establishments. (It is interesting to note that the curves of Figure G.7 are somewhat smoother than the corresponding curves of Figure G.6.) It is apparent that the curves of Figure G.7 could be derived from those of Figure G.6 by shifting the latter curves to the left by amount B/2, where B is the number of establishments in any turnover range; this is equivalent to attributing the average turnover values to the middle establishment of each range.

The similar shape of the curves of Figure G.7 suggests that the "total retail trade" curve provides a reasonable description of the whole retail sector. Further data on the sector is given in Table G.14 below (Board of Trade, 1970, p. 1/66 and p. 1/29).

Table G.14: Data for Total Retail Trade, 1966.

Estimating Procedure	Number of Establishments	End-of-year Stocks (£m)	Purchases P (£m)	Turnover TO (£m)	Ratio P/TO
Simple	530,034	1,302	8,864	12,008	0.738
Ratio	504,046	1,271	8,599	11,689	0.737

(Slight discrepancies are noted between the total numbers of establishments here and in Table G.13.) The ratio of purchases (P) to turnover (TO) is seen to be virtually constant for either estimating procedure; as noted above, the "ratio estimate" is preferred. The ratio P/TO is taken to hold throughout the retail sector; in fact, there is a slight variation for each of the subdivisions of the sector.

Figure G.6: Distribution by Size (of Turnover) of All Retail Establishments, 1966.

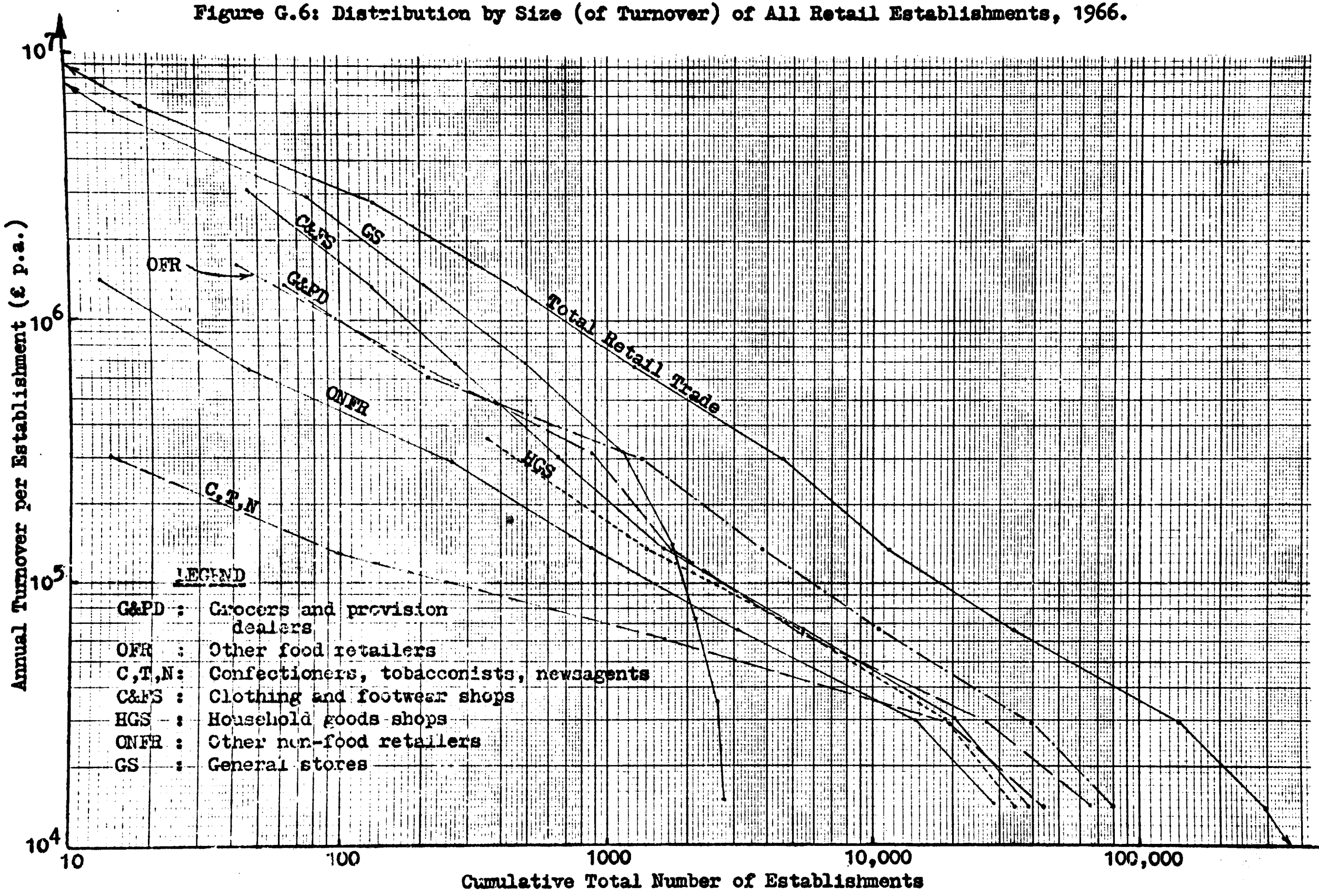
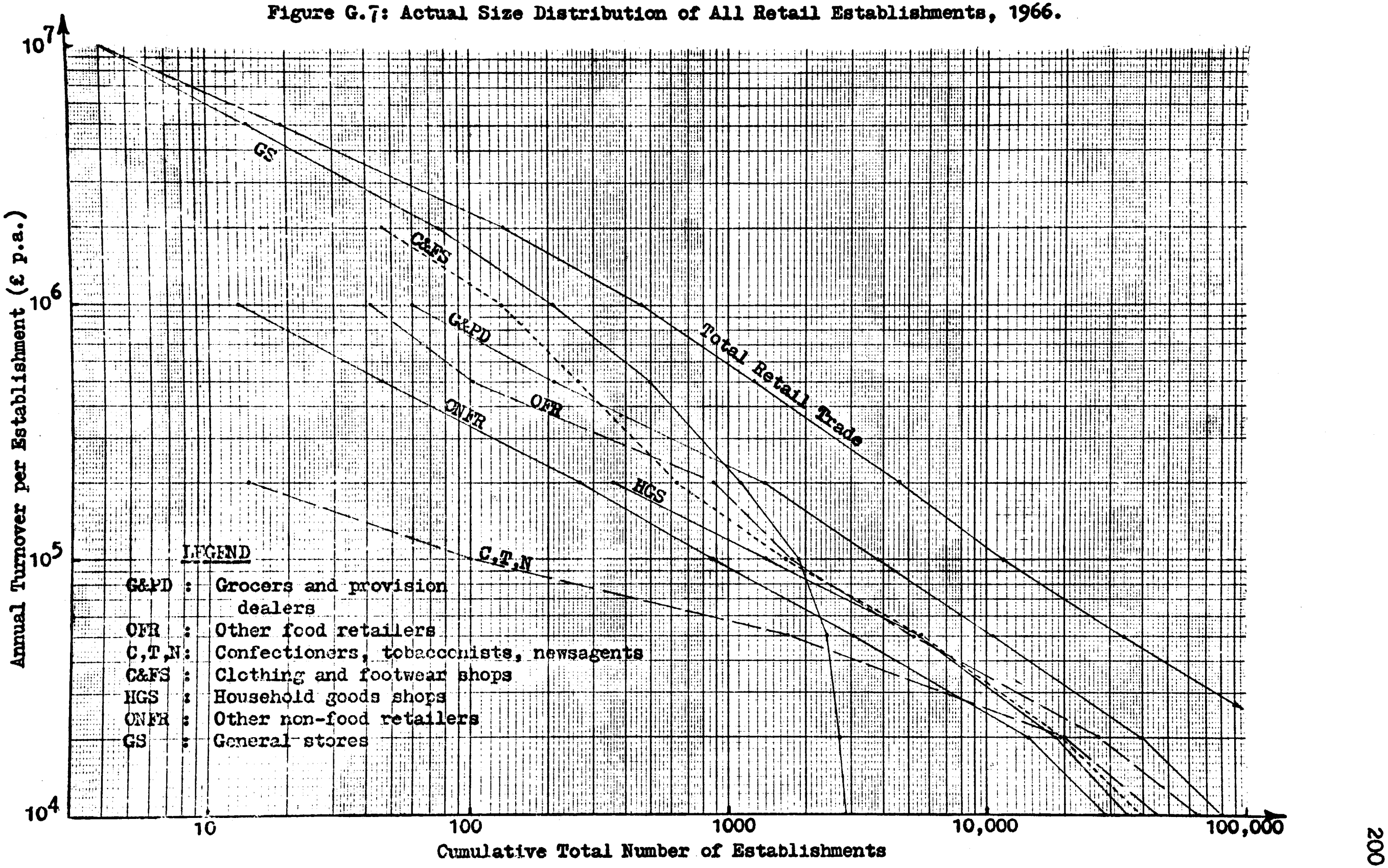


Figure G.7: Actual Size Distribution of All Retail Establishments, 1966.



The growth of retail trade over time is indicated in Table G.15 below, which gives the total value of sales for all retail trade in the form of index numbers (C.S.O., 1968, p.198; C.S.O., 1969b, p.207).

Table G.15: Total Value of Sales for All Retail Trade.

Year	Index Number Definition	Index Number	Estimated Value of Sales During Year (£ million)
1961	1961 = 100	100	9,140
1962		103	9,420
1963		108	9,880
1964		113	10,330
1965		120	10,970
1966		125	11,420
1966	1966 = 100	100	11,372
1967		103	11,710
1968		109	12,390

The estimates of this table are virtually linear when plotted, giving an extrapolated estimate for 1970 of

$$\left\{\begin{matrix}\text{Estimated Value of} \\ \text{Sales During 1970}\end{matrix}\right\} \approx \text{£}13.22 \times 10^9 \qquad \ldots(G.12).$$

It is observed that the estimated sales for 1966 are slightly below the turnover figure of Table G.14. If it is assumed that (the ratio estimate of) turnover is proportional to sales, then estimates of turnover (TO) for 1963 and 1965 are

$$\begin{aligned} TO\,(1963) &\approx \text{£}10.2 \times 10^9 \\ TO\,(1965) &\approx \text{£}11.3 \times 10^9 \end{aligned} \qquad \ldots(G.13).$$

To obtain an estimate of the ratio PTTC to TO, it is necessary to subdivide the SCI figure of £114 million for the distributive trades (Table G.3) into wholesale and retail components. Assuming these components to be proportional to 1965 sales, and using the TO(1965) estimate (or the 1965 estimate of retail sales from Table G.15) with the figure of £14.771 x 10^9 for 1965 wholesale receipts (Table G.17), gives the estimates for 1963 of

$$\begin{aligned} PTTC_{Wholesale} &\approx \text{£}65 \text{ million} \\ PTTC_{Retail} &\approx \text{£}49 \text{ million} \end{aligned} \qquad \ldots(G.14).$$

Taken with TO(1963), this gives

$$\left.\frac{PTTC}{TO}\right|_{Retail} \approx 0.0048 \qquad \ldots(G.15)$$

for the retail trade. The corresponding estimate for the wholesale sector is

$$\left.\frac{PTTC}{REC}\right|_{Wholesale} \approx 0.0049 \qquad \ldots(G.16)$$

taking wholesale receipts (REC) for 1963 to have been about £13.3 x 10^9. It is noteworthy that the ratios of equations G.15 and G.16 are almost identical.

G.10 Data on the Wholesale Trades

The Board of Trade's 1965 large-scale inquiry into the wholesale trades (Board of Trade Journal, 1968) gives the following distribution of sizes (by receipts) of wholesale businesses, other than those operating on a commission basis, which made satisfactory returns to the inquiry.

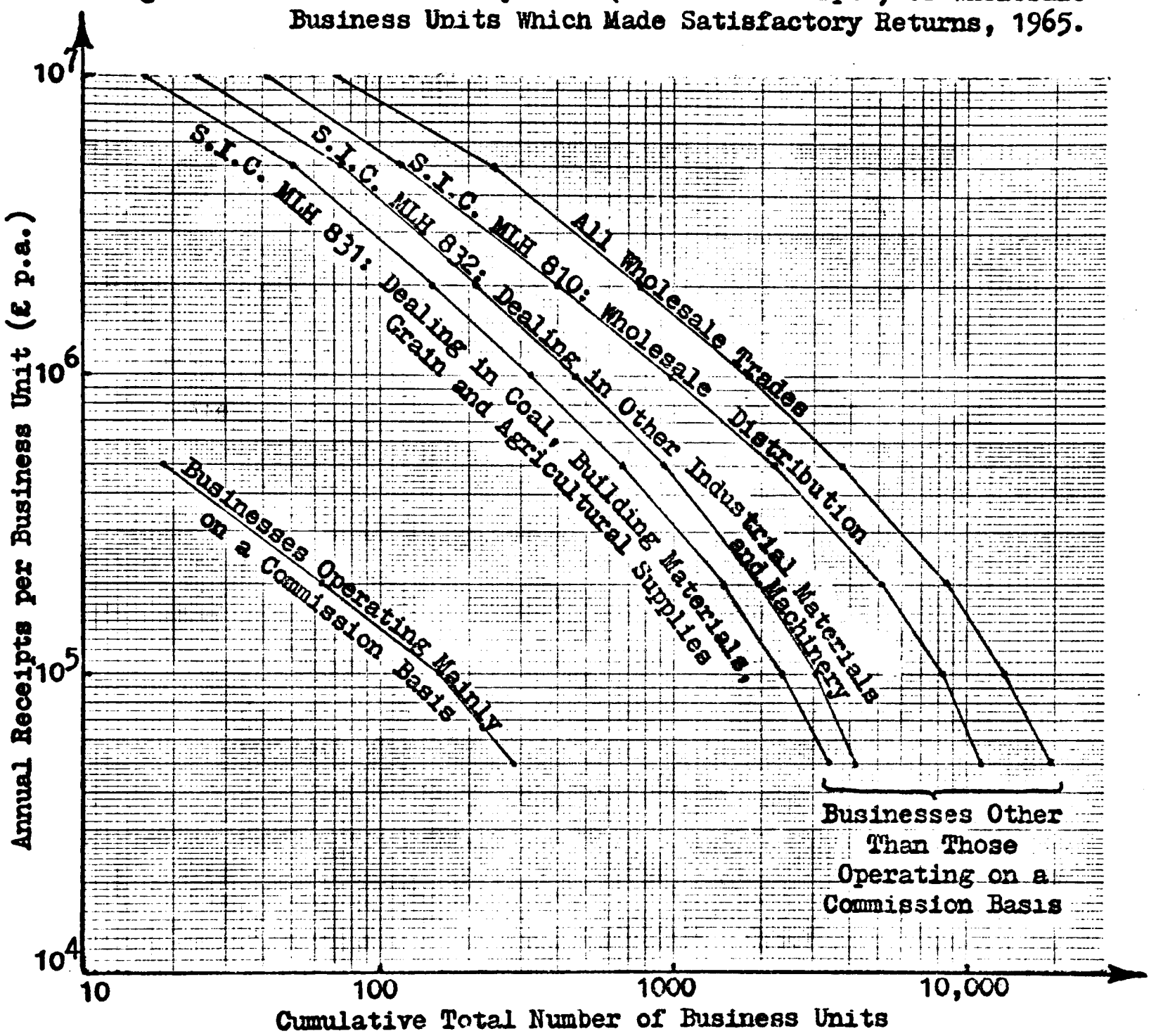
Table G.16: Business Unit Total Receipts for Wholesale Business, Other Than Those Operating on a Commission Basis, 1965.

Range of Total Receipts (£ thousand)	Number of Business Units	Total Receipts During Year (£ million)
< 50	13,333	286.0
50-100	5,623	405.3
100-200	5,062	729.4
200-500	4,784	1499.3
500-1,000	2,004	1407.2
1,000-2,000	996	1383.1
2,000-5,000	512	1872.2
5,000-10,000	165	1908.6
>10,000	89*	4416.5
TOTAL	32,568	13,907.8

*Note: Included here are 7 Marketing Boards, with total receipts of £457,213,000.

The distribution of business unit sizes is plotted in Figure G.8, with the lower ends of receipt ranges plotted against the cumulative total number of business units having at least that amount of receipts.

Figure G.8: Distribution by Size (of Total Receipts) of Wholesale Business Units Which Made Satisfactory Returns, 1965.



Also shown in Figure G.8 are similar plots of the three separate kinds of business which comprise the "all wholesale trades" plot from Table G.16, and a plot giving the size distribution of businesses operating mainly on a commission basis.

Further data on the wholesale sector is given in Table G.17 below (Board of Trade Journal, 1968). Since the overall size distributions of Figure G.8 are for businesses trading with and without stock, these two categories must be considered together. An aggregate value of the ratio of purchases (P) to receipts (REC) is

$$\frac{P}{REC} = 0.874 \qquad \ldots(G.17).$$

Table G.17: Data for Wholesale Trades, 1965.

	Estimates for All Businesses (including Marketing Boards)	Businesses which Made Satisfactory Returns		
		Method of Trading		
		With Stock	Without Stock	Mainly on Commission
Number of Business Units	41,049	28,746	3,822	2,801
Total Receipts (£m)	14,771	12,510	1,397	259
Purchases (£m)	12,876	10,845	1,312	204
Ratio: $\frac{\text{Purchases}}{\text{Receipts}}$	0.872	0.868	0.940	0.787
End-of-year Stocks (£m)	1,180	1,119	-	-

G.11 The Cycle Time

The cycle time ψ is defined, from equation 9.23, as

$$\psi = \frac{V}{VR} \qquad \ldots(G.18)$$

where V is the total value contained within one conceptual cycle (Section 9.5.b),
and VR is the value rate of cyclic flow.

The first approach to estimating ψ follows the "Quantity Theory of Money" (Section 9.5). Taking the total money supply as V, and the national income as VR, the cycle time becomes the inverse of the income velocity, which is a measure of the "efficiency of the monetary stock" (Welham, 1969, p.79).

Thus

$$\psi = \frac{1}{\text{Income velocity}} \equiv \frac{\text{Total money supply}}{\text{National income}} = \frac{M}{NI} \qquad \ldots(G.19).$$

Suitable statistics to quantify this equation are given in Table G.18 below. The "Money" (M) figures for the United Kingdom are taken from the International Monetary Fund's "Monetary Survey" in International Financial Statistics; the "National Income" (NI) figures are taken from C.S.O. (1969a, p.3).

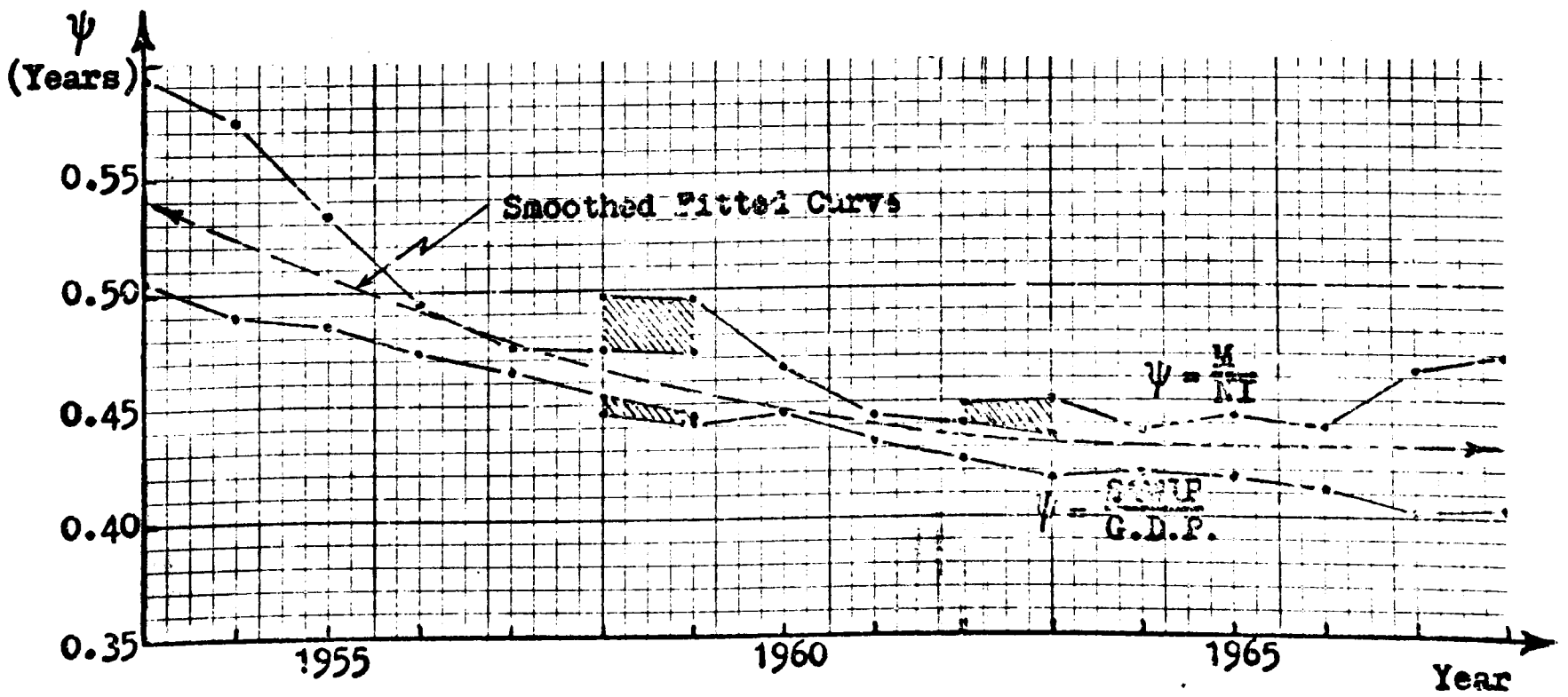
Table G.18: The Derivation of Cycle Time from Monetary Statistics for the United Kingdom.

Year	Money (end of year) M £x10^9	International Financial Statistics Reference	National Income NI £x10^9/year	Cycle Time ψ ψ = M/NI years
1958	9.263	Vol.XVIII,	19.617	0.497
1959	9.675	No. 2,	19.567	0.494
1960	9.735	February	20.861	0.467
1961	9.941	1965	22.326	0.445
1962	10.244		23.366	0.439
1963	10.784		24.900	0.433
1962	10.483	Vol.XXIII,	23.366	0.448
1963	11.195	No. 2,	24.900	0.450
1964	11.770	February	26.881	0.438
1965	12.666	1970	28.667	0.441
1966	13.194		30.069	0.439
1967	14.691		31.657	0.464
1968	15.655		33.311	0.470

(The shift in the M values from the 1965 to the 1970 reference is due to a change in the basis used for consolidating the accounts.)
The cycle time values calculated in this table are plotted in Figure G.9.

Another approach to determining the cycle time may be made by taking the gross domestic product (G.D.P.) as the annual value of flows within a conceptual cycle containing stocks and work in

Figure G.9: The Derivation of ψ Using British Statistics.



progress (S&WIP). Thus

$$\psi = \frac{V}{VR} = \frac{\text{Stocks \& Work in Progress}}{\text{Gross Domestic Product}} = \frac{\text{S\&WIP}}{\text{G.D.P.}} \quad ...(G.20).$$

Table G.19 gives the appropriate annual statistics for the United Kingdom (C.S.O., 1969a, p.78 and p.3).

Table G.19: Annual Statistics for the United Kingdom.

Year	Book Value of Stocks and Work in Progress S&WIP £x10^9	Gross Domestic Product at Current Factor Cost G.D.P. £x10^9/year	Cycle Time, ψ $\psi = \frac{\text{S\&WIP}}{\text{G.D.P.}}$ years
1958	9.024	20.115	0.448
1959	9.288	21.151	0.440
1960	10.018	22.563	0.444
1961	10.514	24.139	0.436
1962	10.732	25.230	0.425
1963	11.146	26.826	0.416
1964	12.102	28.966	0.418
1965	12.852	30.895	0.416
1966	13.485	32.590	0.412
1967	13.814	34.386	0.402
1968	14.669	36.267	0.404

The cycle time values calculated in this table are also plotted in Figure G.9. It is noted that both cycle time series are decreasing in the period from 1958 to 1968; this is confirmed by the extended series plotted in Figure G.9.† A smoothed curve (given by the dashed line in the figure) fitted to both series suggests that the British cycle time has now levelled off at the approximate value

$$\psi \approx 0.43 \pm 0.02 \text{ year} \quad ...(G.21).$$

Taking 250 working days to a year,

$$\psi \approx 107 \pm 5 \text{ working days} \quad ...(G.22).$$

† This trend of falling cycle times is confirmed by American data (obtained as in Table G.18) for the period from 1950 to 1969. However, this conflicts with Selden's (1956, p.192) conclusion that "income velocity has been declining for more than a century". A close examination of Selden's data and the latest available data now suggests that the falling income velocity trend probably ended in about 1932; since that time it has been rising. This change might be attributed to Keynes's great influence after the 1929 crash, to the increasing emphasis upon monetary policies rather than fiscal policies, and to the expansion of domestic credit.

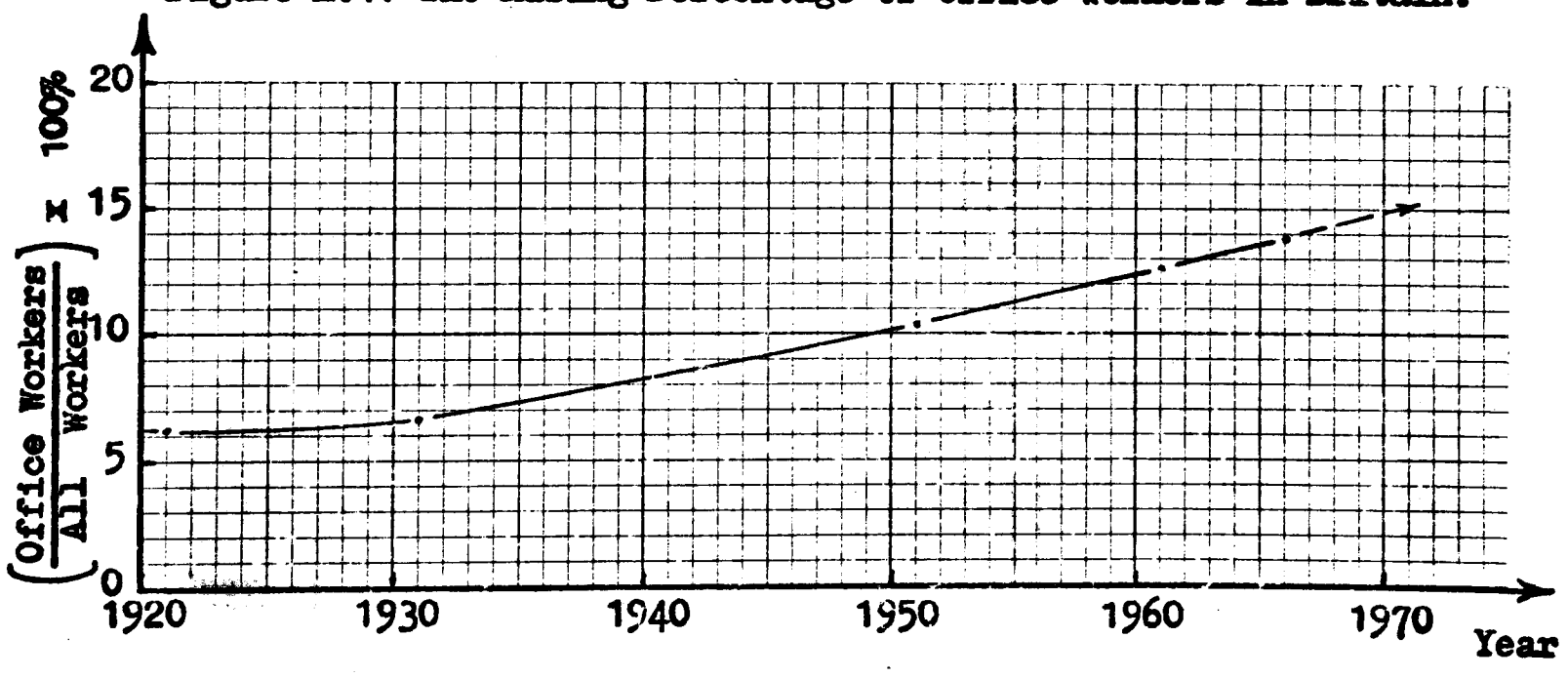
APPENDIX H : THE IMPORTANCE OF INFORMATION-HANDLING

H.1 Employment of Information-Handling Workers

It is apparent that the introduction of a national data network would vastly improve the transmission of and the handling of information, thus changing the job function of many of those involved in handling information. In order to appreciate the impact of this network, it is of value to determine the employment of information-handling workers in the economy.

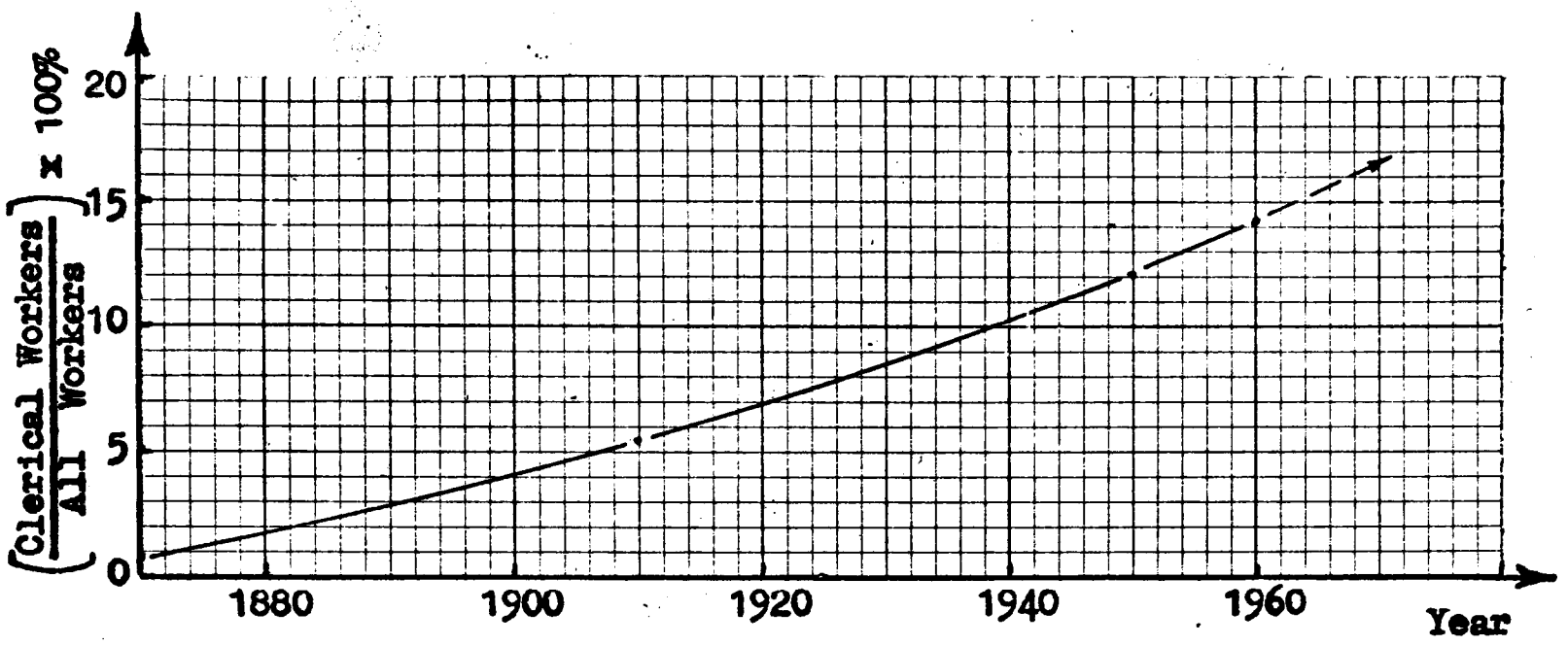
Figure H.1 indicates the rising percentage of all British workers that are office workers (i.e. that are in the 1961 "occupational codes" 220 and 221) (Ministry of Labour, 1968; Central Registry Offices, 1967, 1968). An extrapolation of the fitted curve is of only doubtful validity, since the arrival of computers has considerably changed the underlying features of many office jobs. Nevertheless, this extrapolation gives a rough estimate that about 14.8% of the total British work force is now (1970) involved in office work.

Figure H.1: The Rising Percentage of Office Workers in Britain.



A similar extrapolated figure may be obtained for the American economy (McDonough, 1963); Figure H.2 indicates that some 16.8% of the total American work force is now involved in clerical duties. To this figure must be added McDonough's (1963) estimate that 4% of the total labour force is now involved in white-collar, information-handling jobs.

Figure H.2: The Rising Percentage of Clerical Workers in the United States.



The slopes and first derivatives of the curves in both Figures H.1 and H.2 are both positive, indicating an ever-increasing demand for workers qualified for information-handling jobs. Although the extrapolated figures derived above for Britain and for the United States are not in exact agreement, they suggest that about one-fifth of the work force is involved in information-handling. In fact, this estimate may well be low; other recent estimates suggest that white-collar workers already outnumber manual workers in the United States, and that by the 1980's 55-60% of the total payroll in British industry will be white-collar (Rands, 1969).

Whatever may be the exact proportion of the work force engaged in information-handling, one fact stands out: the national data network will have far-reaching social consequences when it alters these jobs.

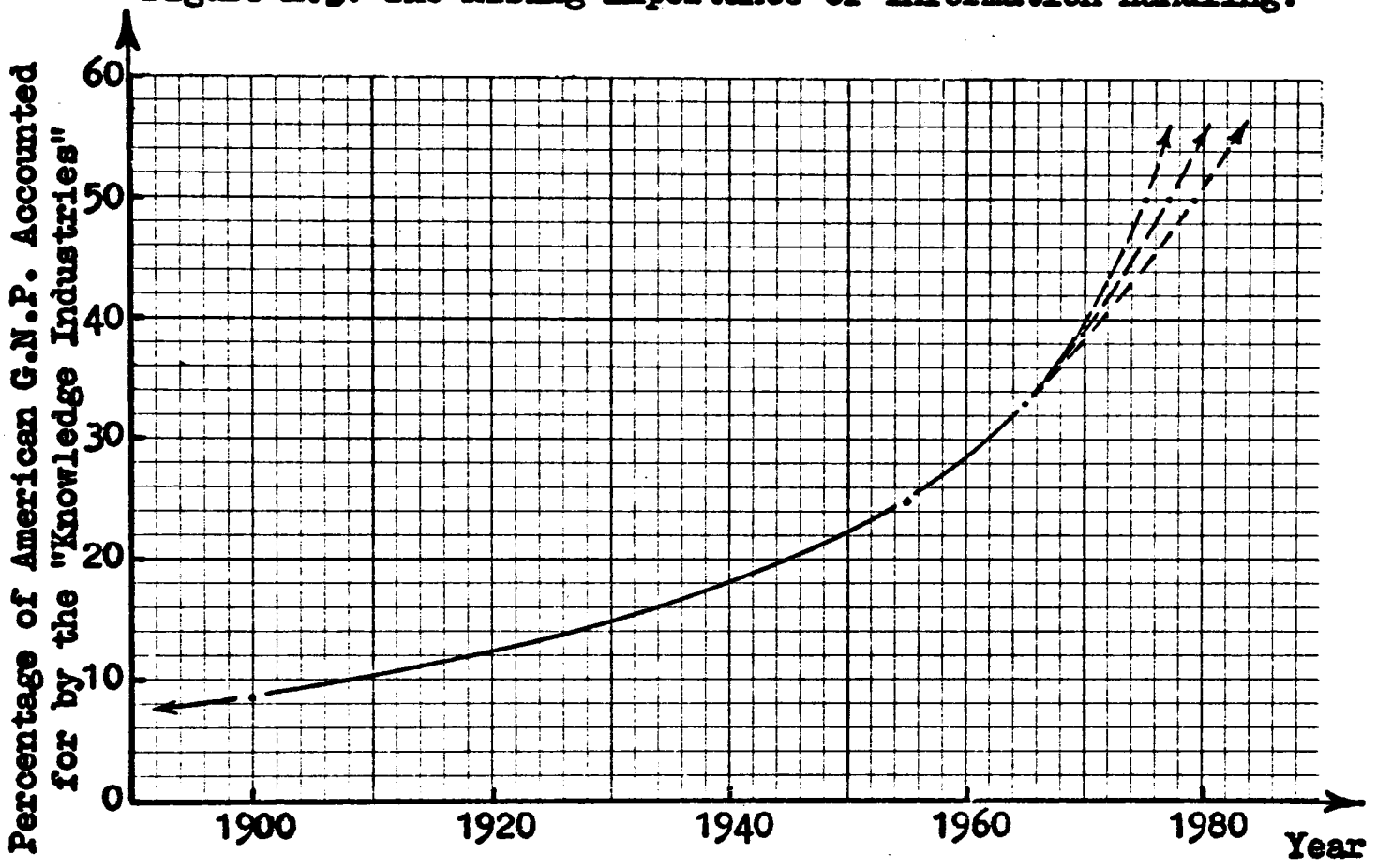
H.2 The Overall Cost of Information-Handling

It is also important to examine what effect a national data network might have on the overall economy. While Chapter 9 has examined some of the macro-economic benefits which should result, this section is more concerned with the overall cost of information-handling within the economy. Drucker (1969) gives an indication of the relative importance of the "knowledge sector" in the American economy. In 1955 the "knowledge industries" (which produce and distribute ideas and information rather than goods and services) accounted for one-quarter of the American G.N.P.; this was already three times the proportion

accounted for in 1900. Yet by 1965 this sector was taking one-third of the G.N.P., and in the late 1970's it should account for one-half of the total.

A curve is fitted to these estimates in Figure H.3; the

Figure H.3: The Rising Importance of Information-Handling.



rapidly rising slope (and its first derivative) indicates the growing importance of information-handling industries. Although economists traditionally classify these industries as "services", Drucker claims that knowledge has actually become the "primary" industry, supplying the essential and central resource of production to the economy. Since data transmission is an essential part of information-handling, it follows that the introduction of a national data network should have profound economic consequences throughout the economy.

GLOSSARY

GLOSSARY 1. Standard Abbreviations

b/s; Kb/s; Mb/s (Kb; Mb; Gb)	:	Bits/second; Kilobits/second; Megabits/second (Kilobits; Megabits; Gigabits)
DP	:	Data Processing
Datel	:	"Data and Telecommunication" services provided by the Post Office
DSE	:	Data Switching Exchange
E	:	Erlangs
G.D.P.; G.N.P.	:	Gross Domestic Product; Gross National Product
GSC	:	Group Switching Centre
H/L	:	High Level
L/E	:	Local Exchange
MLH	:	Minimum List Heading (in S.I.C. (q.v.))
Modem	:	Modulator-demodulator
MUX	:	Multiplexer
NI	:	National Income
NPV	:	Net Present Value
NTU	:	Network Terminating Unit
p	:	New Pence
P.C.M.	:	Pulse Code Modulation
PV( )	:	Present Value of (stream)
S.I.C.	:	Standard Industrial Classification
STD	:	Subscriber Trunk Dialling
T.D.M.	:	Time Division Multiplexing
Δ...	:	A positive change in ...

GLOSSARY 2. "Standard" Computer Program Names

This section lists the parameter and variable names, defined following the rules of Section C.3, which are used in Chapter 5; the numbers in parentheses give page references.

AIC(J)	:	Amount raised annually for Individual Service J subscribers, Constant. (29)
CAPACL(I)	:	CAPital ACcount, Level at time I. (33)
CAPACR(I-1)	:	CAPital ACcount Rate of change during year I-1. (33)
CNIC(J)	:	CoNnection charges for Individual Service J terminals, Constant. (27)
CSCNIR(I-1,J)	:	CoSt for CoNnecting Individual Service J terminals, Rate during year I-1. (27)
CSCNL(I)	:	CoSt for all CoNnections, Level at year I. (40)
CSCNR(I-1)	:	CoSt for all CoNnections, Rate during year I-1. (33)
CSPNIR(I-1,J)	:	CoSt PeNalty for Individual Service J transers from Datel, Rate during year I-1. (35)
CSPNR(I-1)	:	CoSt PeNalty for all transfers from Datel, Rate during year I-1. (33)
CSTL(I)	:	CoSt, Total Level at year I.(39)
CSTRSL(I)	:	CoSt, TRanSient, Level at Year I. (40)
CSTRSR(I-1)	:	CoSt, TRanSient, Rate during year I-1. (27)
CSXTRC	:	CoSt for eXtra TeRminals, Constant. (28)
CSXGL(I)	:	CoSt for eXtra Growth, Level at year I. (40)
CSXGR(I-1)	:	CoSt for eXtra Growth, Rate during year I-1. (28)
CUDIR(I-1,J)	:	Change in Underlying Demand for Individual Service J terminals, Rate during year I-1. (27)
CUDR(I-1)	:	Change in Underlying Demand for all terminals, Rate during year I-1. (26)
DATIL(I,J)	:	DATel number of Individual Service J terminals, Level at year I. (32)
DNDIL(I,J)	:	Data Network, from Datel, number of Individual Service J terminals, Level at year I. (31)
DNDIR(I-1,J)	:	Data Network, from Datel, number of Individual Service J terminals, Rate of change during year I-1. (32)

Cont...

DNTIL(I,J)	:	Data Network Total number of Individual Service J terminals, Level at year I (30)
DNTIR(I-1,J)	:	Data Network Total number of Individual Service J terminals, Rate of change during year I-1. (27)
DNTL(I)	:	Data Network Total number of all terminals, Level at year I. (33)
DNUDIR(I-1,J)	:	Data Network, from Underlying Demand, number of Individual Service J terminals, Rate of change during year I-1. (32)
DT	:	Delta Time, is time interval. (26)
FDC	:	Fraction of average capital cost per terminal raised annually by tariffs to pay off Depreciation charges, Constant. (29)
FDITC	:	Fraction of average capital cost per terminal raised annually by tariffs to pay off Depreciation and Interest (Total) charges, Constant. (30)
GRLMC	:	GRowth LiMit for network before extra expenditure is required, Constant. (28)
I	:	Array subscript for time
IC	:	Year of go-ahead for starting work on new national data network, Constant. (28)
IDIFC	:	Number of Years DIFference between end of IC and start of ISC, Constant. (28)
ISC	:	Year of Start of operation of new national data network, Constant. (28)
J	:	Array subscript for Services.
NIC(J)	:	Number of years of S-curve build-up of Individual Service J terminals transferred from Datel, Constant. (32)
PBC	:	PayBack period, Constant. (29)
PENIC(J)	:	PENalty charge for Individual Service J terminals, Constant. (35)
PNNIC(J)	:	PeNalty charge, Newly defined, for Individual Service J terminals, Constant. (37)
REVIR(I-1,J)	:	REVenue, for depreciation and interest charges, from Individual Service J terminal, Rate during year I-1. (30)
REVR(I-1)	:	REVenue, for depreciation and interest charges, from all terminals, Rate during year I-1. (33)

Cont...

ROIC	:	Rate Of Interest, Constant. (29)
SIC(J)	:	Parameter describing S-type build-up of number of Individual Service J terminals from underlying demand, Constant. (32)
SUDIR(I-1,J)	:	Sum of change of Underlying Demand for Individual Service J terminals, Rate during year I-1. (27)
SUDR(I-1)	:	Sum of change of Underlying Demand for all terminals, Rate during year I-1. (26)
UDIL(I,J)	:	Underlying Demand for Individual Service J terminals, Level at year I. (26)
UDL(I)	:	Underlying Demand for all terminals, Level at year I. (26)
X(J)	:	Capital cost to put a Service J terminal on the Datel network. (35)
XUDIR(I-1,J)	:	EXtra Underlying Demand for Individual Service J terminals, Rate during year I-1. (27)
XUDR(I-1)	:	EXtra Underlying Demand for all terminals, Rate during year I-1. (26)
Y(J)	:	Capital equipment, used by Service J subscriber on Datel, which may be transferred to the telephone network. (35)

GLOSSARY 3. Parameter and Variable Names

This section lists parameter and variable names used more than once; the numbers in parentheses give page references.

A	:	Saturation level. (11)
a_1; a_2	:	Average unit costs. (59)
ABL; ABL'	:	Absolute Buffer Length. (68; 69)
AET	:	Expected Allowable Extra Time.(82)
B	:	Number of establishments in a size Band. (191)
BOT_1; BOT_2	:	Effective Back-Order Time. (84; 85)
C	:	Fractional Manufacturing Capacity. (71)
C_1; C_2	:	Correction factor. (14)
C_i	:	Generalized benefit Coefficient. (129)
Cap.	:	Total manufacturing Capacity. (71)
CC	:	Competitive Costing. (89)
CMS(Y)	:	Contribution of the Manufacturing Sector to the G.D.P. for year Y. (186)
CNTE(Y)	:	Corrected estimated Number of Terminal Equivalents in year Y. (143)
CNU	:	Cost of Network Usage. (109)
$n^{CO}{}_i(t)$	:	Cut-Off establishment size for sector i with integer n (q.v.) at time t. (131)
COT	:	Expected Customer Order-handling Time. (82)
CST	:	Expected Customer Service Time. (82)
ct; CT	:	Cycle Time; expected ". (75)
CU	:	Capacity Utilization. (68)
D	:	Density (of telephones). (11)
d_i^k	:	Size distribution parameter for establishment k in sector i. (130)
dd; DD	:	Daily demand; expected ". (74)
DSB	:	Direct Social Benefit. (93)
dt	:	Time interval. (131)
D.U.	:	Data Unit. (171)
EBL	:	Electronic Business Letter. (59)
f	:	Fraction of stock items for which demand is unpredictable. (73)
F	:	Fraction of total manufacturing capacity devoted to manufacturing items for which the demand is unpredictable. (71)
FG	:	Value of Finished Goods in Inventory. (65) See SUBSCRIPTS (q.v.).

Cont...

FMR	:	Fractional Manufacturing Rate. (71)
GP&WD	:	Goods Produced & Work Done. (195)
ICXD	:	Internal Communications Excess Delay. (176)
ID; KID	:	KID is a modified form of Industrial Dynamics. (164;166)
ih; IH; $\overline{IH}$; $\overline{IH}_e$; $\Delta\overline{IH}$'	:	Level of inventory on hand; expected "; average over time of expected "; effective time average of "; further inventory reduction. (75;76;77;82;84)
ioh; IOH; $\overline{IOH}$	:	Level of inventory on order and on hand; expected "; average over time of expected ". (75;76;77)
L	:	Expected Level for inventory re-order. (78)
M	:	Money stock. (204)
M,S&F	:	Materials, Stores & Fuel. (98)
MD	:	Maximum expected rate of Demand during time PT (q.v.). (75)
MR	:	Manufacturing Rate. (71)
n	:	Integer index : 1,2,3,... (131)
N	:	Number of sectors in closed economy. (129)
$n_j(t)$	:	Number of establishments in sector j on data network at time t. (130)
NO; NO_{co}	:	Net Output; cut-off ". (111;112)
NTE; $NTE_i(t)$; NTE'(t)	:	Estimated Number of Terminal Equivalents on national data network; " for sector i at time t; first difference of " at time t. (114;131;137)
OTS	:	Overall Time Saving. (62)
P	:	Annual amount of Purchases. (81)
PStock	:	Value of Purchased Stocks. (98)
pt; PT	:	Procurement lead time; expected ". (74)
PTTC	:	Annual expenditure on Postage, Telephone, Telegrammes and Cables. (59)
r	:	Rate of interest, or discount rate. (60)
REC; REC_{co}	:	Annual total Receipts; cut-off ". (121)
ro; RO	:	Replenishment order size; expected ". (78)
rt; RT	:	Re-order point in time; expected ". (75)

Cont...

S	:	Shipment rate. (70) See SUBSCRIPTS (q.v.).
S&WIP	:	Stocks & Work In Progress. (106)
Sales	:	Annual Sales of stock items. (85)
SCI	:	Sales by the Communications Industry to... . (182)
Service 1, 2, 3, 4	:	General categories of national data network service. (17)
SS; $\overline{SS}$	:	Expected Safety Stock level; average over time of ". (75;77)
SUBSCRIPTS	:	A - all manufacturing industries D - durable goods industries N - nondurable goods industries W - weighted average. (178)
t	:	Time.
t_o	:	Division point of OTS (q.v.) between customers and suppliers. (94)
T_i; T_{ij}	:	Annual Transactions of sector i; " with sector j. (130;129)
T_i^k; T_{ij}^k	:	Annual Transactions of establishment k in sector i; " with sector j. (129)
$*T_{ij}(t)$; $*T_i(t)$	:	Annual Transactions between sector i and n_j (q.v.) establishments in sector j at time t; " for sector i with all sectors. (130)
$*T_{ij}^k(t)$	:	Annual Transactions between establishments k in sector i and n_j (q.v.) establishments in sector j at time t. (130)
TBL	:	Temporal Buffer Length. (70)
TE	:	Terminal Equivalent. (110)
TO; TO_{co}	:	Annual Turnover; cut-off ". (119;120)
TOC_1; TOC_2; TOC	:	Total Opportunity Cost. (85)
UO	:	Value of Unfilled Orders. (65) See SUBSCRIPTS (q.v.).
V	:	Total Value contained in "conceptual cycle". (105)
$V_c(t)$; $V_s(t)$	:	Customers' valuation of time; suppliers' ". (94)
$V_c(t_o)$; $V_s(t_o)$	:	Total value of time to customers; " tc suppliers. (94)
VR	:	Value Rate of cyclic flow. (105)
WIP	:	Value of Work In Progress. (68)
X	:	Correction factor. (115)
X-distribution;Y-distribution	:	Distribution of order-to-despatch times for goods manufactured to order; " for goods from inventory. (174)

Cont...

ZIL; ZIL_o	:	Zero Inventory Line; original position of ". (82; 86)
α; $\bar{\alpha}$	:	Estimator of ρ(q.v.); long-term ". (65;180) See SUBSCRIPTS (q.v.).
β	:	Fraction of a shop's turnover paid for by cheques. (119)
γ	:	Average number of working days for cheques to clear. (119)
Γ	:	Constant re-order level of inventory. (75)
δ	:	Fraction of PTTC (q.v.) which could be carried as EBLs (q.v.). (59)
Δ; Δ_1, Δ_2, Δ_3, Δ_4, Δ_5	:	Total lump sum benefit; lump sum benefits. (111;61,73,81,85,88)
Δ_i; Δ_{ij}	:	Total lump sum benefit available to sector i; " from transactions with sector j. (130;129)
Δ_i^k; Δ_{ij}^k	:	Total lump sum benefit available to establishment k in sector i; " from transactions with sector j. (129)
ε	:	Ratio of MD (q.v.) to DD (q.v.). (81)
θ	:	Constant cycle time. (78)
λ	:	Average arrival rate of orders. (177)
μ	:	Constant manufacturing rate. (177)
ρ	:	Fraction of manufacturing capacity devoted to manufacturing goods to order. (63)
ϕ	:	Constant re-order point in time. (78)
ψ	:	Cycle time of "conceptual cycle". (105)
Ω	:	Constant replenishment order size. (75)
#	:	Estimated number of establishments on national data network. (114)
$n\#_i(t)$	:	Number of sector i establishments economically justified in having n (q.v.) TEs (q.v.) at time t. (131)

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