STRATEGIC DEVELOPMENT OF TRANSPORT SYSTEMS

A Study of the Physical Constraints on
Planning Processes

DAVID LAURENCE ANDERSON
Doctor of Philosophy

THE UNIVERSITY OF ASTON IN BIRMINGHAM
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Investment in transport infrastructure can be highly sensitive to uncertainty. The scale and lead time of strategic transport programmes are such that they require continuing policy support and accurate forecasting. Delay, cost escalation and abandonment of projects often result if these conditions are not present.

The conventional treatment of uncertainty is a development of the 'demand satisfaction' approach: the emphasis is on the forecasting of demand and those solutions which are most robust to the possible futures defined are preferred in scheme appraisal.

In this study the emphasis is on the possible solutions. It is assumed that the future is inherently uncertain and the requirement is for projects which reduce the sensitivity to this uncertainty.

In Part One the characteristics of infrastructure such as scale and lead times are identified as significant contributors to this sensitivity and as major constraints on planning processes. The extent to which current strategies and techniques acknowledge these constraints is examined.

In Part Two a simple simulation model is developed to evaluate the effects of these constraints. The model is used to assess the importance of scale and lead time in two major projects; the third London airport and the development of the London road network.

In conclusion, the scale of infrastructure investment rather than its lead time is considered the most important of the constraints on the processes of transport planning under uncertainty. Adequate appraisal of such constraints may best be achieved by evaluation more closely aligned to policy objectives.

Keywords: Transport; Infrastructure; Scheme Appraisal; Third London Airport

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STRATEGIC DEVELOPMENT OF TRANSPORT SYSTEMS

CONTENTS Page

LIST OF TABLES

LIST OF FIGURES

PART ONE

TRANSPORT PLANNING THEORY

CHAPTER 1

THE TRANSPORT PLANNING PROCESS

1.1 CONTEXT

1.1.1 Any planning activity involves an element of forecasting and is therefore subject to uncertainty. When the product of planning processes is a rigid system of infrastructure the importance of uncertainty increases. In transport planning both of these factors are present in the extreme. The long lead times of planning, design and construction for major transport schemes require more distant planning horizons and hence imply greater uncertainty. In addition, the majority of transport infrastructure is so specific to its designed use and location that its success is specially sensitive to future demand, much more so than other land uses. Airports and roads are both sensitive in this respect, especially roads which have the added characteristic of being a link in a physical network. Such integration is a further complication.

1.1.2 Traditionally, transport planning evaluated transport schemes by seeking to optimise the relationship between demand and capacity. In quantitative terms this led to maximising user benefits when compared with scheme costs and qualitatively by minimising disbenefits in terms of environmental impacts. The economic appraisal is usually most important. The response to uncertainty was to vary the demand forecast by using two or more scenarios. Then schemes which performed well under more than one scenario would be preferred. Some method of aggregating performance under alternative futures was necessary in order to rank schemes.

Hence the effect of uncertainty was to increase the sophistication of demand forecasting in order to discover those schemes which were most robust to future uncertainty. The majority of research and literature on project appraisal has concentrated on the demand analysis.

Significantly, less attention has been paid to the characteristics of infrastructure itself and how it may be influenced to reduce sensitivity to future uncertainty. This is necessary because a demand satisfaction approach cannot accommodate those factors which are external to the quantitative planning process. It is such factors which were responsible for the failure of many large-scale transport planning initiatives. An appreciation of such factors will lead to less investment in those projects which are highly sensitive to uncertainty not only in the quantified demand forecasts, but also future changes in political and environmental level. Such factors will be considered in chapters 2 and 3. First, the transport planning process will be considered.

1.2. THE DEVELOPMENT OF A TRANSPORT PLANNING PROCESS

The Universal Application of Planning Method

1.2.1. The original concept of transport planning was of a process that was strategic, rational and comprehensive. However, a greater perception of future uncertainty coupled with an increase in the importance of external factors, both political and technical, produced an environment in which initial conceptions of transport planning were found to be inappropriate. In chapters 5 and 6 two case-studies which exhibit these characteristics will be examined - airport planning in Gt. Britain and urban transport planning, particularly the experience in London. Ostensibly, these two examples appear to be subject to two distinct sets of planning goals and constraints. However, the theory of transport planning consistently stresses the universal application of the method, especially at the strategic level:

> 'There is a common basic approach which can be applied to all forms of transportation planning, whether planning for a specific new transport facility, such as a new airport, road or rail improvement scheme, or planning a national, regional or local transport policy.[1]

1.2.2. This universal approach will be a recurring issue which will be examined more closely as the constraints on specific projects are analysed. Historically, the universal methodology owes much to the rationalisation of planning brought about by the adoption of systems analysis and the physical analogies used to describe traffic flow. However, this is only one of the two distinct influences upon the development of transport planning techniques. To understand more clearly the issues involved another particularly British influence must be described.

British Planning Tradition

1.2.3 Transport planning in Britain has developed in part from the work of early town planners. They in turn adopted many of their ideas from the utopian socialists of the 19th century. These ideas found concrete implementation in response to the social problems of the industrial revolution. Entrepreneurs with altruistic notions removed their business from the squalor of the inner city and created totally enclosed environments where it was possible to exert considerable control over the development of settlements.

Robert Owen's New Lanark in the West of Scotland was the most advanced settlement of this type although industrial villages were created throughout the British Isles.

1.2.4 The ideas upon which this industrial planning were based embodied well defined views on technology. Innovation was not seen as a means by which work could be mechanised but only as a process which could provide labour saving devices. Work was essentially an activity that involved people and the early industrial settlements were designed to create environments in which people could live and work without the degradation of existing cities. William Morris epitomised this approach with his emphasis on arts and crafts which sat uncomfortably in an era of progress, industrial development, increasing mechanisation and exploitation.[2] The creation of early industrial settlements was not public 'planning' as it is known today as they were a product of a few individuals and not of the state. Indeed they sought to remove industrial production from the mainstream of Victoria life. As such they were often isolated, closed communities, but their influence was profound. In fact the legacy still exists today as well became apparent later in this chapter.

1.2.5 It was at the beginning of the 20th century that the ideas of Owen, Morris and their contemporaries became formalised as the discipline of town planning developed. The interest of the state in such matters dates from the late 19th century when laws concerning environmental health were passed by Parliament. Once regulations for water supply and housing conditions were on the statute book, interest in the total urban environment grew rapidly. After the first world war Patrick Geddes and Ebenezer Howard[3] were responsible for the growth of the Garden City movement which was an obvious extension of 19th century thought, particularly the ideas of Morris. Garden cities were designed to incorporate the advantages of both the city and the countryside while leaving behind their less desirable elements.

1.2.6 Again, garden cities were removed totally from existing development and aimed to produce completely new environments. The motor-car had not become too serious an issue for planning at this time and the rigid, geometrical layout adopted was due more to the artistry of the planner than mobility needs. The plans for garden cities were the epitomy of 'intuitive' planning and although the state had begun to take an interest the city was designed to be built by private enterprise, a not inconsiderable feat. Economic independence of the settlement is just one facet of the total approach to planning, emphasising the comprehensive approach of the garden city movement. In this respect the plans went beyond the local to the regional level, describing how individual cities would be linked together. Consequently, town design incorporated the potential for growth based upon a close relationship with the existing landscape, a theme which earned this style of planning the description 'organic'.

1.2.7 The first garden city, Letchworth, was opened in 1919 followed in 1922 by Welwyn. In the ensuing years the motor car was to become an increasingly important issue. The Ministry of Transport was created in 1919, although it was not until the 1930's that it began to address the problem of roads. The centres of major cities were particularly vulnerable to traffic congestion, being as they were, the confluence of a series of radial highways which linked the city with other settlements. Nowhere was the problem more acute than in London and in 1937 Charles Bressey undertook the 'Highway Development Survey'[4] to assess the problem. To incorporate any ideas into the fabric of London would require a great deal of skill and the then London County Council (LCC) commissioned the County of London Plan.[5]

1.2.8 The contents of this plan will be examined in chapter 5, but it is necessary here to note the approach upon which it was based. Patrick Abercrombie who was a co-author of the plan had been responsible for a number of industrial villages for mining workers in Kent. Together with Forshaw, the County of London architect, he set about producing a plan that integrated the various functions of a large city, although there was no doubt as to the most important issue:

> 'The transport problem is so insistent- so dinned into our brains and ears, that it may seem superfluous to describe its dominating effect upon planning. Indeed the road plan - the most easily grasped manifestation of the town plan is too much stressed, and town planning is in danger of becoming road planning'.[6]

1.2.9 Abercrombie appreciated the dangers of planning primarily for road vehicles but this is often overlooked when his plans for London are considered. He was able to take the wider view which became even more necessary when he was asked by Central Government to produce the Greater London plan in 1944.[7] Abercrombie here had to accommodate the findings of the Barlow report[8] on the distribution of the industrial population which advocated decentralisation from London and the South East. The Greater London Plan acknowledged this and resulted in plans for the now completed series of new towns encircling London.

1.2.10 Planning for London was however a much greater task than designing a series of industrial villages, because of the major constraint of existing development. It was in this context that the organic approach to planning became important, acknowledging the need to build and develop the city upon the basis of what already existed. This was a new problem altogether as previously planning had benefited from green-field sites with little existing constraint. The necessity of planning for motor transport was however unavoidable although Abercrombie had little available information on the design of road systems, particularly their scale. The Bressey survey provided much data, but it was the work of Alker Tripp[9] which influenced the form of the road network more than any other. He prompted a technical input to planning activity which had previously been intuitively artistic.

1.2.11 Indeed, this was the beginning of a whole 'rational' approach to planning which tended to submerge the artistic approach of those, such as Abercrombie, who saw planning as a fusion of art and science. Prior to considering this rational/ technical approach the characteristics of the British tradition may be summarised as follows:

1. It was comprehensive in its approach to all forms of development and saw them integrated within any plan.
2. It was intuitive in its approach relying on the artistry and experience of the planner.
3. It was organic allowing for natural growth which was sympathetic to its environment.

The Rational-Technical approach to Planning

1.2.12 Whilst in Britain town planning developed into a discipline which sought to be organic and at the same time exploit the benefits of technological advance, on the continent, a more rational ideology emerged. Although Walter Gropius was heavily influenced by the Art and Craft asthetics of William Morris and incorporated them into the activities of the Banhaus school, he and his students were to become the practitioners of modernism. The ideas of the modern movement which came to the fore between the two world wars consisted of rational thought, functional design and a belief in the 'truth' of the engineers asthetic.[10] Here technology was the determinant of planning rather than the means by which it could be achieved. Many of these ideas were transported to the United States when graduates of the Banhaus such as Mies van der Rohe sought refuge there in the late 1930's. In contrast to the British tradition of combining the artistic and technical elements of planning in an integrated manner, the rationalists' thesis was that once the technical features of plans were confirmed, all else would flow naturally.

1.2.13 In the plans for urban and metropolitan redevelopment of the late 1950's and 1960's, transport technology was to become this determinant. However it soon became apparent that even in Britain, a rational base was necessary for dealing with ever increasing traffic problems. As early as 1942 Alker Tripp, the metropolitan traffic Commissioner published his seminal work 'Town Planning and Road Traffic'.[11] Although originating from different motives, Tripp's book contained solutions to the traffic problem similar to those of the modernists. Towns were of an inappropriate form to accommodate the motor car and could not respond to its swift development and diffusion. The rational solution, similar to that which the modern movement proposed was to sweep away the old and provide cities based on systems of highways which allowed the motor car to achieve its full potential. Tripp was somewhat less radical in his plans, but the formation of traffic precincts, the liberal advocacy of grade separated junctions and the segregation of traffic and pedestrians were central to his approach.

1.2.14 Tripp was motivated above all by the need for safety but had no doubt as to the dominating effect of traffic on town design:

> 'Any town plan is on inspection found to be defined mainly in terms of road layout. The road layout becomes so to speak - the skeleton of the body. If it is ill-designed, the whole town plan is permanently deformed: the new layouts, once built are hopelessly rigid, and a great opportunity has then been lost.'[12]

1.2.15 Although there are similarities between some aspects of the rational and organic traditions in planning, perhaps the major difference between the two was the rationalists confidence in a technical response to the needs of vehicular traffic in cities. An alternative, regulation of the motor vehicle, would have been politically untenable at that time. The main features of this approach can be summarised thus:

1. It was comprehensive only in the sense that once the technical problem of design had been solved all others would be ameliorated as a result.
2. Rather than attempting to achieve growth organically, the old should be completely replaced by the new.
3. It was rational in its approach relying on mathematics, geometry and engineering for its ideas.

The two Modes Combined - Rational Comprehensive Planning

1.2.16 Just as each of the two modes of planning examined may seem optimistic in their approach, a combination of such modes which were often opposites appears even more unlikely to succeed. However such a coalition of ideas provided the basis for what was to become the Land-Use transportation planning process.

1.2.17 The new coalition was based on the political and social consensus of planning in the period following the second world war. Co-ordinated planning was very much to the fore as Britain sought to regenerate its economy. The conclusions of the Barlow report were quickly implemented and the New town programme was set in motion. This was to provide a 'green-field' laboratory for town and traffic planners in the 1950's and 1960's. That traffic problems were beginning to dominate town planning was already apparent, but the new towns provided the first real opportunity to plan for the motor-car. The new traffic engineering:

> 'quickly came to carry all before it, and at least for a decade after the late 'fifties, in country after country, almost replaced town planning'.[13]

1.2.18 The techniques to be used in generating such plans were to come from the United States. It was there that the early traffic engineering techniques were developed and the first comprehensive urban travel surveys carried out. The approach was typified by the seminal Chicago study:

> 'The primary reason for taking an inventory of travel is to discover those evidences of orderliness in travel which make it possible to estimate the traffic and mass transportation demands of the future'[14]

Such travel patterns were linked to land use and Land-Use-Transportation models such as the Lowry model[15] were soon adopted by British planning authorities.

Not understand at that time, was that the forecasting necessary for such models was primitive and subject to uncertainty. Even more important were the environmental and social impacts of building for the motor-car.

1.2.19 A team led by Colin Buchanan attempted to incorporate such environmental considerations into 'Traffic in Towns', a study of the impact of increasing motorisation in urban areas.[16] This report for the Ministry of Transport also considered the levels of investment necessary to satisfactorily accommodate redevelopments of varying scale in existing towns and cities. Despite this emphasis, the impact of Traffic in Towns was primarily orientated to satisfying the needs of motor-vehicles. The other elements of comprehensive planning were apparently subsidiary to those needs. Insensitive road schemes such as Westway in London were the result and other modes of transport also suffered. The London Travel Survey of 1964[17] initially failed to consider public transport, concentrating on car-users who were very much the minority at the time. The rediscovery of the importance of public transport several years later will be discussed later in this chapter.

1.3 THE FORMAL PROCESS DEFINED

The Basic Features of the Process

1.3.1 The universal application of planning is reflected in the methodology of its processes. For each particular problem there are a series of discrete steps which may be followed in order to arrive at a solution. These stages form a linear path, each one dependent on the previous until the final policy or scheme is implemented.

> 'In all cases the approach may be summarised by three distinct phases: a survey, analysis and model building phase; a forecasting phase, and an evaluation phase.'[18]

Essentially this is a development of the 'Survey-Analysis-Plan' approach developed by early town-planners such as Geddes and Abercrombie.

1.3.2 However, it is apparent from the above definition that within each of the stages, there are two or more distinct elements. In particular the increasingly technical content of planning, primarily due to the more analytical principles developed by transportation engineers, encouraged a further breakdown of the process. The increasing specialisation by practitioners means that now, transport planners rarely partake in all of the stages in practice. Furthermore, two extra components should be added, firstly a statement of the goals of transport planning, i.e. what is the aim of transport planning endeavour. Secondly, the generation of alternative transport networks to satisfy the needs of travellers.

1.3.3 Based upon the formative influences described above, the transport planning process was thus formulated in the early 1960's and in principle is very similar, though less developed, to that used today. It consists of

1. A formulation of Goals and Objectives.
2. A survey of the existing situation.
3. An analysis of survey data which results in certain relationships or models.
4. A projection of these relationships: i.e. a forecast of future travel patterns.
5. The generation of transport networks to meet the needs of such forecasts.

6. The assignment of forecast demand to transport networks.

7. The evaluation of alternative policies and schemes.

8. Selection and implementation.

Goals and Objectives

1.3.4 The objectives of transport planning are conventionally represented as the initial phase of the process, as they may influence the overall direction of the study. The exact nature and importance of objectives will vary according to the ultimate goals of the transport programme. A centralised agency responsible for one aspect of transport e.g. roads will normally have very general goals relating to the road network such as 'greater freedom for movement' or 'increased accessibility'.

1.3.5 Such generalised goals will usually imply more specific objectives relating to the traffic aspects of the process. These may include 'minimising travel time', or maximising road user benefits. Factors such as these which are a function of the physical system are also likely to dominate the evaluation phase, more so than any overall policy goals. It is also likely to affect the choice of evaluation technique with cost-benefit analysis likely to be considered appropriate.

1.3.6 For a more decentralised agency such as a local authority, roads and transport will only be one of its functions.

There will be a structure or development plan which will attempt to co-ordinate these functions as effectively as possible. Thus the higher level goals are likely to reflect the greater breadth of planning activity and will cover many aspects from employment to shopping and leisure etc.

1.3.7 The objectives of any transport scheme will in turn reflect the broader strategic goals. The impact of the scheme on housing, employment, education etc., will have to be considered. It is therefore likely that such factors will carry more weight in the evaluation phase than those related strictly to traffic effects. The chosen evaluation technique is therefore likely to reflect the need to satisfy strategic goals and a matrix-based method may be adopted.

Travel Surveys

1.3.8 Travel surveys mark the beginning of the 'analytical' transport planning process and may be considered in two categories. Census surveys of travel undertaken by planning agencies often at 10 yearly periods, provide an information data-base for future plans, particularly at the strategic level, and for major schemes (e.g. Greater London Travel Survey, GLTS). Scheme specific surveys are orientated towards assembling information which will enable a transport scheme to be designed. They should also enable the scheme to be incorporated into the existing situation in as harmonious a way as possible. The majority of transport schemes will utilise both types of data.

1.3.9 Strategic surveys have a long history. The Highway Developments Survey[19] of 1937 reported the state of roads in Greater London, and was extensively used by Abercrombie. Many large scale surveys were undertaken in the late 1950's and 1960's when transport planning underwent tremendous growth. The seminal Chicago Transport Study of 1958 was to influence many similar efforts in Britain e.g. the West Midlands travel survey[20] and the London Travel Survey which became a permanent operation: Given the close relationship between land use and travel, such surveys not only accumulated data on transport, but also land use, incomes, employment etc.

1.3.10 Scheme or problem-specific surveys will observe not only overall travel patterns but also in greater detail the mode of transport employed and specific routes taken to travel from A to B. This will be important when considering the effects on reassigned traffic which result from the scheme being implemented and will also ensure that the chosen solution will solve the problem at hand.

1.3.11 Roadside interviews will provide information on the origin, destination and purpose of trips. Traffic counts will give vehicle types and total traffic flows. Together they will give a sample of the patterns of trip movement in the survey area. As with any sample, traffic surveys are not always as objective as they might appear. Although great advances have been made in the design of surveys they can often be biased. Cross-checking of the various surveys will often highlight this bias.

Analysis and Modelling

1.3.12 Raw survey data alone is of little use. To obtain information suitable for analysis it is necessary to expand the sample trip patterns to the level of traffic counts. Several expansion factors will be used, their form dependent on the type of survey undertaken. Beyond this it is necessary to forecast the number of trips to be 'generated' by each zone at some future date. This 'trip generation' phase can be accomplished by simple growth factors or by a form of regression analysis and will establish the number of trips produced.

1.3.13 Once the productive and attractive capacity of each zone has been achieved it is necessary to match the origins with the destinations. For this trip distribution phase a number of models have been developed. Growth Factor methods simply relate the existing number of trips between two zones to a future level by the application of a growth factor. Such simple methods suffer from several drawbacks. In particular an aggregate growth factor can give rise to severe local discrepancies. Consequently they have been used little since early transportation studies. Synthetic methods have also been in use for many years and continue to be used today. The most well known is the gravity model which uses a physical analogy to simulate the number of trips between two zones by deriving them from the zone characteristics. A simple gravity model would take the following form:

$$T_{ij} = \frac{G_i \dfrac{A_j}{D_{ij}}}{\displaystyle\sum_{j}^{k} \dfrac{A_k}{D_{ik}}}$$

where T_{ij} = no. trips between zones i and j.

G_i = total no. trips generated by zone i.

A_j = total no. trips attracted to zone j.

D_{ij} = distance between zones i and j.[21]

1.3.14 In this relationship, the mutual attractiveness of two zones is based only on distance. It soon became apparent that other factors such as accessibility and travel time in particular were influential, not only on whether a trip is made, but also in the choice of mode. Ultimately these factors developed the gravity model so that it now incorporates a form of generalised cost:

$$C_{ij} = A_1 + H_{i-j} + A_2 E_{ij} + A_3 D_{i-j} + S_{ij} + \sigma$$

where: H_{i-j} = travel time

E_{ij} = excess travel or waiting time

D_{ij} = distance between zones i and j

S_{ij} = terminal cost e.g. parking

σ = calibrative constant.

A_1 A_2 A_3 = constants.[22]

1.3.15 Generalised cost is a measure of time and it requires an economic value for time in order that it may simulate the process of travel choice. The gravity model then becomes:

$$T_{ij} = G_i A_j e^{(- C_{ij})}.$$

where T_{ij} = the number of trips between zones i and j.

G_i = the number of trips generated by zone i.

A_j = the number of trips attracted to zone j.

= constant

C_{ij} = generalised cost of travel between zones i and j.[23]

1.3.16 Behavioural factors such as terminal and waiting costs have now been incorporated into the calculation. The growth rates of the parameters associated with these variables must also be forecast for future trip distributions. As with the earlier gravity models, the relationships between the variables should remain constant.

1.3.17 A model created from survey data is not normally used directly for scheme design and evaluation. It is first necessary to test the ability of the model to reproduce future trip movements. Therefore normal practice involves the calibration of a model to a base year when the original survey data was collected. When the model is used for scheme design, a further survey data set is collected in order to validate it. Once independently validated, the model can be used with greater confidence to produce patterns of future trip movement. To ensure a vigorous test for the model, calibration and validation will normally be undertaken several years apart.

Forecasting

1.3.18 Future trip distributions require a variety of forecasts. The growth in trip ends within any planning or scheme zone is required, normally disaggregated by land-use e.g. housing, employment, leisure, education etc. Forecasts of trip ends are themselves dependent on the growth in population, and in the economy via factors such as petrol prices and income. For road planning in the UK these factors are incorporated into a National Road Traffic Forecast. This predicts the future growth in traffic by vehicle type.

1.3.19 If modal split is to be considered, forecasting may be more complex. Adopting standard forecasts for growth in car traffic may be biased against public transport relegating it to being a residual mode. This is a particular problem in dense urban or metropolitan areas where although car ownership may continue to grow, the capacity of the network may restrain growth in car usage. Car usage depends on a number of factors such as parking availability, journey times and the availability of public transport. Thus the process of transport planning ceases to be merely extrapolative and begs questions of policy.

1.3.20 Such questions will be considered in section 1.3. However, once forecasts of traffic are available, they are applied to validated matrices of trips for assignment to future transport networks.

Transport Networks

1.3.21 The design of transport schemes is an iterative process. A series of alternative schemes may be derived to meet the demand predicted by the forecast trip patterns. Following the assignment and evaluation phases, scheme design may be refined to improve operational or economic performance, or to reduce environmental impact.

1.3.22 Although transport schemes will be influenced by the forecasts of future demand, economic and environmental factors may also place constraints on design. Transport policy will also be a determinant, or possibly be subject to evaluation itself. The scheme does not necessarily have to be physical, but could consist of a series of policy measures concerning e.g. public transport.

1.3.23 Contemporary transport planning has concentrated on schemes which seek to extend or amend the network which already exist. Since the completion of the new town programme in the U.K., complete transport systems generated by the need for travel are rare. Very large schemes which ignore existing development are unlikely to succeed for reasons other than those concerning traffic. Economic and environmental constraints negate their implementation, particularly in congested urban areas.

1.3.24 Technically, such networks were derived via a mathematical approach which sought the optimum network configuration. This optimum was based on minimising traveller cost and was more extensively used in the USA where the spacing of links in an urban grid structure was more easily optimised. In Britain, the emphasis was much more on developing existing structures. Abercrombies plans for London sought to add an orbital dimension to a predominantly radial road network.

1.3.25 Although existing transport networks are a strong determinant in scheme design, it is important that a comprehensive range of alternatives are tested. Variations in the scale of the solution are particularly important. Traffic management measures such as junction improvements may negate the need for a large scale road scheme. Similarly improved control of air traffic and more efficient passenger handling may offer a much cheaper, yet viable alternative to a new airport.

Assignment

1.3.26 Assignment is the process whereby distributed trips are allocated to various routes on the transport network. Assignment is based on the costs of competing routes available to travellers. Trips are allocated to the route of least cost between origin and destination.

1.3.27 These 'all-or-nothing' assignments take no account of the increasing cost of using the route to which the traffic has been assigned. Thus some routes may carry large volumes of traffic while adjacent routes may be empty. This is unrealistic, particularly in congested urban networks. In capacity-restraint models, as the level of traffic on links increases so the speed is reduced and the cost of travel increases. Traffic may divert to adjacent routes, originally more expensive in terms of travel cost. A model of this sort will undergo a series of iterations until the flows on links stabilise. In road networks, it is also possible to explicitly model traffic movements at junctions, the major source of delay in any congested network.

Evaluation

1.3.28 There are two levels at which evaluation takes place. In scheme evaluation, the above processes of traffic modelling will have generated a series of alternative future transport networks, each incorporating a scheme option. These schemes will have economic, environmental and policy implications all of which will influence evaluation and ultimately the choice of competing options. In strategic evaluation, it is necessary to rank any number of schemes according to similar criteria. Within a fixed transport budget, there are likely to be a number of schemes competing for implementation and a priority ranking will be required to aid decision-making. For very large schemes the two levels of evaluation may overlap.

1.3.29 Scheme evaluation has largely been considered a direct function of the traffic model output. Savings in travel time, calculated as resource costs for evaluation, reductions in accidents and changes in vehicle operating costs are offset against the construction costs of the scheme in economic evaluation. For the assessment of road schemes, evaluation has progressed from financial appraisal to cost benefit analysis, particularly the COBA programme for economic evaluation used by the Department of Transport. The final output of this programme gives a net present value (npv) for each scheme option, based on the discounted benefits over a 30 year period. Thus npv is used not only to assess scheme options, but also to rank schemes within the roads programme.

1.3.30 In strategic evaluation and increasingly in scheme evaluation where the technical issues are complex, assessment against agreed policies is becoming more important. In the Goals Achievement Matrix, alternative schemes achieve scores according to the extent to which they achieve agreed policy objectives. It is usually more useful in strategic evaluation rather than differentiating between individual scheme options. However, the increasing role for policy in evaluation has resulted in greater attention for matrix based methods although their use in practice is limited. The framework for trunk road assessment may be considered a compromise between CBA and matrix assessment, although the economic component of evaluation is still by far the most important.

1.3.31 For public transport investment, particularly railways, the presence of a revenue collected directly from passengers has prolonged the use of a strict financial appraisal. This may be considered a form of policy in favour of road schemes which involve a broad societal appraisal of economic value.

1.4 TRANSPORT PLANNING AND UNCERTAINTY

1.4.1 The Transportation Planning Process as described above was never fully implemented. There were certainly economic and political circumstances which dictated the retreat from large scale integrated planning, but this only reflected the deepening disquiet about many of the techniques.[24] Recent approaches to Transport Planning have concentrated on a more piecemeal approach to the development of transport networks with the result that several of the major strategic transport issues of the 1960's and 1970's remain unresolved.

1.4.2 Two such issues, those of the third London airport and the roadbuilding plans for Greater London were generated because of large predicted demands for travel which played a major role in their political justification and planning. As such they were of a product of early demand satisfaction approach to transport.

1.4.3 In the wake of these unsuccessful attempts at strategic assessment, transport planning was forced to adopt ad-hoc manoeuvres.[25] Compared with the goals of planning this may be considered a retrograde step. However, the rational-comprehensive methodology had failed in practice. The failure was due to the uncertainties inherent in all stages of the transport planning process. By adopting partial, ad-hoc measures, transport planning could deal with individual problems with greater confidence, even if a co-ordinated attack on all planning problems was impractical.

1.4.4 The inability of traffic modelling to accurately predict the impact of transport schemes was a symptom not only of the uncertainties of travel demand, but also the limitations of the techniques employed. Similarly the environmental impact of major road schemes was not adequately predicted or evaluated, particularly in urban areas. These uncertainties were compounded by changes in values and so preferences which ultimately resulted in a shift in transport policy. Conventional techniques could not easily respond to such changes.

1.4.5 The techniques of transport planning are therefore a major factor in the uncertainty problem. They assumed aggregated values and preferences and their failure to accurately model transport schemes exposed the diversity of values and preferences which in reality exists. Once the failures of traffic modelling and more importantly the environmental impact of many schemes became apparent, opposition to transport planning grew and the policy consensus supporting conventional practice ceased to exist.

The Roots of Uncertainty - the Application of the Techniques of Transport Planning.

1.4.6 Uncertainty arises because of the inability to forecast accurately. This may be due to an incorrect interpretation of available data, or because some factor or influence has been ignored in analysis. Forecasting itself is not confined to one particular stage in the transportation planning process. It permeates all of the individual phases from the initial survey right through to the final evaluation and implementation. However it can be divided into two distinct types for the analysis to be undertaken here.

1.4.7 The prediction of travel demand encompasses forecasts of income, car ownership, public transport use, trip distribution etc. In addition there are forecasts of the impacts of this level of predicted demand. This concerns not only traffic impacts but also economic and environmental analysis which will normally take place during the evaluation stage. It need not be a physical improvement to the transport system, but could be an assessment of the effects of transport policy. The specific impacts of policy have often been overlooked where the emphasis has been on capital investment, but there is increasing awareness of their importance, particularly at the strategic level where policy intervention can have a major impact.

1.4.8 Rational-comprehensive transport planning in its purest form did not recognise many of the uncertainties which are now apparent and recognised in contemporary practice. Two of the basic assumptions of the process make this apparent.

1. Travel patterns are tangible, stable and predictable.
2. Movement demands are directly related to the distribution and intensity of land uses, which are capable of being accurately determined for some future date.[26]

1.4.9 Such assumptions indicated a perceived certainty about the future which would not be affected by subsequent events. Forecasts were assumed to be insensitive to both the provision of infrastructure and the nature of transport policies. Both of these assumptions have suffered increasing criticism. The Department of Transport treats forecasts as matters of policy and therefore only application of the forecasts is openly discussed at public inquiries.

1.4.10 It was in this public inquiry context that traffic forecasts originally acquired a controversial reputation. Car ownership forecasts in particular were subjected to scrutiny because so much depended upon them. Cross sectional data on car ownership led to a saturation level and logistic curve being predicted as a time series for this variable. The profile of this curve was assumed to be relatively insensitive to future policy changes and environmental shocks.[27] Emphasis on this one particular variable may have been too great given the many other forecasts that were required to arrive at a figure which actually represented traffic on the road. It was perhaps the perceived inevitability of the future and the determinism inherent in this forecast that caused so much dissatisfaction.

1.4.11 In fact, the other forecasts have had as great an impact on policy. The large increases in population forecast in the 1960's were one of the reasons why such large scale road plans were developed for Greater London. The subsequent decentralisation of the capital's population (though a long established policy) resulted in large forecast errors.

1.4.12 A simple error in forecasting was responsible for similar large scale plans being generated for London's third airport. At the time of the Roskill Commission the decisive factor was the ability of airports to handle air traffic movements (ATM's), the determinant of capacity. However, the commission reported in 1971[28] immediately prior to the introduction of wide-bodies jets which were able to carry many more passengers. Thus the important variable ceased to be runway capacity and very soon it became terminal capacity, or the number of passengers. This need for large aircraft was compounded by the sharp increase in oil prices in 1973.

1.4.13 When expensive and large scale developments such as a third London airport are sensitive to apparently simple factors, it becomes very difficult to evaluate proposals for infrastructure investment. With hindsight it is easy to criticise such forecasting, but definitive forecasts were required in order to plan transport systems 'rationally'. Transport networks could then be designed to meet a specified demand level at a specific time in the future. The important factor was not that the forecasts were inaccurate or ignorant of certain factors because there will always be elements of uncertainty. Rather it was that the success of particular projects and the decisions to build them should have been so dependent on forecasts, and that there was little appreciation of the risk involved. Such factors did not appear to affect the strategy of transport planning.

1.4.14 The analysis that follows in later chapters does not seek to improve the forecasting procedure directly, rather it focuses on those physical characteristics of the projects themselves that make forecasting so impossibly complex. It considers which of these physical properties can be influenced in order to make decisions more responsive and less sensitive to forecasting error.

1.4.15 From the viewpoint of demand-satisfaction, the need for large-scale investment would not arise if demand was not forecast to be high, and so tackling the problem of uncertainty from the point of view of the projects themselves does not attack the root cause, the forecasting method. However it should be apparent from the examples given that forecasts can be inaccurate, and are subject to the influence of policy so that decisions to supply transport facilities do not automatically follow from predicted demand.

1.4.16 It is commonly accepted that the further into the future the forecast, the less reliable that forecast becomes. There is a 'funnel of uncertainty' that becomes broader the more distant the planning horizon. Therefore it follows that transport projects, which tend to have long lead times, will be particularly sensitive to uncertainty. It is not uncommon for a major road scheme to require a 10 year planning and construction phase, and a network of routes much longer. The Greater London Plan envisaged 40 years to complete the ringways. Similarly in airport construction lead times are usually in excess of five years while projects such as Maplin would have required 17 years for completion.

1.4.17 As lead times become longer so the certainty of the future need for a project decreases. Once a future demand level has been set, the lead time will automatically follow from the nature of the particular option chosen to satisfy it. It would appear that such factors are not subject to control. Consequently, a decision to proceed with a particular option or alternative implies a commitment to a particular future or set of circumstances which the chosen solution is deemed to satisfy. It is at this point that the independence of forecasting from investment ceases to exist. Furthermore, those with a vested interest in a project will be keen to ensure that future circumstances ensure its success. Thus there is developed a commitment to a future which encourages an inertia in planning, even in the face of uncertainty.

1.4.18 Long lead times will normally imply increasing scale of investment, although the relationship between the two may not be of a linear form. A single new road may take 10 years to construct, however three such routes will not take 30 years as they may be built concurrently. This does not normally occur in practice mainly on grounds of cost and efficiency. Such larger schemes will be introduced in a phased programme so as to meet demand as required. There is however an important distinction between a single isolated scheme and a much larger initiative involving a number of projects. It is often the case that a single project is evaluated in isolation, when it is in fact part of a much larger scheme which will have important strategic effects. This is particularly pertinent to road building in urban areas.

1.4.19 Hence although it is potentially the characteristics of major infrastructure that expose transport projects to uncertainty, transport planning techniques were orientated to large scale solutions. The comprehensive process and the policy consensus that once supported it were designed for long term planning that was highly sensitive to uncertainty.

The Consequences of Uncertainty - Political Choice and the Re-appraisal of Techniques

1.4.20 It was often the potential impact of major transport projects that exposed the uncertainty in technical appraisal. Construction of a third London airport was continually postponed because a political resolution of technical uncertainty was not forthcoming. Similarly, little of the road network proposed for London was constructed once the impacts of the first schemes became apparent. Growing opposition to these schemes allowed research into alternatives to major infrastruture investment. These alternatives implied a choice that was more than technical; they required a political commitment which was considered external to the transport planning process. As a consequence the techniques used to plan transport systems required re-appraisal.

1.4.21 An important feature of the transport planning process was its technical simplicity. In its purest form it claimed to represent an objective approach to planning based on a set of predetermined goals. By simply extrapolating the existing situation, these goals could be achieved. Hence the goals were themselves an extension of the existing situation and reflected the more conservative aspect of planning bureaucracies. The achievement of transport policy objectives was not considered a problem. The necessary techniques were available and there was consensus over the way forward.

1.4.22 That this view was oversimplistic has been demonstrated with reference to the problems of uncertainty. Once this uncertainty was perceived, the technical inevitability of transport planning ceased to exist. Not only were the methods of traffic forecasting subject to scrutiny, but in particular, the tendency to make scientific the evaluation and decision-making process created particular conflict. The report of the Roskill Commission represented the epitomy of this technical approach. This was a matter of policy, political choice and resource allocation that could not be reduced to a single correct answer through economic and planning theory.

1.4.23 Disquiet at such trends allowed the possibility of exploring alternative futures to those deterministically laid down by transport professionals. In short they were perceived as prescriptive visions of the future rather than simple objective projections of societal trends.

1.4.24 There were other factors which reinforced this diversity in thought. Firstly, there were societal trends whereby an educated public began to question the nature of the future brought nearer by scientific and technological progress.[29] There was in the late 1960's, a burgeoning of interest groups each educated in their own particular field and able to challenge the established view with alternatives.

1.4.25 The consequence for transport planning was a breakdown of the policy-political consensus which supported its early ambitious intentions. Without this consensus it was unable to operate effectively as the long lead times of many of the projects required a continuous commitment in a dynamic, political and social environment. Thus a society emerged whose values could not be aggregated to make them susceptible to aggregated forecasts and the welfare economics of cost benefit analysis. Road schemes were opposed by environmentalists and particularly in urban areas by those who supported public transport. The third London airport issue was confronted by a variety of interest groups, not least of all the planning profession itself which was concerned at the macroeconomic treatment of what it saw as a planning issue.[30]

1.4.26 The transition from policy consensus to conflict removed the coherent strategic framework which had directed transport planning activity. The traditional techniques of transport planning could not satisfactorily evaluate competing policy options, hence a re-appraisal of techniques was necessary. The techniques available will be examined in greater detail in chapter 3. It is sufficient at this point to highlight the difficulties involved.

1.4.27 Many of the problems of technical appraisal described above reflected a deficient understanding of the problems of change. This is possibly due to the comparatively static nature of transport planning techniques i.e. traffic models are calibrated to one point in time and projected forward using aggregated forecasts. They are used to plan for a future equilibrium when a forecast demand will be matched by the provision of capacity. This 'snapshot' vision of the future seeks to detail the parameters of planning and design at specific points, without a corresponding appreciation of the mechanisms of change which will make these future states possible. It suggests an optimum for the future when in fact transport planning takes place in a constantly changing environment. Techniques which adopt a more dynamic view of change will be considered in chapter 3.

1.4.28 When assessing any possible solutions to a transport problem it is important that scheme impacts can be predicted so that the evaluation of specific options can take place on a comparable basis. The difficulty in achieving such comparibility is one of the major drawbacks of the evaluation methodologies. In particular, the cost-benefit approach to evaluation requires the presentation of costs and benefits in monetary terms. The analysis of the third London airport location was a classic example which demonstrated the many difficulties involved. It represented a rationalisation of evaluation, presenting it as a technical rather than political process. In order to carry out the evaluation it was necessary to attach monetary values to all of the impacts, including the social and environmental effects. The one that achieved the highest 'economic' return was adjudged to be the best solution.

1.4.29 The emphasis then was on maximising 'utility', which served only to reinforce the search for an optimum solution to the problem. Such rigid thinking was partly due to the brief given to the commission, but it also implied a highly inflexible approach to planning and the adoption of the Commission's findings would have been largely irrevocable once underway.

1.4.30 In a situation where alternative solutions to transport problems are based on different policies, evaluation methods designed to identify a single correct option are clearly inappropriate. Techniques which assess transport schemes relative to the agreed policies of the transport authority are likely to be more suitable. Economic evaluation will still be important within such an assessment, but alone it will be insufficient to justify a scheme. The practicalities of such assessment methods will be considered in chapter 3.

1.4.31 With hindsight, the failure of the transport planning process to successfully resolve the major issues of transport investment is to be expected. Although the process aimed to be comprehensive, it was based on extrapolatory techniques. Such techniques may be suitable for the appraisal of incremental changes to reasonably stable transport systems. It is therefore ironic that given its extrapolatory nature, it was applied to major changes which may be considered non-incremental and to which it was clearly unsuited.

1.4.32 The extra benefits which may have been forthcoming from non-incremental investments through economics of scale were rarely realised as few large scale projects were ever fully completed. Although the difficulties of large scale investment imply the presence of some diseconomies of scale, recourse to the philosophy 'small is beautiful'[31] is perhaps too simplistic and ignores the inflexibility of many relatively small infrastructure projects.

1.5 SUMMARY OF ISSUES FOR ANALYSIS

1.5.1 It is apparent that the strategic transport planning process failed to satisfactorily resolve the major issues of transport investment. A significant factor in the inadequacy of the process was insufficient understanding of the impacts of major infrastructure works. Therefore any improvement in the process will require more information concerning these impacts. Hence the first subject for analysis:

1. An investigation of the characteristics of major systems of transport infrastructure.

1.5.2 Although environmental impact is an important factor it is not the most important in terms of the planning and operation of transport systems. It is the physical characteristics such as lead time and scale that are important in this context and which will be investigated in chapter 2.

1.5.3 Transport systems are a product of the planning processes used to devise them. The suitability of appraisal techniques is dependent on the overall goals of a project and the form of investment. Therefore the second issue to be investigated is:

2. The ability of transport planning techniques to reflect the potential constraints of major infrastructure investments.

This issue relates to both forecasting and evaluation and chapter 3 will attempt to highlight those appraisal methods which can explicity acknowledge these constraints.

1.5.4 Transport policy is no longer subject to consensus and the commitment to infrastructure investment varies between transport authorities. Hence the third issue is:

3. The derivation of transport policies which recognise the potential risks of infrastructure solutions.

The situation whereby the risks associated with capital invstment may be ignored will be considered. In addition, the role of policy in the evaluation of transport projects relates this issue to that of techniques. It will also be considered in chapter 3.

1.5.5 In Part 2, a technique for assessing the impact of scale and lead time will be developed. This will be applied to two case studies, when the alternative to large scale construction solution will be considered.

CHAPTER ONE

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30. Ash (1982)

31. Schumacher (1973)

CHAPTER 2

CHARACTERISTICS OF TRANSPORT INFRASTRUCTURE

2.1. CONTEXT

2.1.1. In chapter 1 the inherently inflexible characteristics of infrastructure were identified as a major constraint on the planning of transport systems under uncertainty. It was suggested that as the scale of commitment to infrastructure investment increased, so the responsiveness of the transport planning process to future uncertainties diminished. The characteristics of transport infrastructure, which in aggregate result in this perceived inflexibility, will now be examined in greater detail.

2.1.2. Investigation of these characteristics will involve extensive reference to two areas of work, each corresponding to the case studies examined in chapters 5 and 6. The first relates to the theory of road networks and its practical application. The majority of this research was undertaken in the 1960's when the major land use - transportation studies were instigated and the planning and construction of British new towns required a theoretical base. Although the new town programme is now drawing to a close, the studies provided significant insights into the characteristics of transport systems which are relevant to the more contemporary issues of transport planning.

2.1.3. The second area of work to be considered concerns the planning and development of airports. Research on this subject is generally more recent, given the later growth in air travel compared with that of car transport. Additionally, the issue to which much of the British research was orientated, the third London airport, was not resolved until 1985. Studies of airport capacities and the demand for air travel were based primarily on the economics of infrastructure with fewer planning considerations than those for roads. However, the constraints of investment in airport infrastructure received increasing attention as the uncertainty over future demand became increasingly apparent.

2.1.4. Each study will be reviewed for its treatment of the scale, lead time and configuration of transport systems in relation to growth in demand and the future uncertainty which may affect the development of each system. Costs will also be considered, particularly the effect of the timing of investment decisions on expected benefits. This is particularly important in the context of airport development where much of the work is based on economic analyses and projects are appraised on a financial return basis, rather than the cost-benefit approach used to evaluate highway schemes. Although there are similarities between the two infrastructure modes examined (roads and airports), there are also differences, notably concerning configuration. Variations in the configuration of road networks are easily identified, but are less obvious in airport systems. In the latter, the lack of a physical network relating the various sites implies that configuration will be more suitably expressed as the level of de-centralisation of facilities.

2.1.5. Each area of work will be reviewed independently and a summary of the general characteristics of transport infrastructure will conclude the chapter. This summary will provide the basis for a methodology, developed in subsequent chapters, whereby the constraints of infrastructure may be adequately represented in the planning and appraisal of transport systems.

2.2. STRATEGIC STUDIES OF ROAD NETWORKS

The Search For the Optimum Road Network

2.2.1. From the developments in transport planning described in chapter 1, it was apparent that the relationship between transport systems and urban development was not fully understood. However, early practitioners such as Tripp and Abercrombie[1] were able to observe the dominating effect of road networks on urban form. They generally perceived it to be a positive influence providing a basic structure or skeleton upon which urban areas could be built. Fifteen years later, the Chicago Transportation Study[2] cited the rigidity of infrastructure and its slow rate of development as a firm base for forecasting future travel patterns and planning changes to transport networks.

2.2.2. At the same time in Great Britain, the first generation of new towns were being completed. Their structure relied on the hierarchal principles laid down by Abercrombie which were also extensively implemented in the USA. Their design was thus based on principles of planning rather than technical analysis. The report 'Traffic in Towns' was to provide this technical support for transport planning in Great Britain. One of its main conclusions was that no optimum structure for a road network existed, which would allow all journeys to work to be undertaken in private vehicles.[3]

2.2.3. Although 'Traffic in Towns' was addressing the situation in existing urban areas, this conclusion was to alter the planning assumptions of subsequent new towns. Previously the optimum network had been a product of satisfying the perceived future growth in car travel, and the design of early new towns reflected this, providing little provision for public transport. Although 'green field' sites were available for new town development, the scale of road networks necessary for full motorisation was prohibitively expensive. Thus the optimum network became that which achieved the best balance of public and private transport by minimising capital investment as well as user costs.

2.2.4. Consequently the optimum road network had to satisfy criteria other than simply the needs of the motorist. Further research was necessary to achieve this greater number of objectives. One study listed five principles essential to the analysis of road networks:

1. System Permanence - The relation of the system to the permanent elements of urban structure or configuration.

2. System Adaptability - The ability to work under alternative loading patterns or land-use plans, since, in the final analysis, any future loadings represent a projection that may or may not be actually achieved.

3. Continuity of capacity - The minimisation of differentials in capacity between various points along the system.

4. Equalisation of lane densities - A changing of lanes only at locations where comparable changes in the overall traffic magnitudes are anticipated.

5. Regularity and Clarity - Provision of a clearly discernible and easily recognisable pattern. The elimination of multiphase or offset intersections has its counterpart in freeway system configuration; offsets and stubs should be avoided.[4]

2.2.5. Such principles were obviously designed for applications in the United States, but they illustrated the emphasis on a static optimum network, robust to many possible futures, which provided a coherent and uniform structure. A constant theme of many subsequent studies was the need to avoid deformation of the chosen structure over time, which tended to reinforce the rigidity of infrastructure. One possible interpretation of the Buchanan report is that it attempted to take principles developed in the USA, such as those listed above, and modify them for application in British towns.

2.2.6 However, the more archaic and radically orientated form of British urban areas made application of American theory problematic. To apply the principles of constant capacity and clarity it was necessary to avoid route convergence,[5] a typical feature of most British towns. Hence, the application of American theory in the British context overlooked local conditions in the pursuit of the optimum network for vehicular traffic. It was in this deterministic manner that the design of road networks influenced urban form. The later generations of British new towns provided the opportunity for planning from an equally predetermined position of maximum public transport provision. The effects of these assumptions of the transport systems evolved, will become apparent in the review of studies that follows.

Traffic in Towns (GB Min.of Transport, 1963)

2.2.7. The Buchanan Report was the seminal work in British urban transport planning. The Working Group appointed by the Minister of Transport for this study, evaluated alternative road networks on the basis of urban traffic assignment, followed up in the appendices of the report by rudimentary cost-benefit analysis. None of the urban networks tested -ring and radial, grid, honeycomb - could accommodate all journey to work traffic (the common peak hour factor used in design) by private car. For this reason a pure costing of alternatives was not attempted. In Appendix Two of the report however, three scales of urban redevelopment were costed for one of the small towns examined, that of Newbury. Although the costs of construction were expressed in monetary terms, benefits were expressed in terms of increased accessibility resulting from redevelopment. An accessibility index was calculated for each alternative for the year 2010, and then compared with the zero option. Dimensionally the benefit/cost ratio was of the form Accessibility Index Ratio/£ money. (Tables 2.1, 2.2, 2.3).

2.2.8. Table 2.3. gives the incremental difference between each scheme which allows the advantages, should they exist, of each increase in the scale of redevelopment to be verified. Table 2.3. shows that in this case a minimum redevelopment (Scheme B) achieved significant benefits. Although more extensive redevelopment achieved further benefits, the rate by which they were achieved diminished. However, Scheme A, the minimum commitment, achieved the lowest benefit/cost ratio of all, implying that a threshold of minimum commitment, equivalent to B, existed in this case.

2.2.9. Although this concern with costs was to expand into far more elaborate exercises, the philosophy of Buchanan himself was to remain that of a concern with direct costs. Traffic in Towns thus gave a practical idea of the direct costs and benefits of alternative schemes of varying scale, and it influenced future studies which took a model form, and examined it in greater detail, in order to highlight more clearly the relationship between traffic, the road system and capital cost. Rather than relying on Cost-Benefit Analysis, they analysed the trade-off between capital cost and the distribution of traffic generators within a town. In this context the nature of the influence of traffic distribution and the chosen form of transport system on capital costs could be more easily analysed.

<u>Northampton, Bedford and North Bucks Study (Wilson and Womersley 1965)</u>

2.2.10. This study[6] investigated the possibility of a new city in North Buckinghamshire. It was undertaken as a result of a previous South East Study which had recommended a 300,000 increase in the area's population. Wilson and Womersley decided that this could not be accommodated in town expansions alone. Alternatively, a new city of this size based on conventional forms could not accommodate private transport to a high standard. Consequently, a new town of 200,000 population with a good public transport system was regarded the optimum. With potential town expansion of 160,000 in the area this gave a maximum population increase of 360,000. A city with a population of 200,000 would engender a high level of personal transportation and an efficient public transport system.

The uncertainty of the ratio between the two,:

> 'combined with the requirements arising from different stages of development, make it imperative that both the type of system and its relation to private transport should be considered on a flexible basis'.[7]

Additionally,

> 'interaction between public and private elements of the transport system has considerable influence on the organisation of town form'.[8]

2.2.11. High growth was anticipated so it was not just flexibility between modes that was required, but flexibility in growth for both public and private transport. This was to be built into the plan enabling maximum provision for both if necessary.

The linear form was considered to best satisfy these criteria with development units clustered around public transport stops. Variations on this linear form were tested for finite and infinite growth and compared with the more traditional cart-wheel structure. The analysis was concerned only with traffic - capital costs were not considered.

2.2.12. The purpose of the analysis was to

> 'outline the principles of land-use allocation which are consistent with minimising the transportation facilities, thus facilitating the development of an economic, optimum network'.[9]

The maximum potential expansion of 360,000 was assumed for the study of the linear form. The results are given in Table 2.4.

2.2.13. The results of this analysis can only be interpreted within the terms of reference of the study. The linear structure was chosen at the outset as it was considered the form most compatible with the commitment to public transport. In its infinite form, it was shown to be capable of accommodating

50% motorisation, although the scale of road works required for all linear variation was substantial. Overall, the single-strand linear structure could not be considered satisfactory for high levels of private transport.

2.2.14. The cartwheel form was shown to accommodate car traffic more easily, with roads of much smaller scale. Careful design would be required where radial routes converged and together with the two ring roads the total length of roads required would have been greater than for the linear structure. No analysis of the trade-off between the more extensive, but smaller scale roads of the cartwheel and the single large scale highway of the linear structure was undertaken. The cartwheel structure was only introduced for purposes of comparison. The lead times of the alternatives were not assessed, although the rate of development was determined by the population targets set for specific years in the future. It was assumed the necessary infrastructure would be ready for use by these target dates.

<u>The South Hampshire Study</u>
(Colin Buchanan and Partners 1966)

2.2.15. A broader theoretical perspective of regional structures was put forward by Colin Buchanan and Partners in the South Hampshire Study.[10] Traditionally, the transport network has been perceived as serving a town or region. However, the definition provided by a road network allows it to portray the structure of an area more strongly than the industrial or residential units located within it. Hence the form of urban or regional development chosen implies a similar form of transport system and vice-versa.

2.2.16. This inter-relationship between transport and development was recognised and three structures were tested, both for planning and transport needs. No quantitative analysis of the three alternatives was undertaken, but they were evaluated against a set of 'a priori' goals:

1. There should be maximum freedom of choice, communication and association for people throughout the area.

2. As the structure grows, it should be possible for each phase to function efficiently and not to be dependent upon further growth taking place.

3. The structure should lend itself to change and renewal in its elements, once they have been brought into existence.

4. The versatility of the structure should not be limited by rigid standards in such matters as transport models or housing groupings.

5. The structure should be capable of growth without the risk of deformation or distortion.[11]

2.2.17. This was a most explicit statement of the need for flexibility at a time when similar studies were based on a fixed future. The goals used for evaluation also emphasised that the alternative structures were to be assessed within a dynamic context. The three structures evaluated were the centripetal, linear and grid forms as shown in Fig.2.1.

2.2.18. The centripetal structure consisted of a central town or city surrounded by a series of smaller settlements in the form of a ring. The transport networks by-passed these settlements such that 'through routes' did not impinge on town centres, giving rise to a network of hexagonal form. This structure was found to be very rigid with potentially uneven growth which would distort the catchment area of each centre. The transport network lacked the flexibility to meet variations in demand, the urban satellites were static and the potential of the whole structure to accommodate change limited. The length of time required to complete a centripetal structure was considered a disadvantage because of the development pressures on intermediate stages which would cause it to distort to the linear form.

2.2.19. The restrictions of the single-strand linear structure as applied to North Buckinghamshire were realised at the outset of the South Hampshire study. Consequently the linear form was developed as the directional grid shown in Fig.2.1. Development was located along a series of perpendicular spines which allowed for variable catchment areas. Public transport facilities gave direction and growth to the structure without prejudicing re-orientation to private modes of travel. Overall this structure was regarded as being very flexible, theoretically allowing great freedom of choice, substantial growth and adaptation. The suburban sprawl of many centrally orientated structures was considered unlikely to occur in the directional grid.

2.2.20. The Grid structure tested was actually a series of superimposed grids, each defining a different category of route. The catchment areas of each suburban centre were liable to cause an imbalance in the overall structure and the grid was considered likely to distort to the linear form. The grid was an unsuitable form for public transport.

2.2.21. As portrayed in the above analysis, the directional grid was the preferred structure. A more quantitative analysis would have reinforced the suitability of this form for urban and sub-regional structures under the conflicting demands of private car usage, public transport and the growth of development.

Transportation and Land Use Structures (Jamieson et al 1967)

2.2.22. This study[12] compared a series of variations on the linear form with the ring and radial structure. Each structure was analysed using a traffic model and the evaluation of alternatives incorporated capital costs. However, qualitative planning criteria were still considered important and each structure was evaluated against the following design principles:

1. The design should accommodate a high level of personal mobility by private and public transport.

2. The structure should have an inherent flexibility for expansion without detriment to earlier developments

3. The size of each of the land use units should satisfy planning and sociological as well as transportation criteria.

4. Both private and public transport routes should incorporate hierarchical principles related to journey length.

5. The distribution of land uses should avoid large tidal flows which provide an uneconomic provision of road space.

6. The primate private transport routes should pass between the main land uses.

7. 'Through' traffic should be accommodated on the primary routes.[13]

2.2.23. Seven alternative structures were tested:

Cartwheel 1 - Traditional town development. Ring and radial routes. Highway network of all purpose low speed roads, 15-30mph.

Cartwheel 2 - As above but with motorway inner ring road.

Single Strand Linear - Residential, industrial and commercial units on central low-speed spine. Flanked by high speed routes. Public transport only on central spine.

Two Strand Linear - Industrial and residential units on two strands round a central commercial area again flanked by high speed routes (unidirectional).

Two Strand (11) Linear - Identical to previous but peripheral routes are two rather than one-way.

Three Strand - Some peripheral residential units and peripheral industry. Some high speed and central routes. Secondary low speed routes for public and private transport.

Four Strand Linear - Marriage between cartwheel and linear form. Similar to three strand but diagonal links added.

The Cartwheel 2 and Three Strand Linear structures are shown in Fig.2.2.

2.2.24. The structures were conceived according to the distribution of industrial, residential and commercial units, the communications network being there to serve them. However, the above definitions of structure, highlighted once again the importance of transport infrastructure in delineating town form.

2.2.25. Peak journey to work trips between the residential and industrial areas were assigned to a network defined in terms of links and design speeds. The EGTAC (Elementary Generation of Traffic With Assignment and Costing) model was used to compute peak hour traffic flows of different classes of road, the number of grade separated junctions, average journey times and construction costs. The inputs were the specification of the highway network, design speed and capacity and construction cost indices. This programme was loaded with a matrix of trips between home and the workplace. The assignment for a particular trip was based on the quickest journey between the two points most closely defining the trip. The results obtained from the model are shown in Table 2.5.

2.2.26. The results for 'Cartwheel 1' were not presented in the analysis, however it was stated that the carriageway lengths and capital costs were very similar to 'Cartwheel 2'.[14]

The time saving for trips on 'Cartwheel 2' as opposed to 'Cartwheel 1' was quoted as 90%[15] so it may be assumed that 'Cartwheel 1' was the worst case. Although the authors maintained that many of the costs of a major development were not affected by planning layout (e.g. industrial and residential unit costs), transport costs could vary significantly and these variations were directly attributable to land use distribution.

2.2.27. Again the linear forms achieved the best overall performance. Their capital costs were on average two thirds of those for the cartwheel structures and journey times were shorter because they suffered from less traffic congestion. The 'three strand' linear structure is similar to the 'directional grid' of the South Hampshire study and it achieved a high level of segregation between 'through' and 'local' traffic. This was considered to enhance flexibility as if growth was necessary (perpendicular to its major axis was assumed), it could be accommodated without altering the secondary road system.

2.2.28. By taking the Buchanan philosophy as its base, this study was again car-orientated with implicit assumptions of growth in car ownership and usage. Public transport was once more the residual mode and the treatment of modal split was poor, its effect on costs and trips was not considered. However, the study was principally a consideration of linear structures which were considered conducive to good public transport and they also performed well in terms of car use. This result was contrary to the belief that the needs of private motoring and public transport are diametrically opposed, cars performing optimally in a dispersed form and public transport in a more densely developed structure.

2.2.29. The analysis was a 'static' comparison of alternative structures. Flexibility was a qualitative goal not inherent in the modelling process. Forecasts of population and employment were fixed and so there was no assessment of the effects of growth and increasing scale in a dynamic context. Despite these drawbacks, it provided a thorough test of the linear and cartwheel structures.

Runcorn (Ling 1967)

2.2.30. In relation to urban form, public transport received most explicit consideration in the development plan for Runcorn New Town.[16] The 'a priori' decision to provide good public transport, together with the topography of the site resulted in the adoption of a linear structure for the town. Unlike the linear forms previously considered, Ling chose a figure-of-eight with a central area connecting two rings which contained industrial and residential links. The structure was analysed under 50% and 85% motorisation to observe the effect on modal split.

2.2.31. The peak hour flows in terms of pcu's (passenger car units) predicted for the two scenarios are given in Table 2.6. The results showed that the level of motorisation affected only internal journeys to work trips substantially and commuter trips marginally. The effect on overall traffic flow was therefore marginal and hence the scale of the required road network would be similar; dual carriageway in both cases. However, the scale of the required intersections increased greatly when the level of motorisation exceeded 50% as the threshold of traffic congestion was reached. With their large land take and extra costs, grade separation of junctions was a substantial increase in the overall scale of the road network.

The Structure, Size and Costs of Urban Settlements (Stone 1973)

2.2.32. Whereas the studies reviewed so far were partial in some respects, that conducted by Stone[17] was by far the most comprehensive investigation of urban structures. This study considered all the costs of urban settlements and although many of them were not influenced by transport costs, the variation in the cost of transport provision was a major factor in determining overall settlement costs. Again, because of the influence of transport networks on urban form, transport costs were more sensitive to variations in urban structure while costs for industry and housing were little affected.

2.2.33. One of the significant advantages of this study over the others reviewed was the examination of scale. Three population levels - 50,000, 100,000 and 250,000 were analysed in order to discover the urban structure best suited to each. Other variables included in the analysis were the degree of centralisation (centralised, partly centralised, decentralised) and the settlement pattern (star, rectangular, linear). Within the analysis of transport, modal split was also assessed to a limited extent. Capital and operating costs per head of population were calculated for combinations of these variables. Unlike the similar studies reviewed above, there were no planning goals against which the results were to be evaluated, only discrete situations being analysed. Whereas previous studies were attempting prescription, this analysis proceeded no further than description.

2.2.34. Transport costs were calculated in five stages:

1. Traffic distribution.
2. Main Roads and their capital costs.
3. The costs of Travelling to Work.
4. The costs of Public Transport.
5. Transport operating costs.

Stone also extended the study to the regional level examining the costs of clusters of settlements.

The structures analysed are shown in Fig.2.3 and the corresponding road systems in Fig.2.4.

2.2.35. The EGTAC model was again used to compute the distribution of trips between residential and employment locations. The road network consisted of primary routes and secondary distributors which were through roads, all other estate roads being cul-de-sac. Trips were assumed to begin and end on some node of the primary system - travelling at either end of these trips was assigned to estate costs. This gave an isolated model of trips susceptible to computation.

2.2.36. The EGTAC model produced a workable system though not necessarily the optimum one. It tended to over-design the road network and so a manual design was carried out for a cross-section of five of the alternative structures in order to form a comparison. The greatest savings of the manual over the computed design were in the provision of interchanges which tended to accommodate more traffic than predicted by the EGTAC model. For the 50,000 settlement, savings of two thirds on interchange costs were achieved by manual design. For the 100,000 and 250,000 settlements the savings were one-third and one-sixth respectively.[18] This decreasing rate of saving was due to a minimum threshold of interchange provision in the EGTAC model. This was not considered too great a distortion as interchanges constituted only 15% of road costs.[19] Compared with the 'lumpiness' of carriageway costs (an extra lane to a two lane carriageway is an increase of one-half) the accuracy was thought to be reasonably good.

2.2.37. As before, the EGTAC model compared capital costs of roads on a lane basis. Interchange costs were more complex, the number of feeder roads, approach speeds and lane capacity all being important. Only new town plans provided separate road and interchange costs and these were utilised. The results of the analysis are shown in Table 2.7.

2.2.38. The dual figures for the largest settlement show the effect of increasing the capacity of the EGTAC model from 75 to 149 vertices, the smaller model being insufficient to accurately represent the traffic distribution at this scale. The Tanner constant 'n' was used in the gravity model which distributes trips between origin and destination. This constant, together with another λ, calibrated the theoretical gravity model so that it represented a real situation by taking account of features particular to one location.

The version of the gravity formula used by Stone was :

$$fij = a_i b_j \exp(-\lambda t_{ij} - n \log t_{ij})$$

where fij = total number of trips between i and j

tij = half the round trips between i and j

a and b represent the sizes of the areas i and j

λ and n are the Tanner constants (developed by J.C. Tanner at the Transport and Road Research laboratory).

'λ' was also varied but it was found to have less effect than 'b' and so was not shown in the main results.[20]

2.2.39. Main road costs thus increased with the size of the settlement, but the order of this increase varied with settlement shape and the degree of centralisation. Rectangular settlements showed a large increase as did decreasing centralisation. However the rectangular settlements had the lowest costs overall. The linear form fared next best, its costs averaging 14% more than for the rectangular form while the costs of the star settlement averaged 17% more.

2.2.40. The effect of decentralisation varied with the form of settlement. For the rectangular and linear settlements, capital costs increased with increasing centralisation while for the star form, the partly centralised settlement exhibited minimum costs. The linear structure fared less well than in other studies, probably because of the single-strand structure adopted by Stone. The rectangular structure was probably more similar to the directional grid of the South Hampshire Study than the linear.

2.3.41. The relatively poor performance of the linear structure may also be attributed to the insufficient attention given to public transport. Modal split was not varied for the computation of costs for the linear structure. Costs were generally reduced with increasing dispersal of facilities, conditions under which public transport performs poorly. However it reduced road network costs because of the dispersal of traffic congestion and hence required less extensive junction provision. Stone did vary the number of strands in the linear structure but the effect on costs was minimal, the maximum reduction being £5. per head of population. This variation was not extended to other structures, but earlier research was cited which showed that for a circular settlement, the ring and radial network was the most economic.[21]

2.3.42. Transport operating costs were calculated for each structure and are shown in Table 2.8. The operating costs of private cars and buses were used to compute annual operating costs for the journey to work. The public transport costs included the provision of busways to connect the residential areas.

2.3.43. Travelling costs tended to parallel construction costs, increasing with settlement size although at a faster rate. They rose more quickly in linear settlements and most of all in those partly centralised. However, whereas dispersion minimised capital costs, concentration minimised operating costs. Again the rectangular structure performed best of all, but Stone did not attach great importance to these results, because for a true representation of the effects of decentralisation on operating costs, the probabilities of worker's trips to various workplaces would be required. However the conflict of structure and centralisation was apparent: rectangular structures performed better under decentralisation, linear structures under centralisation. Stone argued that better results were obtained by altering the shape of a settlement to a rectangular form rather than increasing the number of strands in a linear structure.[22]

2.3.44. The routeing of buses was not a determinant of settlement shape and size. As such, public transport was the residual mode in the primarily car-orientated structures. A modal split of 1.6 assumed 80% of trips were made by car, 10% by bus and 10% walking. The effect of increasing public transport usage is shown in Table 2.9.

The costs of bus-only roads were then calculated for the three settlement structures assuming a decentralised layout (Table 2.10). This was only one of three possibilities for operating buses the others being bus links and the existing road system. The cost of bus only routes was considered prohibitive, but bus only links (possibly connecting the cul-de-sacs of estates) would be more cost effective at £50-120,000 (1967 prices).

Finally the costs of railways were assessed - a figure-of-eight being the only economic option. (Table 2.11).

2.2.45. Although the structural comparisons were static in nature, chapter 16 of Stone's book was devoted to phasing and adaptability. This stated that settlements were unlikely to be completed in the forms envisaged at their inception and rates of development would vary from time to time. Flexibility and dynamics were therefore important, but the cost of main road development would depend on the final form of the system and the settlement type. The 'lumpiness' of road provision would cause problems and the author's view was that a grid of two-lane roads with at-grade junctions would minimise the effects of the step function in road costs. The rectangular settlement in this study bears most relation to this prescription as it contains a grid road system. Stone maintained that a linear structure would require considerable capital for a road system unused until the settlement was complete. Previous studies considered the linear form adaptable to needs as they arose.

2.2.46. Stone's linear form was somewhat less refined than that used in previous studies as it was based on a single through route. This would be needed as a link to other settlements and as such was a base requirement. However, from Jamieson et al, the through road may be independent of town development which could take place on parallel and perpendicular stands which could be extended as required. The absence of such variations in the linear form was an omission which detracted from the results of this study. Had it been included, together with a greater appreciation of public transport usage, the results could be accepted with greater confidence. 80% car usage for the journey to work is a very high proportion which cannot be achieved except in the smallest of settlements.

2.2.47. The form of the rectangular settlement may also be problematic in a dynamic context. The 'box' road network like the single strand linear is highly inflexible and requires completion before the system can function effectively. However, the possibility that the system may not be completed in its planned form is one of the main factors in justifying an assessment of uncertainty and adaptability. Stone believed that where rapid growth was expected such an integrated system was worthwhile, as sensitivity to uncertainty would be less important. An assessment of the lead times of the various settlements analysed would have been helpful in this context.

Stone's overall conclusion was that small low density, decentralised settlements were the most adaptable.

Summary of Road Network Studies

2.2.48. Several of the studies of road network structure reviewed above were undertaken in support of the British new town programme. Although this programme is now drawing to a close, the research on urban form and transport infrastructure provides useful insights into the perceived inflexibility of infrastructure which are relevant to the problems of large scale planning under uncertainty.

2.2.49. The majority of the studies compared alternative network configurations and evaluated them against a series of quantitative and qualitative criteria. It was apparent that there was no single optimum network structure which would satisfy all criteria. However, some structures performed better than others in many respects. Overall the least satisfactory appeared to be the ring and radial system which is present in most existing towns. This structure resulted in greater traffic congestion at intersections and higher costs. The grid structure distributed traffic more evenly over the network and as such was more suited to private car usage.

2.2.50. However, the uniform grid provided poor conditions for public transport operation. If public transport is deemed to be important, the linear structure is more appropriate. A hybrid 'linear grid' provides the positive attributes of allowing both private car and public transport usage in an efficient manner. Several of the later new towns adopted this form including Irvine, designed by Wilson and Womersley.

2.2.51. The linear and grid structures were also more adaptable and the linear grid in particular was considered most capable of accommodating growth. The ring and radial structure, while operating satisfactorily on a small scale was susceptible to distortion under growth. The scale and cost of transport infrastructure provision also increased rapidly with network size. For very large cities, the linear forms performed best of all because of the necessity for substantial public transport to which it is most suited.

2.2.52. Given that there is no one optimum structure for transport networks, it is important that the goals and objectives for network development are clearly stated. This is clearly a policy matter that will be discussed in chapter 3. However, those studies which precisely stated the objectives for transport networks were most satisfactory in terms of results as it was possible to gauge the extent to which the alternative structures achieved their aims. To state that one particular structure may accommodate public transport well is of little use unless a need for public transport has been identified, or is considered desirable.

2.2.53. The studies reviewed here have shown that there is no one structure that is ideally suited to urban development. In fact the whole concept of building new towns on the basis of simplified hierarchal structures has been criticised. Jacobs[23] argued that the social environments of new towns could never satisfactorily recreate the urban atmosphere produced by the superimposed land uses in existing urban areas. On a technical level, Alexander[24] argued that it was because cities were not based upon hierarchal trees as many of the new towns were, but were in fact of a semi-lattice form where urban elements related to each other horizontally as well as vertically. If this is the case, then the needs of the transport system may be in direct conflict with those of the urban environment. The requirement is then for a system or structure within which a mixture of land uses may best be achieved and where growth may be best accommodated.

2.3. AIRPORTS

The Strategic Planning of Airports Under Uncertainty

2.3.1. UK research into the strategic development of the airports system has been dominated by the Third London Airport. As a problem of transport planning, this issue will be examined in chapter 5. The review of studies below, concentrates on the infrastructure aspects which were investigated during the evaluation of the project. However, other work, particularly that relating to economics will also be reviewed.

2.3.2. When the Roskill Commission undertook the task of evaluating alternative sites for a third London airport, air travel, particularly for leisure purposes, had not achieved the popularity it enjoys today. However, it was undergoing a phase of rapid growth, similar to that which occurred when travel by motor-car became more accessible. In the 1970's several factors including the introduction of large passenger jets, the increase in oil prices in 1973 and more recently economic recession have reduced this rate of growth. Passenger demand at UK airports remained static between 1984 and 1985.[25]

2.3.3. The level of uncertainty surrounding the future demand for air travel has thus increased substantially. Since the single projection of demand used by the Roskill Commission, there has been greater emphasis on the use of scenarios, both for demand and capacity. These alternative futures have played an important role in the assessment undertaken since. Scenarios of future capacity have particular relevance as they were expressed in terms of lead time and capital cost. Unlike road networks there are no physical links to determine the configuration of an airports system, but factors such as surface access and the degree to which the system is centralised are analogous characteristics.

The Third London Airport Studies (GB Dept.of Trade 1974-79)

2.3.3. The Roskill Commission report was published in 1971. As a result of their brief they were unable to consider alternative infrastructure options for developing the airport system to serve London. Their task was to evaluate alternative sites for a four-runway airport. They were also asked to report on the timing of the need of the airport. Here they gave some regard to flexibility advocating that two runways should be built immediately, further construction being dependent on a continued rise in demand. However their analysis was based on a fixed future, a single forecast of demand that showed that the four runways would be needed by 1990.[26]

2.3.4. The Conservative Government of the day eventually rejected the findings of the Commission and chose to build the third London airport at Maplin. This decision was itself revoked in 1974, which marked the beginning of a reappraisal of the need for a new airport. Both forecasts of demand and the level of capacity required to satisfy them were subject to new analyses. In the Maplin Review,[27] a cross-sectional analysis of capacity at existing London airports was presented together with an assessment of the potential diversion of traffic to regional airports. The development of these facilities and a possible new airport was mapped against the following scenarios:

1. A new airport at Maplin.
2. An increased rate for Stansted and Luton.
3. Diversion of traffic to regional airports.
4. A second terminal at Gatwick.

2.3.5. The results of this analysis are shown in Table 2.12. The scenarios were concerned with variations in capacity, while demand was still fixed at 84.2mppa [28] in 1990. This was significantly lower than the 138 mppa[29] forecasts used by the Roskill Commission which was a 137% increase over the 58.1[30] mppa forecast for 1981. The potential for regional diversion of this traffic together with the possible reductions caused by a Channel Tunnel are shown in Table 2.13.

2.3.6. Once the concept of a single site to accommodate future demand growth was questioned, there were numerous alternatives for increased capacity and greater attention was given to the physical constraints and potential expansion at each site.

2.3.7. This theme received further attention in 1975 when a two part report[31] assessed the capacity requirements of the London and regional airports. The number of scenarios was increased from four to nine and they were mapped against high and low forecasts in recognition of demand uncertainty. The results are shown in Table 2.14. They show how far the development of existing airports could be taken before a new site need be considered.

2.3.8. The potential for regional diversion was assessed based on models developed by the Metra Consulting Group.[32] They assumed free-market conditions reflecting the doubts surrounding the efficacy of policy in controlling the level and distribution of demand. A simple CBA of this diversion was carried out based on the existing situation but no details of infrastructure costs were given. (Table 2.15).

2.3.9. The most comprehensive study of possible London airport sites, in terms of infrastructure was published in 1979. The report of the Study Group on South East Airports (SGSEA)[33] returned to the notion of a single site but explicitly rejected the Roskill Methodology. It contained an assessment of direct costs, lead time and cash flow for each alternative site. This study was not prescriptive in nature (the choice of a third London airport site was thought to be a political decision) and the information presented was designed to aid decision making. Forecasts of demand were not assessed, the figures being taken as given by the Air Traffic Forecasting Working Party (prepared for the Advisory Committee on Airports Policy).[34] Site analyses for Stansted and Maplin are given inTables 2.16 and 2.17 and Figs. 2.5 and 2.6. A summary of the results for all the seven sites examined is given in Tables 2.18 to 2.22

2.3.10. Passenger threshold levels were used to calculate capital costs. The three stages of development corresponded to patronages of 15m passengers per annum, 25m ppa and 50m ppa respectively. As for roads, airport costs tended to be 'lumpy' and because of the lead times for each threshold of provision, an estimate of future patronage was required. The determining factor for the thresholds was either runway capacity or passenger terminal capacity. To increase capacity at increments lower than these thresholds was either not feasible or uneconomic.

2.3.11. For the majority of sites it was expected that 90% of this expenditure would be needed before the opening of the airport highlighting the advance commitment required for a large new airport. The analysis also showed that the costs of constructing the airport itself were only 50% of the total capital costs. For a new large airport there were consequent requirements for new supporting infrastructure in Defence relocation, and road and rail access.

2.3.12. The comparison of Stansted and Maplin shows the large differences in lead time that are dependent upon site selection. These two alternatives represented the minimum and maximum commitments, the lead times of other sites together with phase 1 costs are given in Table 2.23.

2.3.13. The presence of local factors at any site precludes any direct correlation between capital costs and lead time. However, with the exception of Yardley Chase where defence costs were abnormally high, there are three distinct categories of site. - Stansted where basic airport facilities already existed possessed the minimum lead time by three years and also the minimum capital costs. Hoggeston, Langley and Willingale all exhibited similar lead times and costs. Finally, the lead time for Maplin exceeded that of any other site by at least four years and its costs although £80m less than for Yardley Chase were £180m greater than for Hoggeston and Willingale.

2.3.14. It is also apparent that although Stansted possessed the minimum phase 1 costs, phase 3 costs were higher than average due to the limited potential for expansion. Alternatively the Phase II and III costs for Maplin were lower than average with Willingale possessing the lowest subsequent costs overall.

The Second Sydney Airport Study (Carruthers 1980)

2.3.15. The uncertainty surrounding the growth of air travel in Australia was a major influence on the planning methodology for the second Sydney Airport.[35] Decision theory techniques were employed to evaluate alternative developments against a range of future scenarios. Of the maxims available, Expected Cost was considered to best reflect the uncertainty in demand.

$$\text{Expected Cost} = \sum_{1}^{n} (p_n \, en)$$

where p = probability of a scenario occurring

e = expected cost of the scenario

n = total number of scenarios.

2.3.16. Total costs and benefits were calculated using the methodology employed by the Roskill Commission but with two important differences. Uncertainty in demand was a central feature of the study and a series of 5 scenarios were used in the assessment. In addition, costs were defined as a function of demand rather than being derived independently. Nine types of cost were included:

1. Airport infrastructure costs
2. Airport user costs
3. Aviation Costs
4. Defence costs
5. Congestion and closure costs
6. Access capital costs
7. Access user costs
8. Noise costs
9. Urbanisation costs.

2.3.17. The five scenarios of passenger demand were based on assumptions of high, medium and low growth between 1971 and 1985. For the period 1985 to 2005, the initial high growth developed as high and medium forecasts and the initial medium level growth was extrapolated as medium and low growth forecasts. The initial low growth scenario continued as a single low forecast. Scenario 1 contained the highest forecast of 190 mppa and scenario 5 the lowest with 70 mppa in the year 2005. To derive the relative probabilities of each scenario, a Delphi analysis of the five scenarios was undertaken. The results are given in Table 2.24.

2.3.18. The demand increment separating each scenario was equivalent to the capacity of one runway. The economic and social conditions consistent with each scenario were postulated prior to the Delphi analysis.

2.3.19. A three stage site selection process was used based on an initial selection of fifteen sites. The alternative runway alignments at these sites resulted in 48 possible combinations of runway layout and site.

The analysis was designed to be an aid to the selection of a short list of sites from the initial 48 with expected cost being one of the principal factors.

Before a new airport was considered, the first priority was to develop the existing Sydney airport as much as possible. There were 13 possible strategies for achieving this and 20 possible distributions of traffic between the new and existing airports were formulated. Combining these three ranges of factors gave 10^{28} variations for each site layout. The difficulties of comprehensive assessment are highlighted by this enormous range of alternatives. In order to make this problem manageable, a dynamic scheduling model was used to determine the least cost schedule for each strategy.

2.3.20. The output of the schedule selection model suggested the optimum year for the introduction of a new airport was 1995. The expected cost of each of the 48 sites is given in Table 2.25. It is apparent that the expected cost for each site layout was very similar to the costs of scenario 4, that with the highest derived probability. However the author considered the full assessment of the other scenarios worthwhile as it reduced ignorance of the possible future situations. It was also believed that analysis of all the scenarios made the assessment more robust. The analysis was designed to produce a short list of sites for which environmental assessment was also undertaken prior to a final decision being taken.

2.3.21. This study contained several interesting features. The methodology adopted contained a reversal of the demand satisfaction approach present in the majority of studies reviewed previously. The uncertainty surrounding the future demand for air travel was explicitly acknowledged at the beginning of the study and no fixed future postulated. Furthermore, the scenarios used were not simply a product of economic assumptions. They were derived from a knowledge of the inherent step functions in airport capacity concommitant with increases in runway provision. Thus the thresholds associated with the large scale units of runway capacity were a major influence on the whole study.

<u>The Economics of Airport Development</u>

2.3.22. Whereas economics is one particularly important aspect of the evaluation of roads and public transport, it is the central one in the planning of airports. Although many of the major UK airports are in public ownership they are independent entities which must perform well economically in order to survive. Unlike roads, where an annual tax is levied for their use, airport users must pay directly to use the facilities.

However imperfect, there is then a market for the use of airport facilities within which airports operate.

2.3.23. As a consequence, the majority of research into airport infrastructure has taken place within the discipline of economics. Economics of scale and spatial disaggregation have received particular attention, partly as a response to the holistic single-site approach of the Roskill Commission. The situation was described thus:

> 'It is possible, for instance, that it is of greater benefit in national terms to have a few large airports centred on London, pay the extra cost of surface transport and forgo those trips not undertaken rather than build a more widely spread network of airports. On the other hand, this may not be true, and a more even distribution of airport services may generate a larger regional and national rate of grants.'[36]

2.3.24. The evidence concerning economies of scale is conflicting. One of the reasons is the relatively small number of airports and the presence of unique local site characteristics. Fordham[37] cited early american research which showed that larger airports produced a higher return on capital, although the form of the relationship between size and the investment return was unclear. More recent research has been less certain of the benefits of increasing scale. Walters[38] argued that economies of scale occurred in runway provision and that such economies could be measured against demand and cost. However cost could only be offset by the income from airport users and unlike road investment, demand was not perceptibly affected by infrastructure improvements.

Furthermore, there is a lag between expenditure on improvements and the return on investment. The greater the capacity of the improvement, the greater the lag beween outlay and return, because of the greater time to reach full capacity and hence maximum revenue.

2.3.25. Earlier work by Doganis and Thompson[39] had reached a similar conclusion. Economies of scale in airport provision were found to exist up to quite small levels of capacity (1mppa) but they could increase capital costs by up to 200% while hardly affecting revenue at all. The delay between the opening of a new facility and the time when it reached full capacity implied that it was considerably underutilised until that capacity was achieved. The conclusion of Doganis and Thompson was that several small airports could have equivalent or lower costs than a single large site. However, they considered only the internal capital and operation costs of the airport and not externalities such as surface access.

2.3.26. This problem of relating investment to income was exacerbated by uncertainty and in the light of the Roskill report the risk associated with airport investment was more clearly recognised. Commenting on the findings of the Roskill Commission, Forsyth[40] argued that the timing of the new London airport was economically much more important than its location. With the great uncertainty surrounding demand, the costs of executing the project at the wrong time could be very large. For this reason it was suggested that the investment be delayed as long as possible. Fordham[41] went further in suggesting that several airports should be developed rather than a single site.

Summary of Airport Planning Studies

2.3.27. It is apparent from the research into airport investment that the large unit capacities have played an increasingly important role in planning methodology. Even in the approach of the Roskill Commission, the size of the airport was predetermined and its timing was designed to match an expected increase in demand. In the later third London airport studies and that for the Second Sydney airport, future scenarios were determined by increments in capacity equivalent to the perceived economically viable thresholds for runways and terminals.

2.3.28. The high level of uncertainty surrounding the planning of airports has reinforced this approach based on capacity. Evaluation concerns the investment strategy which is robust to the possible scenarios, or the one with minimal capital costs. It is believed that investment risks will be minimised in this way. This contrasts with a demand satisfaction approach whereby demand is fixed and the investment decision concerns the strategy which meets it most effectively in economic and planning terms.

2.3.29. Given the recognised uncertainty in airport demand, the strategies which have long lead times must be considered to be high risk. Shorter lead time alternatives postpone the need for a decision, a delay which is considered desirable in economic terms, because the costs of the decision being incorrect can be so great. Increasing the scale of the commitment will increase the capital costs and as such, the costs of poor decision making. There is also evidence that although economies of scale may exist in runway provision, many of the associated facilities, particularly terminals and surface access, show diseconomies beyond very small passenger capacities.

2.4. SUMMARY CHARACTERISTICS OF TRANSPORT INFRASTRUCTURE

2.4.1. The physical and economic characteristics of infrastructure combine not only to produce rigid transport systems, but also to place great constraints on transport planning as a process. Studies of road networks and airport investment have highlighted the contribution of factors such as scale and lead time to this rigidity. The salient physical and economic factors are summarised below preceded by an appreciation of flexibility, and the extent to which it depends on a technical appraisal of infrastructure characteristics.

Scale

2.4.2. Uncertainty creates difficulties for transport planning that may appear intractable. The scale and cost of capital works are substantial and require great commitment at both the political and technical level. Forecasting is therefore an essential aspect of planning if the resources committed to infrastructure investment are to be effective in achieving the required task. The potentially damaging effects of uncertainty on the outcome of capital projects must therefore be minimised. An initial approach to this problem may result in a rejection of large-scale solutions to transport problems epitomised by the theory 'Small is Beautiful'.

2.4.3. In practise, the situation is more complex. The problems of traffic in urban areas are strategic in nature and any small scale local solutions must not simply shift the problem to an adjacent area. The review of studies above has shown that infrastructure possesses thresholds of capacity which are not easily divided either physically or economically. The size of airport capacities is particularly relevant in this respect.

2.4.4. It is apparent therefore that there exist two levels at which scale must be considered. The first is the strategic level which describes the scale of the overall problem, such as traffic control in a major conurbation. This is more an administrative aspect of the problem of scale, which will be dealt with in chapter 3. The second is that of the infrastructure solution to a particular element of the problem. The two are related, but as shown in chapter 1, infrastructure solutions of the same scale and extent as the problem are doomed to failure.

2.4.5. Large scale planning attempts to be optimal by satisfying demand at minimal cost through the exploitation of economies of scale. High initial costs are traded off against an expected unit return which increases with the scale of the project. This would be understandable in an environment unaffected by uncertainty. However, in its absence, optimality often results in an all or nothing approach to planning, characterised by Walters[42] as typical of airport developments. The third London airport was such a case where acceptance of schemes in their entirety was necessary before construction could begin. The consequences are particularly acute when completion of a long-term plan is necessary before any benefit is forthcoming.

2.4.6. Such 'diseconomies' relate to overall scale. Stone[43] in his work on urban form showed that operating costs of an urban transport network will increase with urban scale even if capital costs per capita are reduced. These operating costs are also far greater in the long term than the capital costs. So it is not only the capital costs of new developments that must be considered, but also the costs of operating the system once completed.

2.4.7. Diseconomies of scale are also apparent in the operation of the smaller units that constitute a much larger system. Collingridge[44] described the effect of increasing unit size on the planning and operation of technological systems. Taking the example of electricity generation, he highlighted the greater potential error cost associated with increasing unit size. As the unit capacity of components increases, so the number of those components decreases. This results in a greater sensitivity to forecasting error of the system as a whole, as larger units require longer construction periods. The sensitivity also extends to operational aspects through technical failure. The malfunction of one unit will severely impair system performance. A parallel exists in transport networks where concentration of traffic on a small number of high capacity routes makes the integration of such routes essential, as well as increasing the costs of a failure (e.g. due to accident).

2.4.8. As scale increases, matching capacity with demand becomes more difficult and the operation of the system more sensitive to failure. The 'lumpiness' of infrastructure makes this problem difficult to overcome and it is often assumed that the economies of scale will more than offset this sensitivity. However, the research by Walters and Doganis and Thompson showed that although economies of scale do operate in airport investment, they do so up to a threshold which is often exceeded in current airport operation.

2.4.9. For land based transport networks, scale may be more difficult to quantify. Stone (1973) distinguished between scale and size in urban networks, scale being the physical limits of a system, size being the system density. As well as increasing operational costs, high density developments were found to make system structures that were less flexible and adaptable.

> 'Facilities such as a primary road network... are likely to be considerable underutilised... This problem tends to be greater, the larger and more centralised the settlement and the greater the density'.[45]

2.4.10. If the diseconomies of scale were thought to be greater than the economies, a move to smaller scale developments would not be unreasonable. However, as Gershuny[46] points out it is probable that only some economies of scale are becoming less important. Small scale on its own will not suffice. Although related to scale, it is lead time that increases sensitivity to long term forecasts. Small, rather than large scale changes may not be any more responsive to uncertainty, but they may reduce the cost of error and ease the problem of balancing capacity with demand.

2.4.11. In order to appreciate the scale of any individual project some form of measurement will be required. There are two possibilities, the first of which relates to capacity. Capacity may be expressed either directly e.g. vehicles/hr. for roads or mppa for airports, or via a ratio of the capacity of the proposal to the total capacity of the existing system. The latter may, with further investigation, suggest whether in terms of planning the proposal is 'incremental' or of such a scale that it is much greater than the minimum threshold described in several of the studies reviewed earlier in this chapter. A second form of measurement utilises the capital cost of a project as a proxy for scale. This is likely to embrace not only the direct costs of a proposal, but also the costs of any associated infrastructure which will also contribute to the overall scale of the project.

Lead Time

2.4.12. An appreciation of lead time is central to the consideration of uncertainty. The relationship between time and the rate of system development can have a significant impact on planning variables, especially costs. Considered as a characteristic of infrastructure lead time will normally increase with scale and imply an increase in costs. Therefore long lead times require accurate forecasts if the relationship between demand and capacity is to be optimised. However there is an alternative approach to the assessment of lead times. They may be considered:

> 'as independent uncontrollable variables. It is then a forecasting problem with the emphasis on minimising the impact of forecast errors. The second approach puts the emphasis on control and attempts to manage the average lead times to predetermined norms'.[47]

2.4.13. Therefore, system development may be controlled by rigidly monitoring and influencing physical lead times rather than viewing them as automatically generated by a 'demand satisfaction' approach to planning. Such an approach could minimise the unwanted problems often associated with long lead times, those of delay and cost escalation. Failure to control lead time will lead to difficulties in the integration of systems and policies. Such problems are ignored in traditional models based on static comparisons and optimal relationships. In such models lead time varies through the internal design of the system, not as a factor which can be influenced to guard against external uncertainties.

2.4.14. This positive approach to lead time was apparent in the analysis of the third London airport. The Study Group on South East Airports (SGSEA)[48] eschewed the cost-benefit approach to planning analysis listing only directly quantifiable factors such as lead time for each planning option. As with other factors which determine the level of control over systems, lead time should be considered at the inception of the planning process. Only then will such factors influence the important decisions. The measurement of lead time is relatively straightforward although for novel developments, or those which contain an element of technical innovation it may be more problematic. It is however a forecast and is prone to underestimates. Unforeseen delays often occur and it is important to highlight which systems are sensitive to them. In decentralised situations, delays may be more effectively diffused throughout the system, with minimal effect on overall lead time.

Configuration

2.4.15. The configuration of a system describes the spatial relationships between its components. Studies of urban network configurations flourished during the 1960's when the British new town programme provided a unique opportunity to design networks that could accommodate contemporary travel behaviour. However, these studies were carried out in the traditional transport planning framework using static comparisons of alternative networks. The issues of flexibility and growth were treated in a qualitative post-hoc fashion.

The South Hampshire study provided a more positive lead:

> 'the essence of the problem is to devise a structure which is capable of responding to and accommodationg growth and change'.[49]

The 'preferred structure' in this study was the directional grid which combined the flexibility of the grid with the potential for growth of the linear form. Other research endorsed this choice. A multi-strand linear structure, apart from having lower costs per capita 'exhibits the greatest flexibility to accommodate growth and change...'.[50] Such a combination was '...adaptable and capable of growth at the desired rate'. Stone[51] believed that the flexibility was due more to the grid than the linear form. A separation of primary and secondary routes was thought to be helpful in promoting flexibility.

2.4.16. However, these studies were orientated towards road networks which served high levels of car usage. Other studies such as that for Runcorn were conceived in terms of public transport and tended to favour more rigid linear forms. A grid may offer flexibility in terms of growth, but not in terms of mode of transport. Truly flexible structures are likely to contain elements of different configurations so that they may respond to changes in both growth and mode. There was evidence to suggest that as the scale of settlements increased, so public transport became more important and hence the most suitable structure altered.

2.4.17. These studies raise the question of whether structures themselves should be susceptible to change, or whether they should be robust to future changes in the demand which they serve. Undoubtedly the studies reviewed here support the latter position. Success:

> '...depends on development control ensuring that the pattern is not detroyed by 'alien' development outside the system'.[52]
>
> 'The ability to work under alternative loading patterns... and the avoidance of compromises in structure or configuration.[53]
>
> 'The structure should be capable of growth without the risk of deformation or distortion.[54]

This emphasis on robustness highlights one of the dilemmas of dynamic response - should system structures provide limits to growth in order to preserve versatility?

2.4.18. Quantitative analyses of configuration are difficult. Geographical methods based on graph theory are possible, but complex and outside the scope of this study. However, for urban road and public transport studies, qualitative planning considerations such as those used in the South Hampshire study may be sufficient. Additionally, it is possible to measure the impact of alternative structures in terms of cost and traffic distribution without resorting to mathematical mapping of the network itself. For airport systems, where there is no physical network, the level of centralisation present within the system is likely to be far more important.

Decentralisation

2.4.19. The scale and distribution of capacity define the level of decentralisation within a system. Increasing the scale of the components of a system of constant capacity will result in increasing concentration. Intuitive assumptions tend towards the belief that decentralised small scale systems are more adaptable and responsive to change. However in urban areas this is not always the case and decentralisation can have serious side effects if it is not effectively managed. If population disperses but industry remains concentrated, large scale transportation systems will be required for the journey to work. The relationship between land use and transport is at its most important here. If industry was decentralised along with population, the costs of transport would be reduced, but the implementation of this approach in Britain has had a devastating effect on the inner cities.

2.4.20. The greater the degree of centralisation in a system, the more difficult the incorporation of change. In particular the system will be less responsive to changes in behavioural demand. The longer lead times associated with large-scale centralised developments means that patterns of behaviour :

> '...may be difficult to re-orientate when the facilities are provided.[55]

To achieve a closer relationship between demand and the provision of facilities there has been more emphasis on the incremental-modular approach to development.[56]

2.4.21. The failure of a 'rational' and centralised approach to satisfying travel demand may, as in the case of airport development, resulted in decentralisation by default, rather than as the product of a positive planning initiative. In the absence of a 'single site' third London Airport as a solution, incremental improvements in capacity have been achieved at Heathrow, Gatwick and regional airports. This has been regarded as second best, but under a dynamic analysis the benefits of more dispersed development may be seen in a more favourable light. Again decentralisation will have its costs, in this case in terms of airport access.

2.4.22. The measurement of decentralisation, like configuration, is problematic. Qualitative criteria may be used and any quantitative measure is likely to be a proxy. For road networks, the ratio of carriageway width to total road length will normally increase with increasing centralisation. However, this will not normally be applicable to public transport where increasing intensity of use of existing facilities is likely to be preferred over totally new railways or busways. For airports, the situation is more simple as the number of sites within the system, and their capacity gives a direct indication of the level of centralisation.

Timing

2.4.23. As with lead times, in a totally rational planning process there is little control over the timing of transport projects. Given forecasts of future demand, any new facilities will need to be available from the date when existing capacity is exhausted. Working back from this date and with the knowledge of the lead time of the individual project, a starting date for construction can be determined, or the project may be phased so that capacity grows with demand. However it is now apparent that lead times and capacities are subject to flexibility. In fact demand itself can be influenced through policies of restraint or growth. In urban transport systems, traffic management, public transport subsidies and less rigid design standards have resulted in more flexible approaches to planning and a greater appreciation of available choice. Similarly, the capacity of airports has fluctuated, partly due to the introduction of wide-bodied jets which meant that passenger terminals rather than runways determined capacity. This enabled decisions over the timing of any new airport to be deferred.

2.4.24. The research reviewed in 2.3. reinforced the view that investment in airports should be postponed as long as possible. This finding is in direct contrast to that of the Roskill Commission which advocated early execution of the third airport so as to achieve the maximum possible benefit from time savings. There is therefore no optimum timing for infrastructure projects. Allied with short lead time, projects may be deferred so as to minimise the risk from uncertainty. However, timing is often dictated by political circumstances rather than economic criteria.

Flexibility

2.4.25. Early transportation studies presupposed little influence on infrastructure form because of its perceived flexibility:

> '...urban structure changes at a glacial tempo, while mode of travel and destinations are being adjusted continually.'[57]

It was thus that transport planning concentrated on promoting static structures based on a physical plan which would be robust to more changeable patterns of demand.

2.4.26. However, in response to the problems caused by uncertainty, flexibility later became a key issue in transport and land use planning. One of the earliest attempts at explicitly planning for flexibility was contained within the South Hampshire Study:

> 'Planning, as we see it, is becoming less and less a matter of precise propositions committed to paper, and more and more a matter of ideas and policies loosely assembled, under constant review, within which, every now and then, some project is seen to be as ready for execution as human judgement can pronounce...This, as we see it, is planning for flexibility.'[58]

2.4.27. However, not all studies viewed flexibility with the same importance. The work of Stone was typical in that it considered flexibility as one element of the planning process. Furthermore it entered the process at too late a stage, subsequent to important decisions on the design of a project. This post-hoc approach was also apparent in the work of the Roskill Commission who, given the task of finding a site for a 4-runway airport, could comment only on the phasing of development:

> 'The issue was captured from the start: all subsequent discussion took for granted that a new airport would sometime be built.'[59]

Consequently, the way in which problems are formulated is as important to the concept of flexibility as the chosen solution.

2.4.28. A recent study of flexibility and related concepts in a corporate setting suggested that flexibility was 'the idea that functioning will continue in unenvisaged circumstances'[60] This wide ranging study of flexibility by Evans highlighted its broad definition and chose to reject only the concept of robustness:

> 'The spirit of robustness seems to suggest that a strategic alternative, if robust, will remain viable even if a 'Kaleidoscopic' shift occurs either in value structures (thereby altering preferences) or in future technological resources. Flexibility is the inherent capability to modify a policy to accommodate and adapt successfully to such changes, whereas robustness refers only to the ability to endure such changes.'[61]

This robustness and the pursuit of it, will have little effect on the design and planning of transport alternatives. It implies only that from a series of predetermined alternatives, preference will be for the most robust. Yet the robustness of a system will tell us little about the responsiveness of transport structures.

2.4.29. As Evans describes, flexibility is a capability inherent to the chosen strategy or policy. The work reviewed in this chapter has shown that there is no single correct physical solution to transport planning problems. Much will depend on the objectives of the policy and problem formulation. Therefore, flexibility must be considered each stage of transport planning process if it is to have any effect on the final decisions regarding infrastructure investment. It is only within this policy framework that the choice of infrastructure alternatives is meaningful. The strategies and techniques whereby flexibility may be thus incorporated will be examined in chapter 3.

CHAPTER 2

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Work Required		(Restricted Network) Scheme A		(Minimum Re-development) Scheme B		(Partial Re-development) Scheme C	
		£(000)	£(000)	£(000)	£(000)	£(000)	£(000)
Primary Distributor	Land	230		456		413	
	Works	180		360		360	
			410		816		773
Central Area Local Distributor	Land	1,292		990		1,030	
	Works	116		150		200	
			1,408		1,140		1,230
Car Parks	Land	720		1,180		960	
	Works	120		240		720	
			840		1,420		1,680
Bus Station	Land	30		30		30	
	Works	3		3		3	
			33		33		33
	Less Capital Value of Site	(8)	(8)	(8)	(8)	(8)	(8)
Redevelopment	Land Cost	-	-	-	-	3,530	-
	Clearance	-	-	-	-	52	
							3,582
	Less Capital Value of Site	-	-	-	-	(1,725)	(1,725)
Cost of Land and Works			2,691		3,409		7,298
Less Site Value Redevelopment			(8)		(8)		(1,733)
Total Net Cost £(000)			2,683		3,401		5,565

TABLE 2.1. NET CAPITAL COSTS OF NEWBURY TOWN CENTRE SCHEMES

Source: Traffic In Towns, Appendix 2.

Scheme	Env. Acc. Index	Benefit	Cost £m.	Benefit / Cost
'Nil expenditure'	11	-	0	-
A	22	11	2.7	4.1
B	57	46	3.4	13.5
C	72	61	5.6	10.9

TABLE 2.2. NEWBURY TOWN CENTRE SCHEMES - BENEFITS AND COSTS OF THE 3 SCHEMES COMPARED WITH SITUATION IN 2010 IF NO WORKS ARE CARRIED OUT

Source: Traffic in Towns, Appendix 2.

Scheme	INCREMENTAL		
	Benefit	£m.Cost	Benefit/Cost
'Nil expenditure'	-	-	-
A	11	2.7	4
B	35	0.7	50
C	15	2.2	7

TABLE 2.3 NEWBURY TOWN CENTRE SCHEMES - COMPARISON OF THE INCREMENTAL COSTS AND BENEFITS OF THE 3 SCHEMES IN TERMS OF ENVIRONMENTAL ACCESSIBILITY.

Source: Traffic in Towns, Appendix 2.

TOWN FORM	PEAK HOUR FLOWS CARS/HRS	CARRIAGEWAY WIDTHS	LEVEL OF MOTORISATION
Finite Development			
1. Cartwheel: Industry at periphery 8 radials, 2 ring roads	15,000 worker trips	4-6 lane dual radials 4 lane dual ring roads	50% possible with careful design
2. Linear: 1 central area Industry at extremities	24,000 worker trips	4 lane dual at centre. 24 lane dual at industrial areas	50% impractical
3. Linear: 1 central area Industry at extremities Some trips through central area	24,000 worker trips	16-24 directional lanes	50% impractical
4. Linear: 1 central area Industrial and residential units interspersed	16,500 worker trips	4-16 lanes throughout	50% still cannot be achieved
Infinite Development			
5. Central areas at 30 mile intervals. Industrial and residential units interspersed.	10,860 worker trips	8-11 lanes	50% private car usage can be achieved

TABLE 2.4. TRAFFIC CHARACTERISTICS OF CARTWHEEL AND LINEAR TOWN FORMS

Source: GB.Min.of Housing and Local Government (1965)

Structure	Mileage of Major Roads: Single Carriage-way	Dual Carriageway Low Speed	Dual Carriageway High Speed	No.of Grade-Separated Junctions	Average Internal Work Journey Time for Private vehicle users (Minutes)	Capital Cost per head (3)
Cartwheel 2	30.6	12.8	4.2	8	6.9	282
Single Strand	5.9	6.3	12.6	8	4.5	201
Two Strand I	28.1	4.4	8.9	nil	7.6	191
Two Strand II	32.5	nil	8.9	8	5.8	244
Three Strand	25.2	nil	6.8	6	5.2	180
Four Strand	32.9	nil	7.9	6	5.9	223

TABLE 2.5. COMPARISON OF HIGHWAY REQUIREMENTS, JOURNEY TIMES AND CONSTRUCTION COSTS.

Source : Jameson et al (1967) p.216.

JOURNEY PURPOSE	50% Motorisation	85% Motorisation
Work (Internal)	3 740	6 380
Commuter	6 140	7 030
Firm's Business	750	750
Personal Business and shopping	590	590
School	330	330
Other	2 040	2 040
Commercial Traffic	2 500	2 260
Through Traffic	2 260	2 260
Total	18 350	21 880

TABLE 2.6 MORNING PEAK HOUR PCU's ASSIGNED TO THE MAJOR HIGHWAY NETWORK FOR RUNCORN

Source: Ling (1967)

Settlement	Traffic: Tanner n	Traffic: Modal split	Traffic: Peaking factor	Capital costs in settlements for: 50,000 persons	100,000 persons	250,000 persons: 75 vertices	250,000 persons: 149 vertices
	..		(%)	(£s per head, 1967 prices)			
Rectangular							
Decentralised	0.0	1.6	62	66	80	99	..
	0.0	1.4	73	72	96	122	..
	0.5	1.4	62	60	86	105	..
	0.5	1.4	73	70	93	114	..
	1.0	1.4	73	70	90	110	..
Partly centra-lised	0.0	1.6	62	..	91	114	..
	0.5	1.6	62	..	86	111	..
Centralised	0.0	1.6	62	90	98	..	..
Star							
Decentralised	0.0	1.6	62	88	107	..	123
Partly centra-lised	0.0	1.6	62	..	99	..	119
	0.5	1.6	62	..	99	..	113
Centralised	0.0	1.6	62	104	114	..	..
Linear							
Decentralised	0.0	1.6	62	80	101	126	121
	0.5	1.6	62	..	..	115	114
Partly centra-lised	0.0	1.6	62	80	105	..	117
	0.5	1.6	62	..	100	..	113
Centralised	0.0	1.6	62	98	111	..	..

TABLE 2.7. CAPITAL COSTS OF MAIN ROADS IN RECTANGULAR, LINEAR AND STAR SETTLEMENTS.

Source: Stone (1973) p.87.

Settlement	Tanner n	Modal split[b]	Peaking factor	Travelling costs[a] in settlements for: 50,000 persons	100,000 persons	250,000 persons 75 vertices	250,000 persons 149 vertices
Rectangular[c]			(%)	(£s per head, 1967 prices)			
Decentralised[d]	0.0	1.6	62	35[e]	41	60	..
	0.0	1.4	73	39	47	70	..
	0.5	1.4	62	36	45	65	..
	0.5	1.4	73	36	45	65	..
	1.0	1.4	73	30	41	56	..
Partly centralised[f]	0.0	1.6	62	..	46	68	..
	0.5	1.6	62	..	42	63	..
Centralised[f]	0.0	1.6	62	38	47	..	..
Star[g]							
Decentralised	0.0	1.6	62	40	54	..	75
Partly centralised	0.0	1.6	62	..	50	..	76
	0.5	1.6	62	..	47	..	70
Centralised	0.0	1.6	62	40	50	..	..
Linear[h]							
Decentralised	0.0	1.6	62	42	57	97	84
	0.5	1.6	62	..	..	88	75
Partly centralised	0.0	1.6	62	39	55	..	81
	0.5	1.6	62	..	52	..	73
Centralised	0.0	1.6	62	40	52	..	..
	0.5	1.6	62	..	51	..	..

TABLE 2.8. ANNUAL TRAVELLING COSTS IN RECTANGULAR, STAR AND LINEAR SETTLEMENTS.

Source: Stone (1973) p.126

Settlement[b]	Costs with modal split (PCU) 1.6[c]	4.0[d]	Reduction in costs[e]	
	(£)	(£)	(£)	(%)
50,000 persons				
Linear	80	58	22	28
100,000 persons				
Linear	101	68	33	33
Star	107	83	24	22
250,000 persons				
Linear	121	74	47	39
Rectangular	99	54	45	45

TABLE 2.9. MAIN ROAD CAPITAL COSTS PER HEAD OF POPULATION: THE EFFECT OF MODAL SPLIT.

Source: Stone (1973) p.140.

£ thousands, 1967 prices

Settlement	Cost of road[a]	Cost of crossings[b]	Total cost
Star[c]	372	78	450
Linear[c]	283	59	342
Rectangular[c]	266	78	344
Runcorn[d]	265	111	376

TABLE 2.10. BUS-ONLY ROADS: CAPITAL COSTS PER 10,000 POPULATION.

Source: Stone (1973) p.141.

	Individual settlements			Cluster of 5 linear settlements
	Star	Linear	Figure 8	
	(£ millions)			
Land	1.35	1.23	0.87	1.02
Track	37.61	33.57	26.36	27.04
Bridges	4.98	4.73	2.35	4.20
Yards and repair shops	2.52	2.52	2.52	2.52
Stations	2.58	2.52	1.05	2.34
Signal equipment	6.47	5.78	4.54	4.65
Power supply	2.02	1.80	1.42	1.45
Total net cost	(57.53)	(52.15	(39.11)	(43.22)
Engineering design	6.90	6.26	4.69	5.19
Rolling stock	4.92	4.92	4.92	4.92
Total cost	69.35	63.33	48.72	53.33
	(£)	(£)	(£)	(£)
Capital costs per head	277	253	195	213
Capital costs per head excluding rolling stock	258	234	175	194

TABLE 2.11. CAPITAL COSTS OF A RAILWAY IN A PARTLY CENTRALISED SETTLEMENT FOR 250,000 PERSONS.

Source: Stone (1973) p.146.

million passengers

Item	1973	Scenario 1990			
		I	II	III	IV
(1)	(2)	(3)	(4)	(5)	(6)
Heathrow	20.3	38	38	38	38
Gatwick	5.7	16	16	16	25
Stansted	0.2	-	16	4	4
Luton	3.2	-	10	3	3
Maplin	-	28	-	-	-
Diversion from London airports	-	-	5	24	-
Total	29.4	82	85	85	85

TABLE 2.12. AIR PASSENGER TRAFFIC ALLOCATIONS AT LONDON AIRPORTS.

Source: G.B. Dept. of Trade (1974) p.17.

million passengers

Item	Scenario (1990)				
	IV	I	II	III	IIIB
(1)	(2)	(3)	(4)	(5)	(6)
(i) London airport passenger demand (assessment figure)	84.2	84.2	84.2	84.2	84.2
(ii) Passengers allocated to London airports	84.2	80.1	78.9	60.1	60.8
(iii) Net diversion away from London airports ((i)-(ii))	-	4.1	5.3	24.1	23.4
(iv) Net gains by -					
Channel Tunnel	-	0.7	0.1	2.5	3.0
Bournemouth, Birmingham and East Midlands airports	-	2.8	5.2	21.1	18.3
Other airports	-	0.6	-	0.5	2.1
Total	-	4.1	5.3	24.1	23.4

TABLE 2.13. DIVERSION OF AIR TRAFFIC FROM LONDON AIRPORTS TO CHANNEL TUNNEL AND OTHER AIRPORTS.

Source: G.B. Dept. of Trade (1974) p.23.

	Millions of passengers per annum								
	A	B	C	D	E	F	G	H	J
Heathrow	30	38	38	38	38	38	38	53	53
Gatwick	16	16	16	25	16	25	25	25	25
Stansted	1	1	4	4	16	16	16	16	16
Luton	3	3	3	3	3	5	10	5	10
Total	50	58	61	70	73	84	89	99	104
Year in which capacity fully utilised:									
High Forecast	1981	1983	1984	1986	1986	1987	1988	1989	1990
Low Forecast	1986	1988	1989	<——— after 1990 ———>					

Notes:

Development A : Represents the capacity of the airports when the current developments at Heathrow and Gatwick are completed.
Development B : Provides for the addition of a fourth, south-side terminal at Heathrow.
Development C : Includes the expansion of the present facilities at Stansted.
Development D : Includes a second terminal at Gatwick.
Development E : Covers Gatwick with a single terminal, but with Stansted at a comparable size to Gatwick as the result of the maximum development within the existing airport boundaries.
Development F : Provides for a second terminal at Gatwick, the expansion of Stansted and an increase in the traffic at Luton to the extent which the airport authority consider should be possible using the present facilities.
Development G : Includes a second terminal at Luton.
Development H : Includes the provision of a fifth terminal at Heathrow on the Perry Oaks site.
Development J : Represents the combination of all the above developments.

TABLE 2.14 DEVELOPMENT SCENARIOS FOR EXISTING LONDON AIRPORTS

Source : G.B. Dept. of Trade (1975a) p.5.

1975 Net Present Value £million

	Case A	Case B	Case C
Investment costs	+ 5	- 5	- 51
Aviation costs	+29	+63	+228
Passenger costs	-20	+ 1	+131
Consumer surplus loss	-	+11	+ 94
Employment benefit (Assisted Areas)	-12	- 3	- 9
Total net cost	+ 2	+67	+393

Costs +
Benefits -

Case A - Regional airport subsidies
Case B - Passenger charge at London Airports
Case C - Constraints on London passenger throughput

TABLE 2.15 A SUMMARY OF RESOURCE COSTS FOR REGIONAL DIVERSION OF AIR TRAFFIC.

Source: GB. Dept. of Trade (1975a)

£million (1979 prices, excluding interest)

Item	Initial commitment (for 15mppa capacity)	Additional costs to provide for 25mppa capacity	Additional costs to provide for 50 mppa capacity
Site acquisition and relocation of defence establishments	20	-	-
Site preparation	20	20	65
Construction of airport and atc facilities	245	205	450
Road access	15	20	20
Rail access	85	15	70
All items	385	260	605

Costs are rounded to the nearest £5 million.

* Excludes secondary relocation costs.

TABLE 2.16 ESTIMATED ATTRIBUTABLE CAPITAL COSTS: STANSTED

£million (1979 prices, excluding interest)

Item	Initial commitment (for 15mppa capacity)	Additional costs to provide for	
		25 mppa capacity	50 mppa capacity
Site acquisition and relocation of defence establishments	260*	-	-
Site preparation	75	5	40
Construction of airport and atc facilities	295	200	445
Road access	110	5	5
Rail access	160	20	85
All items	900	230	575

Costs are rounded to the nearest £5 million.

* Excludes secondary relocation costs.

TABLE 2.17. ESTIMATED ATTRIBUTABLE CAPITAL COSTS : MAPLIN FOULNESS

Hoggeston	220
Yardley Chase	475
Langley	220
Stansted	-
Willingale	260
Maplin (Foulness)	240
Maplin (Sands)	240

TABLE 2.18. THIRD LONDON AIRPORT SITES - DEFENCE COSTS (£m. 1979 PRICES.

Source : G.B. Dept.of Trade (1979a) p.67.

	Journey times to M25 (minutes)	Stage 1 (15mppa) £million	Stage 2 (25mppa) £million	Stage 3 (50mppa) £million
Hoggeston	28	55	20	15
Yardley Chase	42	95	30	5
Langley	28	25	15	10
Stansted	16	15	20	20
Willingale	13	30	5	10
Maplin	32	110	5	5

TABLE 2.19. THIRD LONDON AIRPORT SITES - ROAD TRAVEL TIMES AND COSTS

Source: G.B. Dept. of Trade (1979a) p.67.

	Stage 1 £million	Stage 2 £million	Stage 3 £million
Hoggeston ML/LBL	55/140	15/20	70
Yardley Chase ML/LBL	50/185	20/20	85
Langley	100	20	95
Stansted	85	15	70
Willingale	80	15	50
Maplin	160	20	85

Note:
The costs for Hoggeston and Yardley Chase depend on whether the rail link is provided via the Midland Line (ML) or the London-Banbury Line (LBL) of British Rail. The ML option is not available at Stage 3 without major additional investment.

TABLE 2.20. THIRD LONDON AIRPORT SITES - RAIL ACCESS COSTS

Source: G.B. Dept. of Trade (1979a) p.68.

	Stage 1* £million	Stage 2 £million	Stage 3 £million
Hoggeston	390	240	475
Yardley Chase	360	225	495
Langley	370	245	510
Stansted	285	225	515
Willingale	350	215	490
Maplin (Foulness)	390	205	485
Maplin (Sands)	395	205	485

* A notional figure of £20 million for site acquisition has been included in all cases except Maplin Sands.

TABLE 2.21. THIRD LONDON AIRPORT SITES ROAD TRAVEL TIMES AND COSTS

Source: G.B. Dept. of Trade (1979a) p.68.

Site	Preparation period (years)	Expenditure period prior to opening the airport (years)	Overall lead time from decision to principle to opening airport (years)
Hoggeston	6	6	12
Yardley Chase	7	6	13
Langley	5	6	11
Stansted	4	4	8
Willingale	6	5	11
Maplin*	7	10	17

* Includes both Foulness Island and Maplin Sands sites

TABLE 2.22. THIRD LONDON AIRPORT SITES - ESTIMATES OF LEAD TIMES.

Source : G.B. Dept. of Trade (1979a) p.69.

Site	Lead Time (Years) (Phase I)	Capital Costs (£m 1979) Phase I	Phase II	Phase III
Hoggeston	12	720	272/280	560
Yardley Chase	13	980	275	585
Langley	11	715	280	615
Stansted	8	385	260	605
Willingale	11	720	235	550
Maplin	17	900	230	575

TABLE 2.23 THIRD LONDON AIRPORT SITES - CAPITAL COST VS.LEAD TIME

Source: GB.Dept. of Trade (1979a).

Scenario	Demand mppa	Demand ATM's	Relative probability
1	190	660	0.04
2	170	480	0.07
3	140	420	0.33
4	110	360	0.35
5	70	260	0.21

TABLE 2.24. SECOND SYDNEY AIRPORT STUDY - RELATIVE PROBABILITY OF DEMAND SCENARIOS.

Source: Carruthers 1980

Site	Lay-Out	Net Cost for Scenario 1	2	3	4	5	Expected Cost	Maximum regret
Town Point	CSP	107	72	10	0	0	6	107
Town Point	2x2	971	795	590	531	212	520	971
Wattamolla	CSP	264	212	85	43	7	63	264
Wattamolla	WSP	366	286	117	62	11	91	366
Long Point	CSP	43	0	0	8	10	0	43
Long Point	VEE	184	80	49	36	13	38	184
Bringelly	WSP	269	188	63	42	1	60	269
Badgery's Creek	CSP	263	215	104	57	9	75	263
Badgery's Creek	WSP	346	267	133	76	13	99	346
Badgery's Creek	3	70	328	177	116	29	124	328
Duffy's Forest	CSP	N/C(2)	N/C	N/C	45	12	N/C	N/C
Prospect	CSP	364	309	156	107	25	135	364
Prospect	WSP	471	410	230	176	53	190	471
Prospect	VEE	281	172	106	62	12	76	281
Marsden Park	CSP	184	137	63	43	3	47	184
Marsden Park	WSP	321	154	126	87	18	100	321
Marsden Park	VEE	318	235	132	96	21	104	318
Marsden Park	3	0	277	151	115	35	110	277
St Mary's	VEE	442	341	188	125	26	146	442
Richmond	CSP	395	343	206	153	48	165	393
Richmond	WSP	513	431	251	184	56	203	513
Richmond	VEE	524	430	268	202	64	217	524
Richmond	3	198	437	270	207	68	208	437
Blue Gun Creek	CSP	291	343	134	101	35	109	291
Blue Gun Creek	WSP	342	269	142	100	23	113	342
Blue Gun Creek	3	55	326	177	128	35	129	326
Rouse Hill	CSP	296	244	101	71	17	84	296
Rouse Hill	WSP	447	394	175	118	26	143	447
Galston	CSP	197	156	73	57	22	61	197
Galston	WSP	408	345	204	171	63	174	408
Galston	VEE	450	349	214	175	63	161	450
Somersby	WSP	861	853	478	331	90	380	861
Wyong	WSP	1295	1139	656	461	133	531	1296
Badgery's Creek	2x2	32	321	184	133	41	133	321
Marsden Park	2x2	2	294	163	123	38	119	294
Richmond	2x2	106	410	249	180	55	183	410
Blue Gun Creek	2x2	57	330	175	125	36	128	330
Towra Point	CW	447	319	178	106	39	138	447
Towra Point	CW	981	724	550	482	158	467	981
Wattamolla	CW	368	203	128	103	49	111	363
Badgery's Creek	CW	478	440	267	207	68	218	478
Badgery's Creek	CW	247	445	258	185	60	197	445
Duffy's Forest	CW	N/C	N/C	N/C	83	31	N/C	N/C
Prospect	CW	441	340	205	164	62	173	441
St Mary's	CW	490	419	235	162	43	187	490
Richmond	CW	671	401	359	266	90	279	671
Blue Gun Creek	CW	505	441	269	202	69	218	505
Somersby	CW	1072	944	536	396	127	445	1072

CSP Closed spaced parallel runways — VEE 2 Perpendicular runways
2x2 Two pairs wide spaced parallel runways — 3 2 in line + third in para.
WSP Wide spaced parallel runways — CW Cross wind runway

TABLE 2.25. SECOND SYDNEY AIRPORT STUDY - RESULTS OF SCHEDULE SELECTION METHOD

Source : Carruthers (1980) p.8.

CHAPTER 3

THE PLANNING OF TRANSPORT INFRASTRUCTURE - STRATEGIES AND TECHNIQUES

3.1. THE RELATIONSHIP BETWEEN STRATEGY AND TECHNIQUE

3.1.1. The characteristics of transport and infrastructure are not easily assessed within the confines of the techniques currently used in practice. In chapter 1 it was shown that the basic techniques have changed little since their introduction thirty years ago. As such they are ill-suited to the effective appraisal of uncertainty and ill-equipped to describe the mechanisms of changes in travel demand. Similarly they are unable to assess the resistance to change caused by the characteristics of infrastructure detailed in chapter 2.

3.1.2. According to Atkins :

> 'practical applications of the so-called "second generation" (disaggregate) or even "third generation" (behavioural) models in the UK are still rare.'[1]

These more advanced techniques are generally more complex and require extensive data which is often unavailable and these factors may preclude their use. The first generation of transportation models based on static comparisons may be simplistic, but they have relatively few data requirements and are easy to apply.

3.1.3. However, although the practical application of more appropriate transport planning techniques may be rare, research has been undertaken which deals more directly with the processes of change rather than discrete comparisons. This will be considered in the second half of this chapter. The quantitative measures of scale, lead time etc. described in section 2.4. are relatively simple. Therefore it remains to identify a methodology of assessment which is sympathetic to their use.

3.1.4. Although the technical assessment of the constraints of infrastructure is desirable, alone it is insufficient. In both the previous chapters the importance of policy and strategy in determining infrastructure choice was emphasised. In fact, the infrastructure option is potentially only one of a range of available options for policy implementation. Traffic management or public transport subsidy may be regarded as an alternative to large scale highway construction. Similarly, expansion of existing airports may be preferred to the extensive capital works required at a totally new site.

3.1.5. Rarely will alternative strategies be so polarised. In practice, transport programmes will rely on a combination of measures each with varying commitments to capital works. The question remains to what extent should the strategy be dependent on infrastructure investment? The answer will often be determined by the formulation of the problem and it is at this very early stage that the issues of flexibility should be considered.

3.1.6. Prior to the analysis of suitable transport planning techniques it is therefore important that the issues of policy are clearly examined. At this level of decision-making, planning is obviously at its most political and the relevant policy and decision-making theory will be considered in section 3.2. The issues of scale and flexibility will be considered not only in terms of project implementation but also their administration. It is only within a responsive planning framework that the use of techniques orientated towards a transport planning 'process' will be effective.

3.2. THE RESOLUTION OF CONFLICT IN TRANSPORT DECISION-MAKING

3.2.1. The breakdown of the political consensus which supported rational-comprehensive planning was described in chapter 1. The relationship between the technical elements of transport planning and the formulation of transport policy was effectively redefined. Transport decisions were no longer the logical conclusion of an objective planning process, but could themselves set the terms of reference for technical analysis. The implications of the increased politicisation of policy formulation were described by Schon.[2] Not only did it signify an increase in pressure group activity by those wishing to influence decision-makers. It also increased the need for public learning, as policy was no longer based on the assumptions of rational processes but on the values of policy makers themselves.

3.2.2. Schon described the breakdown in consensus as the loss of the stable state. Policy rested no longer on the superficially coherent identity of rationality, but was more heavily influenced by values and preferences. However, this rationality has been regarded as a facade, the technical representation of planning being an erroneous diversion.

Self argued that such misrepresentation was responsible for the failure of the planning process when applied to important issues such as the third London airport. He described planning as 'co-ordinated policy arrangement' and attacked the holistic application of cost benefit analysis as a 'bogus technical issue.'[3]

3.2.3. Transport planning thus had to embrace a situation where there existed greater potential choice and variation in policy formulation while still retaining the basic techniques required for implementation. Faludi described this conflict as one between rational comprehensive planning and Disjointed incrementalism.[4] In order to resolve the competing interests which lobbied decision makers, a new perspective on planning was required. Given the social status and class of the professionals and activists involved, it was not surprising that the pluralist theory of American policy analysts was most often declared the most suitable. Hall commented:

> 'Marx's proletariat and bourgeoisie are not the contenders in most of the battles we have been studying.'[5]

3.2.4. In his analysis of planning disasters Hall developed a highly eclectic prescription based on game theory. Politicians, the bureaucracy and the community were viewed as participants in the policy process. Each group possessed its own values and objectives which could be expressed in the form of a matrix. The objective of planning then became a strategy which could resolve this matrix by satisfying at least in part, the desires of each of the groups involved. The strategies of the bureaucracy (conservatism) and community groups (pressure for change) were viewed as competing forces which act on politicians. When pressure groups were successful in their lobbying, the system became unstable, which resulted in the policy reversals which were characteristic of many large scale planning failures.[6]

3.2.5. In relation to transport planning as a process, Hall's approach can be used to explain the variations in policy and decision-making over time. It can also accommodate the conservatism of the bureaucracy as a technique which furthers that group's vested interest in a particular outcome. Hall cites the long held preference of Stansted for London's third airport, now realised, as an example. However, as a scheme it passes no judgment on the end product of the process, particularly in relation to uncertainty. The resolution of the conflict will result in a solution which possesses a minimum utility in that it satisfies one or more of the groups concerned. Thus the sensitivity of a particular choice to changes in community preferences, due to some external shock to the system is not assessed.

3.2.6. There is an inherent assumption within the game theory approach that the balance of interests will ultimately result in a 'sensible' solution. Yet this in turn assumes that each group possesses equal power to cause change. This is clearly not the case, although it is a problem for any approach based on the free interaction between interested groups, particularly the politicians and the bureaucracy who usually set the rules for the game.

3.2.7. The distribution of power is also a potential problem for the political analysis of Braybrooke and Lindblom. In developing the theory of 'Disjointed Incrementalism' they delivered a detailed criticism of rational comprehensive planning. This criticism included eight fundamental points which portrayed the 'synoptic' ideal as too optimistic given:

1. our limited problem solving capacity.
2. the inadequacy of information
3. the cost of analysis
4. the difficulties of evaluation methodology
5. the close relationship between fact and value
6. that systems are generally open rather than closed
7. the need for strategic sequences of analytical moves
8. the diverse forms in which policy problems arise.[7]

3.2.8. These criticisms reflect many of the shortcomings of transport planning described in chapter 1. Lindblom then put forward the processes of partisan mutual adjustment and as an alternative policy-making paradigm to that which claimed to be based on rational analysis. Each of the participating groups sought to maximise their own objectives based on their own values. However, through negotiation, groups would mutually adjust and a compromise would be found from the conflict and multiplicity of values. In order that this process should be continuous and because of the other technical sources of error in decision-making such as in the lack of information or the evaluation method, alternative policies should differ only incrementally from each other and from the status quo.

Choice is made through a comparison of these differences and becomes serial, remedial and reconstructive. Policy is then a series of decisions which continually seek to remedy previous errors.

3.2.9. In a transport planning context, Hart summarised the implications of Disjointed Incrementalism as follows:

1. It reduces the amount of information required
2. It reduces the reliance upon theory
3. It reduces the need to clarify objectives and empirically strategise.[8]

Such a strategy could be considered the antithesis of planning as the emphasis is on correcting past errors rather than creating an improved future state. Such an opposition to conventional forms of planning is no reason for rejecting this strategy, providing that it can effectively deal with the issues involved, in this case the development of transport infrastructure. However, the commitment that is required for infrastructure investment may be incompatible with the processes of partisan mutual adjustment.

3.2.10. Thus there are three critical areas which must be further investigated before the contribution of Disjointed Incrementalism to transport decision making may be ascertained. They may be categorised as:

1. The irreversibility of infrastructure commitments
2. The distribution of power between partisans
3. The means and ends of policy making.

3.2.11. Incremental changes are not easily achieved when implementing infrastructure projects. Even if such changes can be achieved, they may not be susceptible to control under the incrementalist strategy:

> 'Are small changes necessarily reversible? The incrementalist model assumes that they are but this is not necessarily so. How often do we obliterate a motorway however small?[9]

However, potential reversibility of decisions is not the only tactic available under this strategy. The serial and reconstructive nature of incrementalism implies that policy is constantly seeking to ameliorate the errors of past decisions. Given the permanency of infrastructure once in place, complete amelioration must be considered unlikely. However, unforeseen consequences of highway construction can often be tempered by traffic management measures.

3.2.12. An alternative tactic, that of prevention is more plausible. Given that policy-making is subject to error and non-incremental decisions may prejudice the continued operation of partisan mutual adjustment, emphasis should be placed on those policies and projects which minimise potential errors. This approach was adopted by Collingridge[10] in applying the incrementalist model to technological decision-making. From a series of alternative strategies preference should be for that which minimises the commitment to infrastructure, or is the least 'capital intensive'. It will require less future commitment and therefore be more easily superseded should it be found to be in error. Therefore, it not only seeks to minimise error, but also to reduce the costs associated with it.

3.2.13. An alternative to the rigorous application of the incrementalist model is to adapt and extend it so that it encompasses a greater range of decision-making situations. Lindblom himself stated that partisan mutual adjustment was useful in some situations and not in others.[11] The strategic development of infrastructure is one area where the incremental decision-making may not be possible, at least in its simplest form.

3.2.14. Etzioni suggested a third approach to decision-making that combined both the incrementalist and rational models. Mixed scanning[12] assumed that for certain problems, a consensus was required which could not be achieved by the interaction of partisans. This was provided by a higher level planning framework. Within this framework the incremental decisions would be taken in anticipation of those more fundamental policies at the higher level. Thus policy-making proceeded via the constant interaction between these two levels of decision-making.

3.2.15. In a more detailed treatment of this approach[13] Etzioni acknowledged that at the strategic level, decision-making was dominated by normative and political factors. However at the incremental level, technical competence was more important and rationality was likely to play a greater role. Thus strategic policy has formulated through the political choice of technically derived alternatives. This differed significantly from the rationalist model where the comprehensive ideal assumed rational choice even at the highest level. It also differed from partisan mutual adjustment where incremental policies were achieved through negotiation and bargaining of the desires of interested groups.

3.2.16. Schulman accepted the incrementalist model within its limitations. However he advocated an extension of the theory to cater for the analysis of major projects where incremental analysis could not plausibly explain some of the phenomena observed:

> 'These are enterprises distinguished by their demand for comprehensive rather than incremental decisions; synoptic rather than piecemeal outlooks and vision. These policies are characterised by an indivisibility in political commitment and resources they require for success.[14]

3.2.17. Schulman described some of the characteristics of these enterprises. They had a long start-up period which involved checking the feasibility of the project as well as assembling the necessary resources. They also required a consensus of support so as to overcome the threshold between incrementalism and non-incrementalism. However, non-incremental policies often exhibited instability and were not considered susceptible to steady state analysis because of the large concentration of resources required. This concentration could not be achieved through the aggregation of smaller-scale decisions because of the indivisibility of research and technical appraisal necessary. Urban transportation was considered to be one such area where non-incremental decisions were required.

3.2.18. The second critical issue for the incrementalist model concerns the distribution of power between interested groups. If one group achieves an inordinate level of power, the process of partisan mutual adjustment may break down, as such a group will have less need to negotiate policy and hence it will become representative of one partisan group, however great the claims of others. Lindblom himself analysed this problem at some length and did not advocate equality between partisans:

> '... in any system of partisan mutual adjustment, the weights given various values from one decision-making situation to another, and the weights in one situation will often correct deficiencies in earlier weights.'[15]

Hence the remedial processes of partisan mutual adjustment constantly readjust the weights given to the values of partisans to the long stability of the decision-making process.

3.2.19. Furthermore, Lindblom considered the more widely shared, and the more intensely held preference, the greater its weight in the decision-making process. The views of those having special concern with the issue under consideration were also considered to achieve greater influence in the process. However, policies or programmes that are non-incremental confer extra power on those responsible for them. If a strategic decision is taken to construct a major new inter-urban highway, then the future tactical decisions that will be necessary will be subject to limited negotiation as the outcome will be determined to a large extent by the strategic policy that already exists.

3.2.20. The direction given to policy making that is achieved by such strategic decisions relates to the third critical issue for incrementalism, the overall purpose of decision-making. A criticism of incremental decision-making is that it makes no attempt to anticipate a desirable future as there are no explicit policy objectives. Thus the means by which decisions are made, partisan mutual adjustment, becomes the ultimate goal. In fact, the incrementalist model assumes that societal goals are more likely to be achieved through the expressions of preference by partisans in the decision-making process, rather than a set of objectives defined by a centralised authority.

3.2.21. Thus the concept partisan mutual adjustment should be considered similar to that of flexibility described in chapter 2. As a means by which the results of the decision-making process are left open to future adaptation. This requirement is necessary because decisions will usually involve some error and in addition, there are likely to be some future 'shocks' which will cause a reappraisal of policies and programmes.

3.2.22. Partisan mutual adjustment describes the activity associated with many decision-making situations that occur in the UK. It may be observed at any public inquiry where interested groups put forward their views and cross-examine witnesses of competing interests. It is at this level that the technical content is at its highest as partisans assemble evidence in support of their case. Whether all this activity affects the non-incremental nature of decisions regarding infrastructure for roads or airports is less certain. Such inquiries relate only to the implementation of policy. The policy itself is formulated at a higher political level.

3.2.23. Strategic policy making involves less technical evaluation and is subject to greater political influence. Thus it cannot be consistent with the rationalist model. However, the absence of rationality makes it no less strategic. A strategy implies a mode of operation which embodies a set of values or preferences. As such it sets the framework for the decisions affecting implementation. The influence of such high level strategies was described in chapter 1. From the earliest planners, such as Owen and Howard, through the Modern Movement, Abercrombie, Buchanan to the more recent overall emphasis on public transport, each has set a framework within which planning has operated.

3.2.24. Kuhn described the impact of such 'gestalts' in the scientific community.[16] The direction of scientific research was governed by a dominant 'paradigm' or prevailing theory. The results of such research would highlight inconsistencies in theory which were accumulated over time resulted in a crisis for the dominant paradigm. At this point a new theory would emerge to challenge and ultimately usurp the old, setting a new context for research.

3.2.25. However, planning theory cannot be subjected to the rigorous tests of validity that determine the acceptance or rejection of scientific theories. Therefore there is no guarantee that each successive strategic framework is any better than the one it replaces. This lack of validity for strategic planning theory was one of the factors influencing Popper's[17] choice of piecemeal reform as the method by which such theory should advance. The benefits of 'social engineering' could not be ascertained with any certainty and were likely to constrain future freedom of choice.

3.2.26. The philosophy of Popper is often cited in support of the incrementalist model of policy making. As such it faces similar difficulties in dealing with the rigidities of infrastructure. Ironically, one of the problems affecting incremental change is the presence of consensus, a necessary requirement of the rationalist model. Partisan mutual adjustment specifies no criteria by which the output of decision-making processes should be judged. Thus if a consensus exists, and no adjustment between partisans occurs, major strategic initiatives may be allowed to proceed. However, their efficacy as a solution to the problem under consideration cannot be verified without hindsight.

3.2.27. Thus the processes of partisan mutual adjustment may not satisfactorily operate for certain strategic decisions. The new towns programme in the UK and more recently the completion of the M25 motorway around London are examples of major projects which proceeded with very little opposition. The adverse impacts of these schemes could not possibly be foreseen at the time the decision was taken, yet the presence of consensus did not in itself validate them as correct solutions.

3.2.28. If the results of decisions are to be subject to some criteria such as Popper's preference for piecemeal reform, or Collingridge's preference for minimal commitment to infrastructure, they imply a set of criteria which should be applied to policy making over and above the processes of partisan mutual adjustment. If such criteria are to be accepted then some form of evaluation method is still required.

3.3. THE SYSTEMS APPROACH

3.3.1. Although transport planning decisions ultimately depend on political processes, there are technical analyses of any problem which provide the information in support of decisions at each stage of scheme and/or policy implementation. The incrementalist approach of Lindblom and others reduces the dependency of decisions on this technical support although it is considered a necessary element of the debate between partisans. However, transport planning techniques are often more important than this would suggest, as it is through their standard application that power is vested in transport authorities. An explicitly partisan approach is also less likely to gain acceptance from those professionals engaged in transport planning as they themselves are partisans with a vested interest in such standard techniques.

3.3.2. An alternative strategy involves increasing the dependency on technique. Rather than stressing the political and partisan nature of strategic planning, the field of technical application may be extended to include evaluation and the assessment of uncertainty. This 'scientific' approach to the management of transport programmes may be considered as part of a broader 'systems' approach to planning. The modelling of systems through mathematical relationships is only a part of this broader systems viewpoint.

3.3.3. The systems view of planning has its roots in the 1960's when it was applied at a variety of levels from urban district to regional and national. As a result of systems analysis, certain projections of the future could be made which would provide the basis for the formulation of policies designed to achieve pre-determined goals. The implementation of the policy would invoke some change in the system, either that predicted or, more likely, some different state. The difference between the projected and realised states would, via feedback alter the conception of the system, its future projections and the resulting policies. Although the process was designed to be continuous, it involved:

> 'the choice of those future states of a system which are thought to yield optimum conditions, as described by reference to criteria derived from the goals of the system.'[18]

3.3.4. Despite claims concerning its continuity, basic systems analysis contained a paradox. While the importance of time and uncertainty was acknowledged by the use of feedback, it also contained a static element based on traditional rationality. This was apparent from the concepts of maximum utility and optimality which were endemic to the process, yet would never be achieved because of the need for feedback.

3.3.5. Friend and Jessop applied the concepts of systems analysis to strategic Decision-making at the level of local government.[19] Rather than a single homogeneous system or the tripartite approach of Hall, they considered the interaction between two systems, the Government and the community. (Fig.3.1.). The Government field contained politicians initially, but it gradually expanded to encompass the bureaucracy as more information was required to inform and support decisions. The governmental system perceived trends and problems in the community system, derived and appraised alternative solutions and subsequently implemented policies to ameliorate the problems and anticipate the trends. The community then adjusted to the new initiatives so altering trends and creating new problems. Again it was a cyclic process.

3.3.6. Three types of uncertainty were acknowledged; those pertaining to the external environment (UE), value judgements (UV) and related fields (UR). UE referred to the uncertainties inherent in the technical planning process where trends or impacts could not be accurately predicted and UV related to the uncertainty of community preferences. However, it was with UR, the uncertainty in related decision fields that the process became one of strategic choice or planning.[20]

The possibility that a decision in one field would affect that made in another gave rise to the need to plan or coordinate.

3.3.7. Therefore, the presence of uncertainty in decision-making enhanced the need for coordination in planning activity. As such it resulted in a technocratic approach which sought to extend the rationality of technical planning into the evaluation and decision-making phase of the process. Proponents of evaluation techniques such as Cost Benefit Analysis and the Goals Achievement matrix suggested that they were designed to assist rather than determine choice. Williams[21] considered CBA as one element of a feedback loop which existed within the decision-making framework defined by Lindblom. Similar claims were made on behalf of decision theory which aimed to analyse uncertainty.

3.3.8. However, CBA and other techniques have been presented in a much more deterministic manner. The COBA (Cost Benefit Analysis) programme used in the assessment of British trunk road schemes is regarded by the Department of Transport as the standard technique for the economic evaluation with very few exceptions. Furthermore, increased objector activity in the 1970's led the Government to announce that policy matters could not be challenged at public inquiries. National traffic forecasts themselves were regarded as policy, as was the use of COBA and hence only their application, rather than assumptions, could be challenged.[22]

3.3.9. Such standardisation of techniques, although designed to achieve consistency between public inquiries, served to strengthen the position of the bureaucracy. In fact the increase in the technical elements of transport planning process required a large bureaucracy to administer them. Hence an increasingly technical transport planning perpetuated the need for the technical bureaucracy. Once entrenched, standard methodologies become difficult to change because it is normally in the interests of the bureaucracy for them to continue. Furthermore, because of the difficulty in proving that any new methodology is better than existing techniques (c.f. 3.2.25) new ideas will rarely be adopted. The possibility that in some cases no technique at all may be the best option will not be considered.

3.3.10. It is thus that bureaucracies appear to acquire an inertia which is impervious to criticism. Schon described this characteristic as dynamic conservati [23] The bureaucracy was conservative in terms of political and social change yet the solutions to transport problems that were generated by the application of standard techniques (i.e. major infrastructure works) would in themselves cause major change in the environment of the transport system. Vickers adopted a similar viewpoint. Bureaucrats tended to be:

> 'wildly radical in matters that concern our own change of our (physical) environment and rigidly conservative in the social matters that determine our adaptation of it.'[24]

3.3.11. It is this physical radicalism that adds further inertia to the operation of the technical bureaucracy. The investment programmes implemented would require technical support over many years. Emphasis on such a programme together with government policy on road traffic forecasts reduces uncertainty over future developments.

3.3.12. A branch of systems analysis which hitherto has received little attention in the transport context is System Dynamics. This branch of systems thought seemingly holds possibilities for dealing particularly with the problems of 'static' large scale planning because of the emphasis on change. The use of systems analysis described so far, although incorporating the idea of 'process', is still rigid in terms of the plans and projections generated because of its continued orientation to traditional, rational and comprehensive modes of planning.

3.3.13. System Dynamics has been defined as:

> 'A method of analysing problems in which time is an important factor, and which involves the study of how a system can be defended against, or made to benefit from, the shocks which fall upon it from the outside world.'[25]

Based on this definition, the concept of system dynamics would appear to have a contribution to make to the analysis of some of the problems identified in chapters 1 and 2. Time is certainly a problem, because of the long lead times associated with infrastructure investment. As a result, future uncertainty leaves the transport 'system' particularly susceptible to external shocks.

3.3.14. A further important emphasis of systems dynamics is the end objective of any study:

> 'In general a Systems Dynamic study has a two-fold objective :
>
> 1. Explaining the system's behaviour in terms of its structure and policies.
> 2. Suggesting changes to structure, policies or both, which will lead to an improvement in the behaviour.'[26]

Hence two further important aspects: the explicit (and inherent) role of policy, which many analytical approaches treat as an externality. Secondly the importance of system structure (in terms of the variables defined in chapter 2) in determining the operation of the system.

3.3.15. Although System Dynamics was developed as a corporate tool for the planning of industrial manufacturing systems, one of its leading exponents, J.W.Forrester applied the approach much more widely. Moving from industrial to urban to World Dynamics, Forrester attacked a series of problems of increasing scale and complexity. Although one might expect Urban Dynamics to be most relevant to transport planning, the transport system received little attention. More helpful were some thoughts on large scale technological systems contained in Industrial Dynamics.

> 'The dynamic study of such an industry shows how a combination of commonly accepted factors can interact to create a persisting instability'.[27]

3.3.16. Considering that early system dynamics work was concerned with controlling the production of small units - i.e. the products of manufacturing, this consideration of the problems of larger scale inflexible systems is illuminating. The concept of System Dynamics, while addressing some of the problems of infrastructure development is clearly within the comprehensive tradition of planning. However, its more explicit treatment of policy whereby impacts of defined courses may be investigated and the requirements of adaptability, necessary in the corporate and market setting for which it was developed, are attributes which may be beneficial when considering the control of much larger systems. The techniques of systems dynamics will be discussed later in this chapter.

3.3.17. The systems view of planning is clearly within the comprehensive mode of transport planning. Its use is largely appropriate for the comprehensive planning of the large scale system. It could be used to test smaller more decentralised initiatives, but its primary use is for those authorities with centralised control over planning. The system dynamics approach has the advantage of giving prominence to two most important aspects of large scale planning: policy and time. Its assessment of time-dependent change and the influence of policy upon such change is an improvement over the static-comparative pursuit of optimality characteristic of some systems analyses.

3.4. THE TECHNIQUES OF TRANSPORT PLANNING 1 - EVALUATION

3.4.1. The acknowledgement of uncertainty has effected changes in all stages of the transport planning process. In the earlier stages of technical analysis, the input parameters will have been varied to reflect perceived uncertainty. The implications of such variations will become apparent when the output of the modelling phase is evaluated. The costs of each alternative for a scheme will be compared with the range of benefits forthcoming under the various input assumptions. In effect this is a sensitivity test which assesses the robustness of each alternative. As the main input parameters will be economic, it is the economics of each scheme that is acknowledged in uncertainty appraisal. This uncertainty is most commonly reduced to variations in future economic growth. Under high economic growth, demand for the system and hence traffic levels will be greater.

3.4.2. The above description of uncertainty in evaluation methods reflects the current UK practice, particularly that of the Department of Transport in relation to trunk road schemes. The range of sensitivity in benefits is derived from assumptions of low and high economic growth. The method used has developed from a rigid cost-benefit analysis into a more general framework within which economic analysis is only one element. It is however the most important criteria within the framework which also contains information on the impacts on groups of transport users, environmental impact and policy. Environmental impact tends to be insensitive to uncertainty, the intrusion caused by a new road or air-port will vary little with economic growth and the proxies for pollution such as noise are affected little by increases in traffic levels.

3.4.3. Once the range of benefits has been determined, a comparative measure of costs and benefits is required. The Department of Transport prefers a measure of net present value for road schemes, that is the difference between the costs of the scheme and the stream of benefits discounted over the evaluation period (normally 30 years). This measure (npv) has been criticised on a number of grounds, most importantly in this context, because of its tendency to favour large scale schemes. Compared with larger schemes, those on a smaller scale will not normally be able to compete on grounds of npv. Large schemes beget large benefits but not always when compared with cost. Small scale schemes perform better under the criteria of benefit-cost ratio, or net present value-cost ratio.

3.4.4. Consider two alternative schemes, A and B. A costs £15m and has benefits of £30m. B costs £5m and has benefits of £15m. This produces the following cost-benefit measures.

	Scheme A	Scheme B	Scheme A-B
Cost (£m)	15	5	10
Benefits (£m)	30	15	15
npv (£m)	15	10	5
b/c	2	3	1.5
npv/C	1	2	0.5

In this example, scheme A is preferred to scheme B under the npv criteria and scheme B is preferred under benefit/cost ratio, i.e. for every £1m spent, scheme B achieves £3m in benefits whereas scheme A achieves only £2m. Furthermore the incremental cost of A over B, at £10m double that of B itself, produces only £15m in benefits, or as much as B alone. Thus each extra £1m spent on A achieves only £1.5m in extra benefits.

3.4.5. However, it must be possible to pursue further schemes of type B if the extra benefits are to be achieved. Should there be no opportunities for schemes of that type, investment would revert to type A, or some intermediate with a lesser benefit-cost ratio. Thus benefit-cost ratio appears to be a suitable method for ranking schemes within an investment programme. Yet the Department of Transport continues to use npv for scheme ranking. Overall, a strategy to maximise the npv of a fixed budget programme should result in similar schemes as one which seeks to maximise the benefit-cost ratio.

3.4.6. In the road building context, CBA has also been criticised for its technical treatment of aspects of evaluation which could be considered the prerogative of policy makers. The values associated with time and accidents are two areas where empirically derived values are less than conclusive. Similarly, the analysis of the Roskill Commission was criticised for attempting to cost environmental impacts such as the loss of historic buildings or open landscape.

CBA has now largely withdrawn from such controversial valuations and concentrates on those aspects which research has shown to be susceptible to quantification. Although the COBA[28] programme incorporates values of time it is now only one (very important) element of the evaluation framework for trunk road schemes. This framework, based on the planning balance sheet developed by Lichfield,[29] was recommended by the Advisory Committee on Trunk Road Assessment[30] in 1977.

3.4.7. A further criticism of CBA is the emphasis on economic utility. There is an implicit assumption that economic benefit will be society's benefit, yet CBA makes no distinction as to who benefits. This has particular problems from a policy point of view, where policies may be orientated towards specific groups of transport users. CBA makes an explicit assumption concerning policy but although it can be used to measure an aggregate effect of a policy it cannot accurately assess distributive effects.

3.4.8. A further related difficulty for CBA is the use of money as a measure of utility. There is clearly a market mechanism which determines some of the factors in evaluation such as construction cost. For others, money is only a proxy. Whether it can be considered a suitable measuring tool for all factors is debatable. For those not directly quantifiable, a value judgement is implied. This does not necessarily destroy cost benefit analysis. It may be perfectly acceptable to evaluate using value-laden techniques providing assumptions are clearly stated.[31] It is only claims for the objectivity of the technique that suffer.

3.4.9. The other evaluation methodology used to any extent in UK practice relies on matrix-based techniques. Beginning with the Goals Achievement Matrix (GAM) developed by Hill,[32] some local authorities have used 'points scoring' methods to evaluate transport schemes. The matrix used is policy orientated and employs a series of objectives derived from the goals of decision-makers. Schemes are then evaluated against these objectives, being accorded points for the extent to which they further the aims of agreed policies. Each objective is weighted according to the wishes of decision-makers and the scheme or option achieving the most points is the one preferred.

3.4.10. The GAM can be criticised further than CBA in its attempt to apply technique to decision making. However, its reliance on policy can be seen as a stronger emphasis on need than the economic utility of CBA. Certainly where the problem is complex and costs and benefits are difficult to quantify (e.g. in assessing roads in urban areas) its more simple and less rigid format will have advantages. The problem of uncertainty is less difficult to incorporate because of the positive approach related to policy rather than the quasi-objective forecasting used in CBA. However, the impacts of schemes will still vary with e.g. economic growth and the points awarded could be adjusted as a consequence.

3.4.11. One further aspect of evaluation under uncertainty that has been the subject of much research, but little used in practice is Decision-Analysis. One of the problems for Bayesian Decision Analysis is the need for information on the range of uncertainty, particularly the probabilities of each expected scenario. As this information is itself subject to uncertainty, Collingridge defined a further area of 'ignorance'[33] where the expected outcomes could not possibly be known. Certainly others in the field of decision analysis realise the poor level of understanding of possible futures and importantly, the problems of large scale developments in infrastructure:

> 'Fixed capital investment in transport is often effectively irreversible and very expensive. No matter how well conceived the planning process, there are bound to be mistakes; the scenario-based approach is not a panacea.'[34]

3.4.12. Any decision analysis will be based on scenarios, but allied to a goal-orientated approach for generating them, rather than objective probabilities, it may be of use in the pursuit of more flexible policies.[35]

3.4.13. In summary cost benefit analysis creates too objective an image of scheme evaluation. The uncertainties in both future benefits and the value attached to them are not normally recognised. Particularly at the strategic level, transport planning is determined by the policies of decision-making authorities. This is best recognised using a matrix-based assessment technique which explicitly evaluates alternative schemes based upon their compatibility with policy objectives.

3.4.14. Economic evaluation still has a place within such a framework. In fact at the strategic level, some preliminary economic analysis is desirable as the total benefits of a strategy are likely to be less than the aggregate benefits of the individual schemes which constitute that strategy. This is possible because of double counting which may occur where schemes overlap. Within the evaluation framework, benefit-cost ratio could be considered a proxy for the increased risk associated with large scale projects. This would still allow some large projects to proceed should the benefits be sufficiently great in relation to the cost.

3.4.15. A matrix based assessment would allow the incorporation of similar measures relating to other characteristics of infrastructure such as capital intensity, configuration and lead time. In techniques such as CBA these aspects are not easily introduced into the utilitarian equation.

3.5. THE TECHNIQUES OF TRANSPORT PLANNING 2 - TRAFFIC MODELLING

3.5.1. From chapter 1 (Sec.1.3.), one of the important assumptions of the transport planning process was the stability of travel patterns. This was regarded as a pre-requisite of modelling techniques so as to allow accurate forecasts of travel demand to be constructed. Such forecasts were necessary because of the long lead times associated with transport infrastructure projects. However, stability in travel behaviour was also required because traffic models in the past assumed patterns of behaviour rather than explicitly modelling them. Consequently they have not contributed to the understanding of travel behaviour and how changes in that behaviour may be anticipated.

3.5.2. The stagnation in traffic modelling practice is apparent from the continued use of first generation models. However, research into the development of disaggregate and behavioural techniques has meanwhile continued apace. They are generally more sophisticated as they attempt to model patterns of behaviour rather than assume them. They are orientated towards profiles through time rather than cross-sectional appraisal. Such 'dynamic' characteristics may better explain the processes of change. Conversely, they may also be suitable for analysing those characteristics of infrastructure described in chapter 2, in particular, the way in which they inhibit rather than promote change.

3.5.3. One of the primary functions of traffic models is to produce traffic forecasts. They may be forecasts of changes in demand through time or alternatively, predictions of changes in the distribution of traffic within a system, as a result of modifications to the system structure. Despite the problems that have beset forecasting in the past, it is an activity essential to any framework which seeks to evaluate competing transport schemes. However, the likelihood that the forecasting will be in error must also be accepted.
The importance and cost of forecast errors may increase with the size of the system.[36] It is also usually the case that as the scale of the scheme increases, so the decision field

becomes broader and the uncertainty greater. It is therefore ironic that:

> '...if the cost of making a forecasting error is very large, then this normally justifies the costs of setting up an elaborate forecasting machinery and vice-versa.'[37]

3.5.4. Over sophisticated forecasting may be incompatible with the environment of uncertainty that surrounds strategic planning. However, disaggregated techniques which are considered an improvement over current practice are usually more complex and have greater data requirements. Thus there is a conflict when recognising the uncertainty of large-scale planning. Highly disaggregated techniques that are too elaborate may achieve spurious accuracy, yet precision in forecasts is required if improvements in technique are to be verified.

3.5.5. The second major forecasting issue concerns the appropriate treatment of time.

Traffic models such as those used in the studies reviewed in chapter 2 were orientated towards future steady state conditions or equilibrium. They were very useful for their designed purpose and for planning as they:

> '...could be, and were, used for forecasting, but in the comparative static mode. It was assumed that the systems of interest were always in equilibrium, though in practice, of course, this was unlikely to be the case.'[38]

These models were concerned with comparing two cross-sectional states, present and future, rather than with the time dependent mechanisms of change required to reach the future state. It is this latter problem that Dynamic analysis seeks to address.

3.5.6. Dynamics analyses of travel demand have their roots in human geography, mapping patterns of human activity through time. Much of this work is concerned with the micro-level daily patterns of travel behaviour. Although it is recognised that such dynamic trends occur at the macro level,[39] they have been the subject of less investigation.

3.5.7. The essential elements of dynamic models may be classified as:

1. An analysis of the process of change that occurs during the transition between two states A and B, rather than a static comparison of those two states.
2. A representation of change not only with time but also with space.
3. A rejection of equilibrium, absolute space, fixed variables, separation of processes or calibration.[40]

3.5.8. Dynamic analyses of travel demand will usually favour the use of longitudinal data. Such data plots the change in behaviour of individuals through time as they are affected by discrete events, such as moving home or changing jobs, as well as transport policies. The advantage of this approach is that it is causal, pinpointing the events which result in changes in behaviour. This is important because over long-time spans (lifecycles) individuals will shift from one group of transport users to another. Furthermore, the delay in the individual response to these events is an important characteristic of travel behaviour. It is in this emphasis on change in individual circumstances that longitudinal analysis differs from other techniques such as time-series analysis, which concentrates on one variable through time, and cross-sectional analysis which assesses a number of variables at one point in time. The different techniques were represented diagrammatically by Clarke et al,[41] as shown in Fig.3.2.

3.5.9. Whereas longitudinal analysis may be considered dynamic, time series data may be considered static, as it consists of a repetitive series of cross-sectional analyses. However, it is apparent that dynamic analyses of travel demand will require extensive research and development before they may be operationally viable. Given the current state of modelling practices, the use of time series data in appropriate situations may be considered an advance. In the interim, the use of dynamic concepts to formulate the problem at hand will still be of use, particularly at the strategic level.

3.5.10. While the dynamics of travel demand has been the subject of substantial research activity, only recently has this been allied with a complementary analysis of the supply of transport facilities. This contrasts with the long history of time-dependent system dynamics. Developed as a management tool in the 1960's, it has been used in the corporate setting for the analysis of manufacturing systems.

3.5.11. The comparative static mode of planning will be insensitive to dynamic trends in travel demand. As with much early transport forecasting, once a future demand is fixed, the emphasis is on achieving a 'best fit' between that future and the system which serves it. The aggregation of demand will also tend to disguise dynamic behaviour and, given a large administrative bureaucracy, may favour aggregate solutions.

3.5.12. The attempt to achieve an equilibrium between demand and supply will thus be liable to failure because the aggregated approach represents an insufficient understanding of the nature of change and the measures required to meet it. Even in a certain environment, this approach will tend to result in a poor match of demand and capacity because of the lumpy characteristics of capacity; uncertainty will complicate matters further. The dynamic forces that dictate system behaviour will tend towards disequilibrium, and so there will be an ever-present uncertainty and an ever present disparity between the existing and desired system states:

> 'Equilibrium can only be conceived as a state of affairs, not a course of affairs. If equilibrium rejects time, then comparative statics evades it by comparing a number of different equilibria without assigning any meaning to the question of how any transition could be made from one to another.'[42]

3.5.13. Thus a key issue in understanding and explaining system behaviour is the treatment of time. Any infrastructure project therefore, must not be perceived independently, with a future operating date to which forecasting and planning is orientated, but only as a part of the programme of development of the total system through time.

3.5.14. The timing of projects will be very important when they are perceived to be inflexible or irreversible, as is usually the case with infrastructure. The more static systems analysis regards timing as the means by which 'optimum conditions' may be achieved.[43] However there are simulation techniques more suited to a dynamic approach. Systems Dynamics itself was developed for the simulation of industrial production and distribution systems. It can either map the trajectory of an entity through a system (discrete), or monitor through time overall levels in the various components of an interactive system (continuous).

3.5.15. The 'continuous' form of system dynamics will be of most interest here although applications of this approach to planning and transport planning in particular are rare. However, Forrester followed his Industrial Dynamics with Urban Dynamics,[44] a study of the urban system. Even here however, transport was not an explicit component of the system. Urban Dynamics plotted the relationship between housing, industry, employment etc. over a timescale of many years, not dissimilar to that for transport planning.

3.5.16. The systems dynamics approach centres on two main variables, levels and rates. Levels are inventories of stock in the various sub-components of the system and rates represent the flows between these systems. Demand is normally an exogeneous input. Delays are also an important concept in System Dynamics, as they are in longitudinal analyses of demand. Changes in levels will invoke changes in other parts of the system, but their effect will not be instantaneous. There will be a delay between cause and effect and the nature of those delays is a major determinant of system behaviour. (Fig.3.3)

3.5.17. From this brief description an analogy with transport systems is apparent. Levels of capacity and rates of investment (changes to levels) may be mapped against exogeneously modelled demand, possibly derived from the dynamic methods discussed previously. The most obvious example of a delay is the lead time of investment, but more advanced models could incorporate delays in information and data processing.

3.5.18. Forrester's urban dynamics model was criticised for its weakness in equilibrium and calibration.[45] However, equilibrium is not a valid concept in a dynamic context, because of its steady state assumptions. Calibration also represents 'fixing' the model to cross sectional data at one point in time. From a dynamic viewpoint this calibration is merely transient, a passing phase in a dynamic continuum which is only a partial representation of the system.

3.5.19. The validation of such system dynamics models is notoriously difficult and Forrester himself was never explicit on the issue. Rather than a conventional validation for some specific point in time, a longitudinal verification is ideally required, but this presents significant problems, not least of all that problem which affects all dynamic models, the availability of time series or longitudinal data. Forrester linked validation explicitly to the goals of the system themselves. This meant that if the model was considered to have achieved its purpose, then it was validated, but this is difficult to verify.

3.5.20. Policy is an important factor in system dynamics. The objectives of systems dynamics given by Coyle (cf. 3.3.14) show that the influence of policy is recognised explicity. Therein lies the difference between corporate planning and that in land use and transport. It is taken for granted that the planning of a manufacturing structure and policies (e.g. for marketing) can influence the demand for a product. Yet in transport planning such influence is underplayed in the face of a demand generated by travellers' behaviour as 'free agents' which is not susceptible, nor should it be, to policy 'interference'.

3.5.21. Dynamic analysis clearly has a contribution to make to the understanding of travel behaviour and the performance of transport systems. Although the longitudinal analysis of the demand for large scale systems is not yet practical, there is now sufficient evidence of the existence of dynamic behaviour and the effects that policy may invoke. A dynamic analysis of transport systems may complement those for travel demand. Systems dynamics is one technique that has been used in a non-transport context. Although its reliance on variable profiles through time may classify it as a 'static' technique, the use of time series data is a first step away from the restrictions of cross-sectional analysis in this context.

3.6. EMPIRICAL ANALYSIS OF CASE STUDIES

3.6.1. It is apparent that the techniques of transport planning have a considerable impact on the form of solution adopted. However, strategic transport issues are inherently political and therefore require political choices. An acceptance of such choices would still require a development of techniques so that any diversity in policy may be recognised in project appraisal.

3.6.2. In relation to infrastructure it is the potential constraints of systems that require further analysis. In this context, a model will be developed in part two which can simulate the development of transport systems through time. This model will be designed with a view to analysing the infrastructure aspects of the case studies that follow.

CHAPTER THREE

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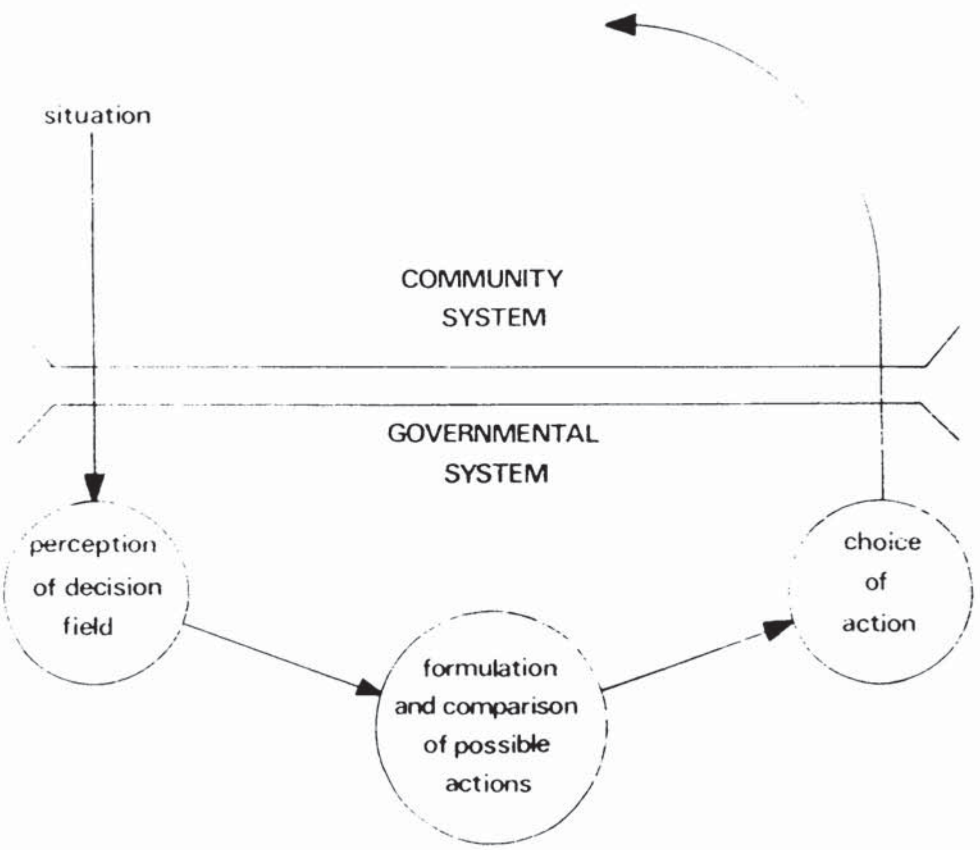

FIGURE 3.1 Strategic Choice and Local Government

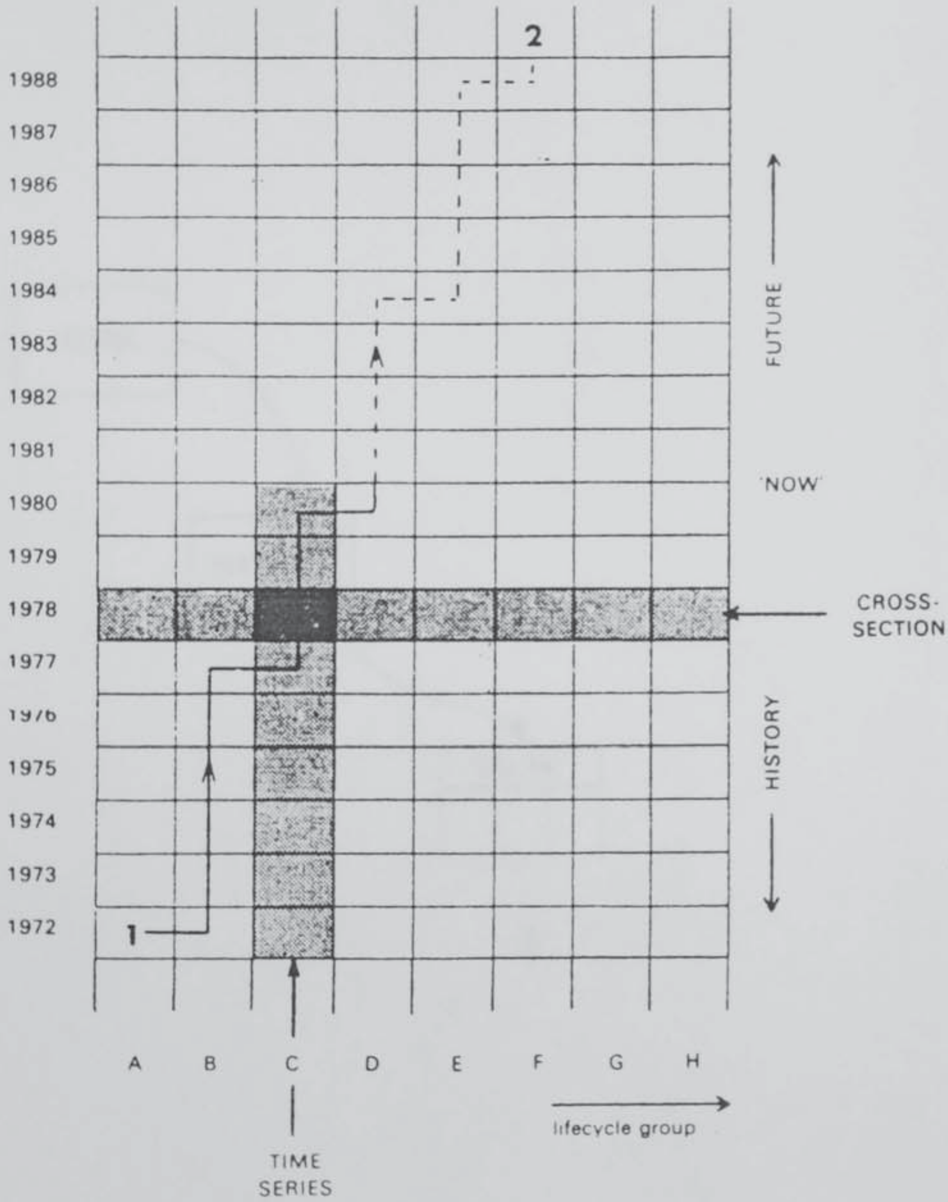

FIGURE 3.2 A Comparison of Cross-Sectional, Time Series and Longitudinal Analyses

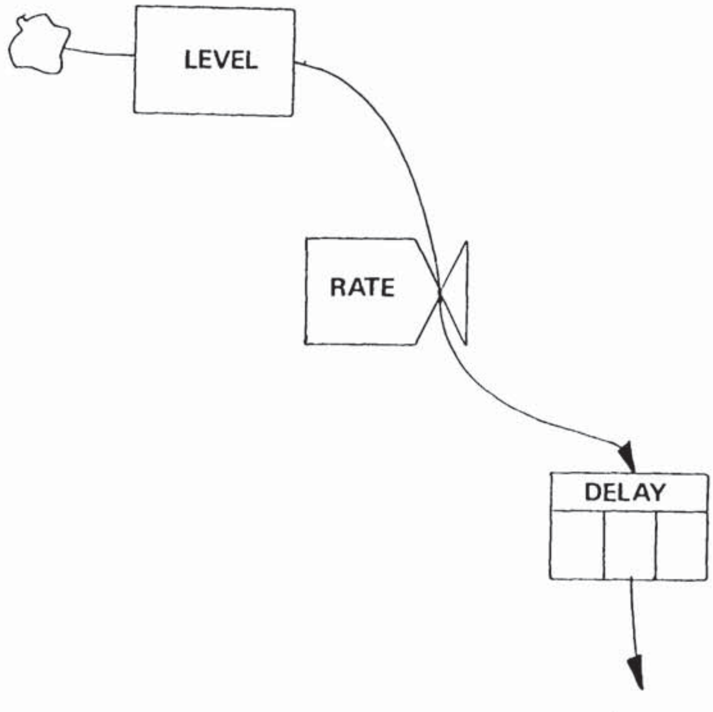

FIGURE 3.3 Levels, Rates and Delays in a Systems Dynamics Model

PART TWO

TRANSPORT INFRASTRUCTURE APPRAISAL

CHAPTER 4

MODEL SYNTHESIS

4.1. INTRODUCTION

4.1.1. The survey of planning methods and system structures in Part One concluded that the physical constraints of infrastructure are important factors in the planning of transport systems under uncertainty. Although recent advances in travel demand modelling recognise the dynamic nature of change, similar responses on physical planning may be more difficult with apparently inflexible infrastructure. Similarly, it will be difficult to translate so-called flexible policy options into physical reality. The remainder of this chapter will describe the synthesis of a model for assessing these constraints, and for the simulation of alternative policy strategies for major projects.

4.1.2. Since the inception of transport planning, mathematical modelling has been used for the analysis and forecasting of travel demand, and to represent its distribution on transport networks. At the strategic level, such models are usually large and require extensive data. To attempt to create such a model here is clearly unrealistic and beyond the scope of this project. The problem to be analysed requires a simple model with minimal data requirements. Such a model will be partial and ignore many practical complexities. However, the problem is only one of many that could be analysed. Any modelling process begins with a very simple representation of the real world and gradually becomes more sophisticated as knowledge increases. In this context there are two important factors. Firstly, transport models in the past have been far less accurate in representing the 'real world' than is apparent from the justification of their use. Secondly, quantified knowledge of the constraints of infrastructure is still limited. Therefore any representation of such constraints will at this stage be simplistic and partial.

4.1.3. At the outset of any modelling exercise it is important to define its objectives. Failure to do so will result in a poor definition of the questions asked of a model, and possibly of systems and process that are themselves to be modelled. The results would then be either incoherent in the first case, or in the second instance, precise, but irrelevant to the solution of the perceived problem (misconception or poor definition of a problem is a common difficulty in any modelling exercise as the case studies in chapters 5 and 6 will show). The objectives of this exercise are:

1. To map through time the relationship between the demand for, and capacity of, transport systems.
2. To identify those parameters of physical systems to which the above relationship is at its most sensitive.

4.1.4. The parameters of the system will be those discussed in previous chapters, principally the scale and lead time of the unit components. The results of the modelling will show the variance in the demand-capacity relationship as a consequence of varying those parameters.

4.2. GENERIC STRUCTURE

4.2.1. At the strategic level, the development of any system of infrastructure may be defined by the following iterative procedure:

1. Determine current levels of demand through observation.
2. Prepare forecasts of future demand.
3. Compare the forecast demand with the current and planned status of the system.
4. Determine the timing and form of action to ameliorate any discrepancy in 3.
5. Within budgeting constraints and guided by policy, implement decisions.
6. In the case of capital investment proceed with works.
7. Commission works, so changing the status of the physical system.
8. Repeat.

This process is represented diagramatically in Fig.4.1.

4.2.2. This representation is extremely simplistic and in practice, the actual planning process although in principle following the same procedure, is much more complex. However, the modelling objective is not to accurately represent planning in practice. Rather it is to investigate the constraints upon the iterative process that are due to capital works. To this end, it is the feedback loop of decision, implementation and change of system status that is most important.

4.2.3. It is via the decision algorithm that alternative investment strategies may be represented. Here the choice of solution, be it capital intensive, large or small-scale will be made. The lead time is represented via the delay experienced during work in progress. This will often be determined by the chosen scale of solution. Finally the status of the system is represented by its capacity. This need not be of a composite form as shown in Fig.4.1. but could be disaggregated to represent various modal and spatial distribution of capacities.

4.2.4. Demand is shown as an exogenous input but this is not inconsistent with the objectives of the model. However, a consistency in the choice of demand profiles for the testing of alternative strategies must be ensured if fair comparisons are to be made. The exogenous form of demand also allows the user to specify certain degrees of uncertainty through the application of pre-determined levels of 'noise' to the chosen profiles. As for capacity, demand could be disaggregated where necessary.

4.2.5. Although the forecasting phase is shown as part of the model itself, it also operates independently of the main feedback loop, providing an input to the decision function. Again this may not be representative of state of the art transport planning, but it suits the needs of this particular modelling exercise. It is not the accuracy or efficacy of forecasting that is being subject to analysis, so the nature of the chosen forecasting method is relatively unimportant as long as it is consistently applied to the tests of alternative strategies. However, given the earlier criticism of forecasting procedures, the derivation of forecasts within the model should, as far as possible, be consistent with the principles laid down in chapter 3.

4.2.6. The operation of this model is based on iterations, the time period between each specified by the user at the more detailed stages of model design. The output of the model will be in the form of longitudinal profiles of demand, capacity and the 'workload' of the process through time.

4.3. MODEL TRANSLATION

4.3.1. A generic model structure such as that described above requires further development before it can be of use. Prior to describing a more detailed version, the method of computation must be chosen. The model (to be called TRAIN) may be defined as a simulation model for which there are three computing alternatives:

1. Manual computation
2. A programme written in a general all-purpose language such as FORTRAN
3. A specialised simulation language.

4.3.2. In the early stages of model synthesis a series of manual computations were carried out based on the generic structure. However, as simulation models require the computation of each variable at each time period throughout the model run, this was extremely time consuming and subject to human error. Given that many such runs would be carried out during a simulation study, the first alternative was rejected as being unrealistic.

4.3.3. Once the decision to take advantage of the available computing facilities had been taken, the next step was to decide on a programming language. Computer simulation textbooks[1] describe the procedures for choosing a language based on the nature of the problem being addressed. There are a large number of alternatives available, as shown in Fig.4.2, each of which may be applicable to certain types of problem. However, the most important differentiation to be made is that between continuous and discrete techniques.

4.3.4. The choice between continuous and discrete methods or a third 'hybrid' approach which is composite of the two, is made on the basis of the problem to be investigated. The concept of continuous simulation has already been discussed in chapter 3 as being a suitable medium for describing the environment within which transport planning is situated. However, the problems described in previous chapters can be viewed as hybrid. The constraints of infrastructure are such that it is only possible to respond to this environment of continuous change in a discrete manner. However, it does not necessarily follow that the problem must always be viewed as hybrid. One of the aims of the study is to seek ways in which to limit the discrete nature of transport planning solutions. In effect this is searching for ways in which the responses to change may be made more continuous and so more compatible with the environment for which they are designed.

4.3.5. Emshoff and Sisson stated that all simulation models should be able to:

1. Create random numbers.
2. Create random variates.
3. Advance time, either by one unit or to the next event.
4. Record data for output.
5. Perform statistical analyses on recorded data.
6. Arrange outputs in specified formats
7. Detect logical inconsistencies and other error condition.[2]

4.3.6. These criteria show how a specialised simulation language may have considerable advantages over general programming languages such as FORTRAN, for other than the experienced or advanced programmer. Simulation languages will normally contain random element generators and the advance of time as built in features. They will also manipulate the output of the model, which is very important in simulation as each variable equation will be executed at each time period throughout the run. In addition, the expansion of a model designed for a purpose-built language will normally be more easily achieved than altering the logic of a FORTRAN program. The error diagnostics of a simulation package will also be useful in this context. For these reasons, a simulation package was the preferred option for TRAIN.

4.3.7. In choosing a simulation language it may not be possible to logically follow one of the paths in Fig.4.2. As Coyle[3] states, one of the key determinants is likely to be availability of the language to the user. Other important factors will be the extent of technical support and the availability of expertise in the use of the program. However it has already been suggested that the continuous approach would be most suited and within this category, one language that was available with some technical support was DYNAMO. This language is also very easy to learn as it is based on a few simple concepts. Given that some advice on its use was also available, the DYNAMO program was chosen to translate the generic model TRAIN.

4.3.8. Although there will be some drawbacks with the use of DYNAMO, in particular its manipulation of output is far less advanced than some other languages, the experience of Coyle in the use of simulation languages is pertinent:

> 'The choice of a particular simulation language is far less important than the intelligent use of the language available.'[4]

In fact the package available was MINI-DYNAMO, a smaller version of the original DYNAMO program.

4.4. BASIC OPERATIONS OF DYNAMO

4.4.1. The method of computation having been chosen, the generic model structure given in 4.2. must now be converted to a form recognised by the computer program. In order to facilitate this conversion, the basic operations of MINI-DYNAMO will now be briefly explained.

4.4.2. MINI-DYNAMO is an iterative, continuous model and is therefore well suited to problems concerning the development of systems through time. At each iteration, MINI-DYNAMO executes the whole of the model, so that the result of a model run is a profile of the value of each variable at each iteration. The actual operations which constitute the model are in principle very simple. There are two basic operations, the computation of rates and levels. Apparently complex DYNAMO models are essentially constructed from these two operations.

Levels

4.4.3. Levels represent the status of the system at each iteration. They are the contents of each inventory which would exist if the operation of the system were to cease. The capacity of the transport system is a level in DYNAMO terminology. Levels may be physical quantities or information and are represented in diagramatic form as a rectangle.

Rates

4.4.4. Rates represent the flow that takes place between the levels of two consecutive iterations. Again they may be physical quantities or flows of information or resources. Rates contain the decision functions within any system through which the flows are controlled. Thus a decision to invest in infrastructure to meet a travel demand is a rate, controlling as it does the development of the system. The flow here would be of resources, converting finance into capital works. Rates are represented diagramatically by a valve device.

Rates and levels in unison

4.4.5. A basic law of any DYNAMO System is that each rate must feed a level and each level must feed a rate. Thus the system develops through the interaction of rates and levels. This may be represented as shown in Fig.4.3.

4.4.6. However, as there may be several levels feeding a rate and vice-versa, the equations representing these operations could become lengthy and complicated. This is avoided by the use of 'auxiliaries'. Auxiliaries do not perform any operation, they simply reformat the input to a level or a rate. For example, a decision to invest in infrastructure may depend on the level of demand and the level of capacity. Rather than feeding both of these levels into the decision function, an intermediate auxiliary may be defined, such as the difference between demand and capacity. Auxiliaries are represented by a circle as shown in Fig.4.4. Although intermediate, auxiliaries may have independent meaning.

The Treatment of Time in DYNAMO

4.4.7. The Basic building blocks of the system now defined, it is necessary to specify in more detail their relationship with each other. This is accomplished via the representation of time in the development of the system. The progress of time is endemic to DYNAMO; at the beginning of each simulation the length of run is specified together with the solution interval in the same units. For the development of transport systems the run length could be specified as e.g. 25 years and a solution interval of 0.5 would involve iterations every six months.

4.4.8. At each iteration DYNAMO follows a strict order of computation. Level equations are the first to be executed followed by auxiliaries then rates. There are no exceptions to this rule. For the representation of time, the notation, J, K, L - is used. K is the current iteration, J the previous and L the subsequent. (Fig.4.5.)

4.4.9. This notation is applied to all variables in the equations representing the system. A level may be specified thus:

$$SC.K = SC.J + (SCR.JK)\ DT$$

where
SC = System Capacity

SCR = Rate of Growth of System

DT = Solution Interval.

System capacity is equal to the capacity at the previous iteration plus the growth during the intervening period.

4.4.10. Once all levels have been calculated, the auxiliaries are computed. Auxiliaries have the same equation form as levels thus:

$$DCD.K = SDEM.K - CAP.K.$$

where DCD = the demand-capacity difference

SDEM = Smoothed Demand

CAP = Capacity.

Here the difference between demand and capacity at time K is treated as an auxiliary which then forms an input to a decision function.

4.4.11. Decision functions are represented by rates as they control the flow of material, resources or information throughout the system.

$$ORD.KL = \frac{DCD.K}{(UC)(LT)}$$

where ORD.KL = rate of ordering of new capacity

DCD.K = shortfall of system

UC = unit capacity of units

LT = lead time.

The above equation results in the addition or subtraction of a number of units to correct the difference between demand and capacity. Rates do not occur instantaneously, but are regarded as proceeding linearly between two consecutive iterations K and L. Once the execution of rate equations is complete, so the 'run' proceeds to the next iteration.

Delays

4.4.12. The above rate equation introduced the concept of delays into dynamic system modelling. Delays are very important in determining flows throughout any dynamic system. Lead time is a form of delay as the desire to instantaneously correct the demand-capacity balance is frustrated by the time taken to plan, construct and commission the new capacity. Forrester[5] described a series of exponential delays for different situations. The choice of delay representation is a matter of judgement based on existing knowledge of the system.

4.4.13. Delays are represented in terms of the input and output to a level. As such they are an intrinsic part of rate and decision functions. Two possible forms are given in Fig.4.6.

4.4.14. For the first order exponential delay an impulse input results in an initially high output which decays exponentially. For a continuous input, the output increases exponentially until it reaches the level of the input. Second and third order delays offer similar growth and decay output curves as they are simply combinations of two or three first order delays respectively, i.e. they are 'cascaded', one delay output forming the input to the next. These exponential delays are characteristic of many of the manufacturing systems for which systems dynamics was developed. They involve large flows of relatively small packages of goods which undergo a series of delays in manufacture, transit and retailing.

4.4.15. This is clearly not the case in transport planning. Provision of capacity will usually be the addition of relatively few large scale 'units' over a period of many years. The order may be placed instantaneously and this is a highly discrete input. The output does not occur until the new facility is commissioned many years later when the capacity of the system is suddenly increased by a factor equivalent to that of the facility. In this situation, it is discrete delays in Fig.4.6. that are most appropriate. In the full DYNAMO model a facility called a 'boxcar' was available to simulate such discrete delays, the output following the input a predetermined number of iterations later. However, this facility was not available in MINI-DYNAMO and for the model an alternative constructed from auxiliaries was used.

Solution Interval

4.4.16. The choice of solution interval is dependent on the length of delays. It does not necessarily coincide with the iterations of the system itself. Indeed it will normally be much shorter than that time period. The relationship with delays arises from the fact that a solution interval greater than the shortest delay within the model will not allow that delay to be adequately represented in performance of the model. For this reason, Forrester suggests that the solution interval should be less than half of the shortest delay.[6] For example, a strategic transport model may be based on annual iteration of forecasts and ordering. Hence the delay in converting orders (rates) into capacity must be at least 1 year and the solution interval no greater than 0.5 years or six months.

Other Dynamo Facilities

4.4.17. MINI DYNAMO contains a number of supporting facilities. These include functional specifications such as data inputs in tabular form and logical functions similar to those used in FORTRAN. There are also noise functions for distorting input data and incorporating random elements into variables as well as various options for controlling output. Where necessary these will be introduced as the model is developed. A full annotated list of all the functions is given in Appendix A.

4.5 THE BASIC MODEL

4.5.1. A generic structure for a model of transport infrastructure development has been defined. In MINI-DYNAMO, a modelling language has been chosen whose basic operations are consistent with the principles of the model. It now remains for the generic structure to be defined in detail in the language of MINI-DYNAMO. This will form the core model which will be amended as each set of simulations are undertaken. The overall model can be sub-divided into 5 elements or sub-models. They are for the computation of Demand, Forecasts, Decision Functions, Construction Delay, and capacity of the system.

4.5.2. As shown in Fig 4.1, demand is an exogeneous input to the model. This takes the form of an annual demand volume, one for each year of the simulation run. This raw demand data provides the input to the first internal building block of the model - the forecasting sector. Two alternative forecasting methods will be used, although they employ similar techniques. Demand is first smoothed using the errors in previous forecasts. A linear function of future demand is then produced for LT years ahead, where LT is the lead time of the investment.

4.5.3. The forecast of future demand provides one of the inputs to the decision sector. Forecast demand is compared with the capacity of the current system and that of any work in progress. A projected shortfall in capacity will usually result in a positive decision to invest, although the decision function may be amended by decision rules which simulate e.g. a fixed budget, so as to avoid excessive capital spending.

4.5.4. The investment decision made, the project enters the Work in Progress sector where it remains for LT years. At the end of the lead time period it is transferred to the current system capacity. This capacity provides an input to the decision sector so completing a simple feedback loop. However in the basic model, system capacity has no effect on demand, which is an exogeneous variable, nor on the forecasting sector. Each sector within the model will now be considered in more detail.

Demand Profiles

4.5.5. The generic structure of TRAIN portrayed demand as an independent variable. The generation of rates of demand was not influenced by other events in other parts of the system. In previous chapters this assumption has been questioned in the context of transport modelling in practice. However, TRAIN is not designed to be a representation of the entire transport system, nor is it designed to reproduce the behaviour of a small part of that system. Its purpose is to test the performance of the system under various infrastructure strategies and profiles of demand. The measure of the performance of any system, is the extent to which it is able to meet this demand. Thus demand as an exogenous input forms the background to the test.

4.5.6 For the basic model, this independence of demand will be sufficient, providing that each strategy is subject to the same demand profiles. As an exogenous imput, several different profiles may be used to test the efficacy of each strategy under varying demand conditions.

Although demand is an exogenous input, this does not preclude amendment to the profile within the model. Any exogenous input will be in the form of a smooth curve to represent a particular form of demand behaviour. However, within the model it is possible to incorporate random elements, specified by the user, which help to simulate the small and occasionally large fluctuations which occur in any real system. These help to test the performance of any strategy under 'environmental shocks' i.e. events which are beyond the control of the system.

The Demand Variable

4.5.7 The test that determines whether a variable is a rate or a level considers the value of the variable when the system is at rest. Any variables which are zero under these conditions are rates, any which retain some value are levels. However, the application of this test is not clear cut in the case of exogenous demand. If the decision 'loop' within the model is brought to rest, an equilibrium in demand and capacity is implied. Demand could still retain a value under this situation. However, this equilibrium is only one special case of the 'at rest' situation. In a larger model, where the whole transportation system were at rest, demand would clearly be zero, and so a rate.

4.5.8 This broader perspective provides the key to determining the form of the demand variable. An exogenous input implies a flow from another system which, for the purpose of the problem, does not need to be modelled. Such a flow is by definition a rate, as levels cannot be transferred within a DYNAMO without passing through a rate. In TRAIN, demand is in fact a flow of information from the demand sector which is represented by an exogenous input. Thus, demand is represented as a rate variable.

4.5.9 This definition of demand as a rate is corroborated by inspection of other DYNAMO models[7] where demand passing from one sector to another, or as an exogenous input is represented as a rate. In TRAIN, the input rate will be converted to a level in preparation for the forecasting of future demand (described later in this chapter).

4.5.10 As an exogenous input, the form of the demand profiles is specified by the user. This is essentially a matter of judgement and should reflect,

1. the conditions which will provide the most useful results from the model.
2. the situation pertaining in the system to be modelled.

4.5.11 Profile 1:

Traffic forecasting in practice considers travel to be closely linked to economic growth. Thus the first profile considers simple linear growth (Fig.4.7). The curve shown, represents a 200% increase in demand over the length of the model run.

4.5.12 Profile 2:

This considers exponential growth of demand rising to three times the initial value of demand over the length of model run.

4.5.13 Profile 3:

Although exponential growth is often used in travel demand forecasting, it soon results in infinite levels of demand. The concept of a 'saturation level' for demand beyond which no further growth takes place, tempers the rise to infinity and results in an S shaped curve. The logistic curve is one such example of this saturation forecasting and its form is shown in Fig.4.7.

4.5.14 Profile 4:

The first three profiles all exhibit increasing demand with time. However, the situation where demand is in decline will also be of interest. Hence the fourth and final profile simulates a period of rapid growth followed by such a period of decline.

These demand profiles are described more fully in Appendix B.

4.5.15 Fig.4.8. represents the input of demand profiles to the model. Demand DEM reads its values from the table DTAB at periods specified by the level T which accumulates the passage of time.

4.5.15cont The equations required are:

R	DEM.KL = TABHL (DTAB, T.K, TMIN TMAX, ≠, TINCR)	D - 1
T	DTAB = $d_1/d_2/d_3......./d_L$	D - 2
L	T.K = T.J + DT	D - 3
N	T = 0.0	D - 4

where: DEM.KL = demand during subsequent time period KL.(d/t)

TABHL = the look-up function requiring table DTAB to be read.

DTAB = contents of the table.

T.K. = current time (t)

T. = initial value of time (t)

L = constant defining the (t) length of model run.

TMIN = is the minimum value of the independent variable T.

TMAX = the maximum value of the independent variable T.

TINCR = the increment between values of d.

4.5.16 To create a more realistic demand profile than the smooth curves described above, it is possible to incorporate random fluctuations in the demand variable. MINI-DYNAMO possesses two functions for creating such fluctuations:

1. NOISE ( )
   - this produces random numbers between $^{-1}/_2$ and $^{+1}/_2$ every DT.
2. NORMRN (MEAN, STANDARD DEV)
   - creates random numbers as above but normally distributed according to the MEAN and STANDARD deviation specified.

4.5.17. Two further functions are available which allow more pre-determined fluctuations to be incorporated into the demand variable:

1. STEP (HEIGHT, STTM)
   - introduces a STEP function of the specified HEIGHT at time STTM
2. PULSE (HEIGHT, INIT, INTVL)
   - creates pulses of length DT at the specified INTERVAL, the first occurring at time INIT.

4.5.18. Any of these functions may be simply added in to the demand variable (Fig.4.9.) By expressing the function as a fraction F, of the initial value the equations for the demand incorporating both NOISE and STEP functions would be:

R	DEM.KL	=	TABHL ($d_1 \ldots d_n$) + RDEM.K	D - 1
A	RDEM.K	=	NDEM.K + STDM.K.	D - 5
L	NDEM.K	=	(NOISE( )) (IDEM) (F)	D - 6
L	STDM.K	=	STEP (HSDM, FSTD)	D - 7

where : RDEM = Random fluctuation

NDEM = Noise level in demand

IDEM = Initial value of demand. (d)

F = The fraction of demand to which noise is applied.

STDM = The step in demand

HSDM = The height of the step in demand

FSTD = The time at which the step is applied to demand.

4.5.19. As well as their use in evaluating system performance in simulating environmental shocks to the system, these functions are useful in test inputs when the model is being validated.

Forecasting Sub-Model

4.5.20. In order that decisions on infrastructure investment may be made, forecasts of future demand are required. The forecast must be for a period that is at least equal to the lead time of the proposed investment. As the forecasting period increases so the variation in demand may influence the choice of investment because of the increase in uncertainty with increasing lead time.

4.5.21. Forecasts must be updated at each iteration of the model and so a method of forecasting is required which can predict on the basis of time-series information, the product of the model. Furthermore, the limited information available (only a demand time series in the basic model) implies a simple method of generating the forecasts.

4.5.22. The Box-Jenkins Method and its derivations are adequately suited to these requirements. Forrester also developed a similar method of continuously updating forecasts based on information from a single variable.[8] Both the Forrester method and a Box-Jenkins derivative will be developed for use in TRAIN.

4.5.23. From equation D-1 a value of raw demand is available. However this cannot be directly entered into the forecasting phase as any short term fluctuations would cause erratic forecasts to be generated. To remove these fluctuations and discover the underlying trend, the demand input must be smoothed.

4.5.24. The level of smoothed demand is constantly updated via comparison of the actual and smoothed demand from previous iterations. However, the current value of smoothed demand is insufficient in itself to generate a growth rate. A further previous value of smoothed demand is also required to give two points on a linear curve and hence a gradient or rate of growth. To achieve this, the smoothed demand is itself smoothed. The doubly-smoothed and singly-smoothed demand together provide the input to the forecasting equation. The flow diagram for the forecasting sector is given in Fig.4.10.

4.5.25. The initial smoothing of demand is given by the equation:

L SDEM.K = SDEM.J + (DT)(DEM.JK - SDEM.J)/SDD F-1

where : SDEM = smoothed demand (d)

DEM = input demand. (d)

DT = the time period between each iteration in the operation of the model.(t)

SDD = constant - the delay in smoothing demand.(t)

4.5.26. Doubly-smoothed demand is given by :

DSDEM.K = DSDEM.J + (DT)(SDEM.J - DSDEM.J)/DSDD F-2

where : DSDEM = doubly-smoothed demand (d)

SDEM = smoothed demand (d)

DT = solution interval (t)

DSDD = doubly-smoothed demand delay (t).

4.5.27. DSDD represents the time between the values of demand as smoothed by DSDEM and SDEM respectively. DT is the proportion of that time elapsed at time K, hence giving the growth rate between SDEM and DSDEM. To generate a forecast, this growth rate must be projected into the future. What, in engineering terms, is called the design year is the year for which the forecast is made. For the basic model. the design year will be assumed to be the year of opening and so the forecast period will be equivalent to the lead time. The forecast demand for time K + LT will then be given by :

A FDEM.K = SDEM.K + (LT)(SDEM.KODSDEM.K)/DSDD F-5

FDEM = IFDEM F-6

where : FDEM = forecast demand

SDEM = smoothed demand

DSDEM= doubly smoothed demand

DSDD = doubly smoothed demand delay

IFDEM= initial value-forecast demand.

LT = lead time

Forecast error

4.5.28. The forecast of future demand has now been generated. However, it is very unlikely that the forecast will be correct. There will be a forecast error at time K + LT equivalent to the previously forecast and actual demand. To define this error and determine the performance of the system under variations in forecast error, the forecast must be stored until such time as it can be compared with the demand it was designed to predict. The boxcar function would again be useful here and although it was not available in MINI-DYNAMO it can be simulated using a string of levels and auxiliaries. (Fig.4.11). Each time period, the stored forecast shifts from one level to the next until at a point specified in the Forecast error equation, it is converted to an auxiliary and hence through the auxiliary string within one solution interval. This retrieved forecast is then compared with the actual demand DEM from equation D-1 to produce a forecast error. The string of levels is fed by the auxiliary variable FDEM, this procedure being possible as MINI-DYNAMO treats auxiliaries and rates as equivalents.

4.5.29. The equations for this string are:

L DF10.K = Switch (FDEM.J, DF10.J, TI.J)	F - 7
N DF10 = 1	F - 8
L ADF10.K = DF10.K	F - 9
N $ADF10_2$ = 1	F - 10
L DF9.K = Switch (ADF10.J, DF9.K, TI.J)	F - 11
N DF9 = 1.0	F - 12
A ADF9.K = DF9.K	F - 13
N ADF9 = 1.0	F - 14

L DF1.K = Switch (ADF2.J, DF1.J, TI.J) F - 29

N DF1 = 1.0 F - 30

A ADF1.K = DF1.K F - 31

N ADF1 = 1.0 F - 32

L TI.K = CLIP (0, TI.J + DT, TI.J + DT, 1-DT) F - 33

N TI = 0 F - 34

4.5.30. Although apparently complex, this string of equations performs a simple function. In equation F-7 the switch function has three inputs and two possible outputs. If the third argument, TI.J is equal to zero then DF10.K = FDEM.J. If TI.J is ≠0 then DF10.K is equal to DF10.J, i.e. it retains its previous value. This ensures that forecasts are shifted only every time period, when TI.J = 0, TI.K is given by equation F-33 which counts the number of solution intervals within each time period, returning to zero as each time period is completed. The CLIP function carries out this computation. This process is repeated throughout the string, the stored information moving from one level to the next each time period.

4.5.31. To retrieve the information a further string of auxiliaries, PF, was required. This in effect provides an exit from the strings ADF/DF at the point required. The value of each PF variable is dependent on the forecasting period or lead time LT. Thus, referring to Fig.4.11, if LT > 4. PF1 = PF2 = PF3 = PF4. PF5 to PF10 are equivalent to these corresponding auxiliaries and are not used. Within one solution interval, the stored forecast travels through auxiliaries PF4, PF5, PF2, PF1 to PPDEM, the level of demand previously forecast for the current time period K. The equations for this string are :

A PPDEM.K = CLIP (PF1.K, ADF10.K, LT,1) F - 35

A PF1.K = CLIP (PF2.K, ADF.9.K, LT,2) F - 36

A PF9.K = CLIP (ADF1.K, ADF1.K, LT,10) F - 44

where : PPDEM = previously predicted demand (d)

PF1,2 etc = previous forecast no.1,2 etc (d)

LT = lead time (t)

ADF = auxiliary demand forecast (d)

4.5.32. However, there is a further problem concerning the initial value of forecasts. Until the first forecast can be retrieved at LT time periods into the run, the previously forecast demand PFDEM would be equivalent to zero, or the initial values of the levels in the forecast storage string. To avoid this problem, initial values of the variable PFDEM were introduced via a table. Thus until time LT, PFDEM will equal values drawn from the table INFOR. Beyond time LT, the value of PFDEM will be drawn from the forecast storage string. The equations are as follows:

A PFDEM.K = CLIP (INFOR.K, PPDEM.K, LT,T.K) F - 45

L INFOR.K = TABHL (FTAB, T.K, -DT, 10-DT,1) F - 46

N INFOR = INFORC

T FTAB = $FTAB_1$/$FTAB_2$/ .... $FTAB_n$.. F - 48

L T.K = T1.J + DT F - 49

N T = 0 F - 50

where : PDFEM.K = current previously forecast demand (d)

PPDEM.K = available previously predicted demands (d)

LT = lead time (t)

T = Time into run - a simple counter (t)

INFOR = initial previously forecast demand for time 0 - LT

FTAB = table containing values for INFOR

INFORC = constant-initial value of INFOR.

4.5.33. The forecast error is now given as follows:

L FE.K = DEM.JK - PFDEM.J F - 51

N FE. = 0 F - 52

where : FE = forecast error (d)

DEM = demand (d)

PFDEM = previously forecast demand (d).

4.5.34. The forecast sub-model is now complete. Although the process for storing forecast information may appear laborious, it is essentially a simple operation requiring many equations because of the limited functions in MINI-DYNAMO. Furthermore, the definition of forecast error will be a useful output of the model.

An Alternative Forecasting method

4.5.35. Forrester's method of forecasting is adequate for the purposes of the TRAIN model. However, there are two reasons why an alternative method should also be developed :

1. At the validation stage to test the sinsitivity of the results to the forecasting method.
2. To allow a more explicit role for variables such as forecast error and growth rate.

4.5.36. Comparisons of infrastructure strategies will only be carried out using results based on a single forecasting method. However, the order of magnitude of the output variables will differ when based on different forecasts. The sensitivity of the model to variations in forecasting methodology should therefore be tested.

4.5.37. MINI-DYNAMO is a model with all-embracing language and procedures. In this sense it is rigid and allows little scope for the introduction of other methods of generating variables. However, the Forrester method of forecasting is a DYNAMO form of standard statistical smoothing procedures. Such standard methods explicitly include growth rate and forecast error in their methods. Holt's method is a variation of the commonly occurring Box-Jenkins method and it has been used in a similar context[9] to that existing in TRAIN. This method was adapted for use in the model. A detailed description is given in Appendix D.

4.5.38. Holt's method, like that of Forrester produces a level of smoothed demand. The direct inputs to the smoothing process are the forecast error and an underlying growth rate. This difference implies an alternative representation of the smoothing process as shown in Fig.4.12. The forecasting equations and storage, and the generation of demand remain as in the previous Fig.4.11.

4.5.38. Holt's method consists of two general equations:

$$S_k = S_j + R_k + a\,E_j$$

$$R_k = R_j + b\,E_j$$

where S = smoothed demand

R = rate of growth of demand

E = forecast error

a,b = constants

4.5.39. In DYNAMO language, the equations to represent Fig.4.12 are :

L	STFE.K	= DEM.JK - SDEM.J + (UGR.J)(DT)	F - 53
N	DEM	= IDEM	F - 54
N	STFE	= IFE	F - 55
L	SDEM.K	= Switch (SDEM.J+(ROG.JK)(DT) + (A) (DFE.JK), SDEM.J, TI.J)	F - 56 F - 57
N	SDEM	= DEM	F - 58
N	DFE	= IDFE	F - 59
L	UGR.K	= Switch çUGR.J+(B)(DFE.JK), UGR.J,TI.J⅔	F - 60
N	UGR	= GR	F - 61
R	DFE.KL	= STFE.K/FORDE	F - 62
R	ROG.KL	= UGR.K/GRD	F - 63

where : STFE = short term forecast error (d)

DEM = demand (d)

SDEM = smoothed demand (d)

UGR = underlying growth rate (d/t)

IDEM = initial level or demand (d)

IFE = initial forecast error (d)

ROG = rate of growth (d/t)

DFE = delayed forecast error

IDFE = initial delayed forecast error

IGR = initial growth rate

FORDE = the delay to forecast error

GRD = the delay to growth rate.

4.5.40. Here the forecast error is a short term error based on the previous time period to allow constant updating of forecasts. The long term, or actual error in the forecasts is derived as before.

The Decision Function

4.5.41. Estimates of future demand are required so that decisions on investment may be formulated. In the basic model, the only information to be carried forward from the forecasting and demand sub-models is of forecast demand for LT years ahead when any decisions regarding capacity will take effect. To complete a simple algorithm comparing forecast demand and system capacity of the system, information regarding the current and planned capacity is also required. Based on this information, and the investment strategy already partly determined by the parameter LT, investment decisions may be made. This process is represented in Fig.4.13.

4.5.42. In the decision sector, three auxiliary equations are required to produce information in the form required by the capacity ordering equation. These three equations correspond to the variables CADED, RECAP and CAPR shown in Fig.4.12:

A CADED.K = FDEM.K - SC.K - TWIP.K. R - 1

where CADED = capacity-demand differential (d)

FDEM = forecast demand (d)

SC = system capacity (c)

TWIP = Total Work in Progress (planned capacity)(c)

4.5.43. This equation generates a simple capacity demand differential as a basis for ordering new capacity. However, divisions are rarely based on this simple information. Normally some safety factor is involved. This is expressed as a proportion of the forecast demand:

A RECAP.K = CADED.K + (CC)(FDEM.K.) R - 2

where RECAP = required capacity (c)

CADED = capacity-demand differential (d)

CC = capacity constant

FDEM = forecast demand (d)

4.5.44. If undercapacity in the future system was regarded as unacceptable, CC would be positive. Alternatively, excessive capital investment could also be regarded as a risk and CC would become negative. In the basic model,
CC=0.

4.5.45 Although the model is designed to deal with large scale capital investment, it is unlikely that this could be ordered 'en bloc'. An order is likely to consist of a combination of elements or 'units'. The definition of the parameter CA1PU, the unit capacity is a further factor which defines the investment strategy (i.e. large as opposed to small units). Furthermore the model is based on an annual decision profile and so the capacity requisition is given by:

A CAPR.K = Switch (RECAP.K/CAPU, 0, TI.K). R - 3

where, CAPR = capacity requisition (c)

RECAP = required capacity (c)

CAPU = constant-unit capacity

TI = time increment (t)

4.5.46 The result of this equation is that capacity is only requisitioned when TI=0, i.e. at the end of each time period (1 year). CAPR.K is then equal to RECAP.K/CAPU.

4.5.47 However, CAPR.K is unlikely to be an integer and as only whole units may be ordered, the value of the variable must be adjusted further. To achieve a whole number of units for ordering, a boxcar is again simulated by the string of auxiliaries CAPØ to CAP9 in Fig.4.14.

The equations for this string of auxiliaries are:

A CAPØ.K = CLIP (0, CAP1.K,0,CAPR.K) R - 4

A CAP1.K = CLIP (I, CAP2.K, I, CAPR.K) R - 5

A CAP9.K = CLIP (9, CAP10, 9, CAPR.K) R - 13

where CAPØ, 1, 2 etc = Ø, 1,2 etc. units of of capacity (c)

CAPR.K = capacity requisition (c)

4.5.48. The CLIP function selects the second argument if the third is greater than or equal to the fourth and the second if the third is less than the fourth. Each of these equations will be executed until CAPR.K is exceeded by the third argument. Thus if CAPR.K = 2.3, CAPØ.K = CAPI.K_2= CAP2.K = CAP3.K = 3 and hence three units will be selected. This is a conservative criteria for decision-making as if CAPR.K = 0.1, the selected number of units would be 1, 10 times the required amount! However, this effect may be offset by the capacity constant in equation R-2. The rate of ordering is then given by:

R CAPO.KL = CAPØ.K. R - 14

where CAPO = capacity order (c/t)

CAPØ.K = the number of units required. (c/t)

Work in Progress

4.5.49. In this basic model there is one decision function which concerns the actual ordering of capital works. In reality, large scale infrastructure projects are subject to a series of not necessarily consistent decisions over a number of years. In particular, the decision simulated in the previous section is likely to be preceded by a feasibility study of some description, which itself will have been the product of a government decision. This stage is omitted in the basic model.

4.5.50. Beyond the decision function in TRAIN, there remains the detailed design and construction of the chosen alternative.

This option is determined by the investment strategy simulated in each individual model 'run . This strategy will determine the period required for the design and construction phase. In TRAIN, this phase is simulated by a composite lead time entitled 'Work in Progress'. It may be that there will be more than one project contained in the Work in Progress at any one time.

4.5.51. To represent this phase in the model a linear boxcar identical to that used to store forecast information is used (Fig.4.15). The equations for the string of levels and auxiliaries are:

```
L   WIP1Ø.K = SWITCH (CAPO.JK,WIP1Ø.J, TI.J-DT)       W - 1
N   WIP1Ø   = IWP1Ø                                    W - 2
A   AWP1O.K = WIP1Ø.K                                  W - 3
L   WIP9.K  = SWITCH (AWPIØ.J, WIP9.J, TI.J-DT)        W - 4
N   WIP9    = IWP9                                     W - 5
A   AWP9.K  = WIP9.K                                   W - 6

L   WIP1.K  = SWITCH (AWP2.J, WIPI.J, TIJ-DT)          W - 28
N   WIP1    = IWP1                                     W - 29
A   AWP1.K  = WIP1.K                                   W - 30
```

where: WIP10,9,8,7 etc. = the capacity contained
IWP10,9,8,7 etc, in each phase of the boxcar(c)

CAPO = the capacity ordered (c/t)

IWP1Ø,9,8,7 etc = from equation constants - initial values of boxcar levels (c)

TI = time increment counter (t).

4.5.52. As in the forecast storage, the order enters the string in equation W-1 and is retained for 1 time period, counted by T1, when it passes via equation W-2 to the next level equation, W-4. This process is repeated down the string. Initial values, for works ordered prior to the start of the model 'run' may be introduced by the use of the initial value constants.

4.5.53. Again, as in the case of forecast storage, a further string of auxiliaries (CC∅-CC9) is required to retrieve the capacity from the string for addition to the system. The point at which the capacity is retrieved is dependent on the lead time and the equations required are:

A CC∅ = CLIP (CC1.K, AWPI∅.K, LT,1) W - 31

A CC1.K = CLIP (CC2.K, AWP9.K, LT,2) W - 32

A CC9.K = CLIP (AWP1.K, AWP1.K, LT,10) W - 40

where CC∅-9 = completed capacity (c)

AWP10-1 = Work in progress in levels 10 to 1 (c)

LT = lead time. (t).

4.5.54. For example if LT = 4, CC∅.K = CC1.K = CC2.K = CC3.K = CC4.K. CC4.K = AWP7.K and so capacity would leave the work in progress phase as it reaches WIP7, or in the fourth time period after entering the string.

4.5.55. During any time period the level of total work in progress (TWIP), required by the decision function (eqn.R-1) is equal to the previous value of TWIP plus any order entering the string during the previous time period (CAPO.JK) less the capacity leaving the string during the same time period. Capacity leaving the string will always be given by CCØ.K, so:

A	CADS.KL = SWITCH (CCØ.K, 0, TI.K, 1-DT)		W - 41
N	CADS = 0		W - 42
L	TWIP.K = TWIP.J + (CAPO.JK - CADS.JK)(CAPU)		W - 43

where TWIP = total work in progress, (c)

CAPO = capacity ordered during the period J-K (c/t)

CADS = capacity drawn from the string during time period J.K. (c)

CAPO = constant-unit capacity-to convert units in store to capacity.

Model Output

4.5.56. For the output for individual runs, comparison of demand (DEM), capacity (SC), and the retrieved forecast (PFDLM) will provide the main characteristics. In addition, the profile of ordering (CAPO), forecast error (FE) and the difference between demand and capacity will also be of interest.

4.5.57. For the comparisons between runs, the parameters of lead time (LT) and unit capacity (CAPU) will provide the basis of the comparison. As they are varied, the change in the demand capacity difference will be monitored. Changes in the parameters within the decision function may also be compared in this way.

These comparisons between runs will also be necessary as sensitivity tests in the validation stage.

4.5.58. An example of the output from the TRAIN model is given in Fig.4.16 and 4.17. It is based upon a simple simulation of airport development under Demand Profile No.3. The initial capacity of the system was 25 mppa and the investment strategies tested were as follows:

Strategy	Lead Time (yrs)	Unit Capacity (mppa)
1	5	10
2	10	25

4.5.59. As actual demand levels off during the later stages of each run there is a delay before the forecasts of demand adjust to the changes in real demand. Hence the forecasting sub-model continues to predict increases in demand and hence the need for more capacity. Obviously strategy 1 with the shorter lead time is capable of responding to demand changes more quickly and because of the smaller scale units results in less surplus capacity.

4.5.60. The greater responsiveness of strategy 1 is confirmed by the summary characteristics for each run given in Table 4.1. The total forecast error (LTFE) was 262 m.pass. with a total difference between demand and capacity (TDCD) of 313 m.pass. The corresponding figures for strategy 2 were 452 and 674. The ratio DCD/LTFE which gives the difference between demand and capacity per unit foreecast error was 1.19 and 1.86 for strategies 1 and 2 respectiviely. Although this large difference is partially caused by the greater degree of overcapacity at the end of the run for strategy 2, it is still apparent in the earlier stages of each run. For the first 25 time periods the DCD/LTFE ratio was 0.51 and 0.67 for strategies 1 and 2 respectively.

4.5.61. This example is very simple and contains many assumptions. More detailed runs of the model for airport development will be undertaken in chapter 5.

4.6 VALIDATION

4.6.1 The performance of any model can only be assessed relative to its validity. The validation phase of model building verifies that the structure of the model is a suitable representation of the system under analysis. Once the suitability of the structure is confirmed, then changes in the model parameters may be effected to simulate changes in the policies which guide the operation of the system.

4.6.2. The most common test of validation is a comparison of synthetic and observed data. This test assesses the ability of the model to reproduce 'real-world' conditions. In the traffic models described in chapter 1, this test took the form of cross-sectional validation, whereby the traffic flows on a road network predicted by the model wave compared with observed traffic counts. Similarly for airports, the distribution of air traffic to the various sites within the airport system was compared with that observed. The deficiencies in this form of validation were highlighted in Chapter 3.[10]

4.6.3. Such cross-sectional validation is not appropriate for time-dependent models, particularly those based on systems Dynamics principles. It is the development of the system through time that is of interest and reproduction of time profies that is more pertinent for validation. The problem for this class of models is the scarcity of time series data particularly for time periods in excess of 10 years.

4.6.4. However, the reproduction of time-dependent profiles is only one test of validity. Forrester argues that the validity of the model can not be separated from the goals of the model themselves.[11] The goals of the TRAIN model were not to reproduce real-world conditions (it is too simple a model for that), but rather to test the sensitivity of system performance to changes in parameters relating to the form of investment i.e. scale and lead time. Decisions regarding major airport investments are subject to so many factors, many of them political that a comprehensive simulation would be beyond the capabilities of the TRAIN model, even if time series data were available.

4.6.5. A series of eight tests for the validation of Systems Dynamics Models was given by Coyle. They were classified as being one of three distinct types:

VE - Verification that the operating mechanisms in the real system have been correctly transcribed into the model.

VA - Validation of the overall behaviour of the model.

LE - Legitimation in the sense that the model obeys the 'Laws' of system structure, or any other generally accepted 'runs'[12]

The eight tests defined by Coyle will be used as a basis for the validation of TRAIN.

1. Is the Model Structurally Coherent (LE)?

4.6.6. The structure of the model may be ascertained from the diagrams given earlier in the chapter. The important rule in MINI-DYNAMO concerns the relationship between rates and levels. Each level should feed a rate and each rate should feed a level (apart from intervening auxiliaries). This rule was contravened in the forecasting model of Forrester, where two consecutive levels occurred in the smoothing processes. This does not occur elsewhere in the model.

2. Are the Equations Dimensionally Valid (LE)?

4.6.7. Model equations which do not balance dimensionally will highlight errors in system structure. The step-by-step development of the equations used in TRAIN confirms their dimensional validity. Within the model it is acceptable for rates, auxiliaries and levels to be expressed in the same units, particularly in the demand and forecasting phase.

3. Are the Model's Flows Working Properly (LE)?

4.6.8. In a small model such as TRAIN, scrutiny of the model output will normally confirm whether the flows within the model are functioning correctly. In terms of physical entities such as system capacity, that which is ordered must ultimately form a part of the system. Thus a balance sheet for the whole run would read as follows:

$$ISC + \int_{o}^{T} CAPO = SC_T + TWIP_T$$

where ISC = initial capacity

CAPO = capacity ordered

SC = system capacity

TWIP = total work in progress

T = Time period at the end of the run

4.6.9. Therefore the system capacity at the end of the run together with the Total Work In Progress at that time should equal the initial capacity plus the total capacity ordered during the run. In the example given in 4.5.58, the values were as follows:

Strategy	ISC	CAPO	SC_T	$TWIP_T$
1	25	60	85	-
2	25	75	100	-

For flows of information, the inputs and outputs to levels should be scrutinised. Should they remain at zero throughout a run, or if a level value remains unchanged, then an error in a rate specification is implied.

4. Can Individual Relationships Within the Model Function Independently (VE)?

4.6.10. As described earlier in the chapter, each sub-model within TRAIN was developed independently. In this manner it was possible to ensure that each was valid in its own right. Particular attention was given to the forecasting and demand models which were subject to sensitivity tests detailed in para 4.6.14.

5. Are the Parameter Values Consistent With Known Data (VE)?

4.6.11. There are three sets of parameters within the basic model. The first, define the investment policy in terms of the scale and lead time of projects. In the case of airport development these values were adopted from official estimates.[13] They are discussed within the context of the case study in chapter 5. The second set of parameters occur within the regression equations of the forecasting sub-model. The derivation of these equations is given in appendices C and D. The third set of parameters occur within the ordering sub-model and relate to the factor of safety built into decisions. They are discussed in the context of the individual case studies.

6. Does the Model Produce Any Nonsensical Values (VA)?

4.6.12. For this test it is necessary to examine the model output for each time period. The output for strategy 1 in the example previously described is included in Appendix E. No unusual values were apparent in any model output used.

7. Does the Model Behave Like the Real System

4.6.13. The difficulties of comparing real and modelled systems have already been described. However, in such a small model with simple algorithms it is not difficult to monitor performance. Hence manual observations such as that undertaken for test 3 can be used to determine whether the behaviour of the model is satisfactory. It is of course possible that behaviour unlike the real system is due to deficiencies of a model, which like TRAIN, is in the early stages of development. In the absence of comparisons with observed data, robustness during sensitivity tests is the best indicator of satisfactory model behaviour.

8. What is the Response of the Model to Shocks

4.6.14. The response of a model to shocks incorporated into input datas is part of the systems analysis itself. In chapter 5, the impact of 'shocks' due to random and STEP functions will be tested.

Sensitivity Tests

4.6.15. The sensitivity of the TRAIN model output is primarily dependent on the parameter values input. Those parameters present in the ordering and capacity sub-models e.g. lead time and scale are central to the investigation and the effects of their variation will be examined in chapter 5.

4.6.15. The other important parameters occur within the forecasting and demand equations and relate to delays in information. The delays in question, SDD and DSDD, occur in the demand smoothing equations and they were assumed to be unity in the basic model. The effect of reducing them by 50% and increasing them by 100% is shown in Table 4.2. The effect of a variation in the solution interval DT is also shown. It is the effect on the variables TDCD and LTFE that has been illustrated as they will be used to measure model performance in chapter 5. Changes in delays initially affect the forecasts of demand and hence LTFE, followed by the ordering of capacity. This change determines changes in the capacity of the system and hence TDCD.

4.6.16. The variation in results shown in Table 4.2 shows no regular pattern. The largest change is observed in the variable LTFE when the delays in the smoothing equations are varied. This is not unexpected as these delays directly affect the forecast demand. However, the maximum change of 38%, although large, is of a lower order than the changes in the main output variables DCD, which occur as a result of variations in the primary systems parameters LT and CAPU. This will become apparent in chapter 5 when the model, considered to have satisfied a sufficient number of the validation tests, is subject to more extensive use.

CHAPTER FOUR

REFERENCES

1. Emshoff and Sisson (1970), Shannon (1975)

2. Emshoff and Sisson (1970)

3. Coyle (1977), p.97

4. ibid, p.99

5. Forrester (1961), p.90

6. ibid, App.D

7. ibid, ch.15

8. ibid, App.L

9. Paul Taylor of Warwick University used Holt's method in a similar modelling context

10. Paras. 3.5.1ff

11. Forrester (1961), p.115

12. Coyle (1982), p.362

13. Taken from GB Department of Trade (1979b)

STRATEGY	TDCD	LTFE	TDCD/LTFE
1	313	262	1.19
2	675	452	1.49

where: TDCD = total absolute difference between demand and capacity

LTFE = total absolute difference between actual and forecast demand

TABLE 4.1 SUMMARY OF MODEL OUTPUT FOR TWO STRATEGIES OF AIRPORT DEVELOPMENT

		OUTPUT VARIABLE	
		TDCD	LTFE
1.	DT = 0.01	-25%	-2%
2.	DT = 0.5	-31%	-1%
3.	Delays = 0.5	-26%	-34%
4.	Delays = 2.0	-26%	+38%

Percentage changes in variables compared with base run

(DT = 0.1, Delays = 1)

TABLE 4.2 TRAIN OUTPUT VARIABLES - EFFECT OF SENSITIVITY TESTS ON SMOOTHING DELAYS AND SOLUTION INTERVAL

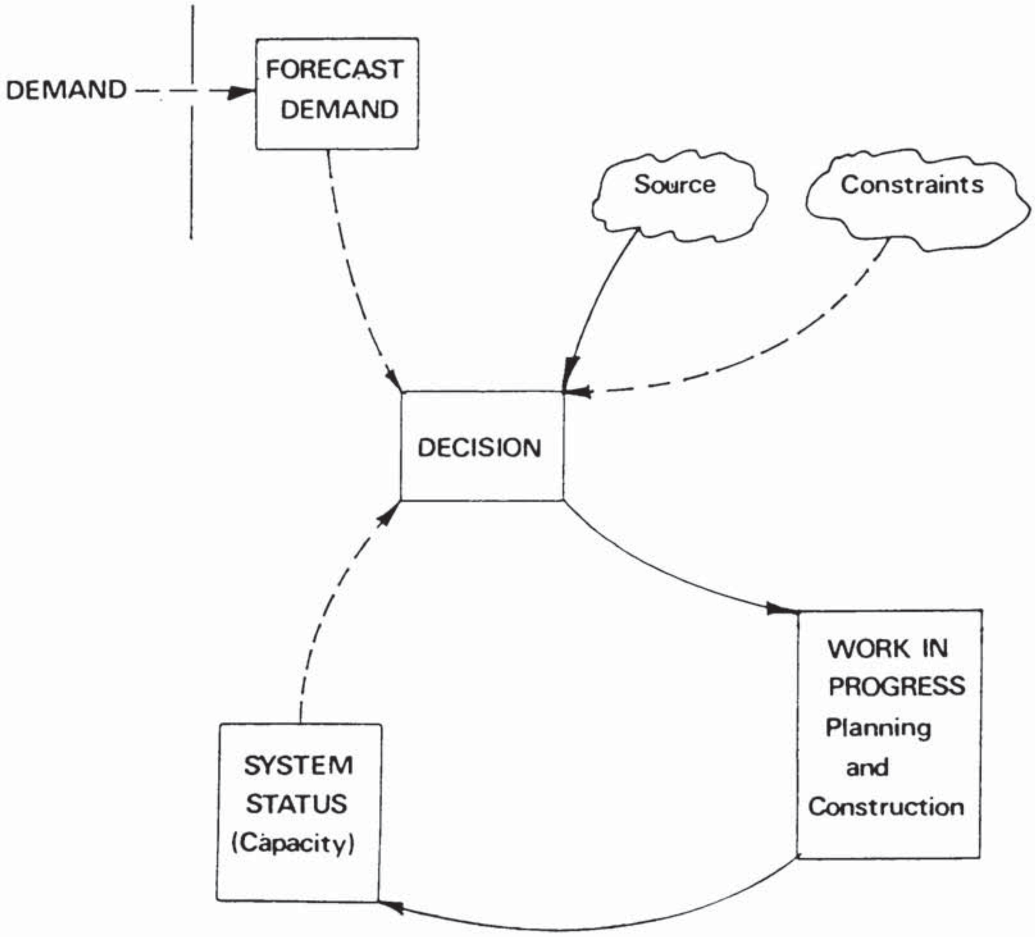

FIGURE 4.1 The Planning of Infrastructure Systems

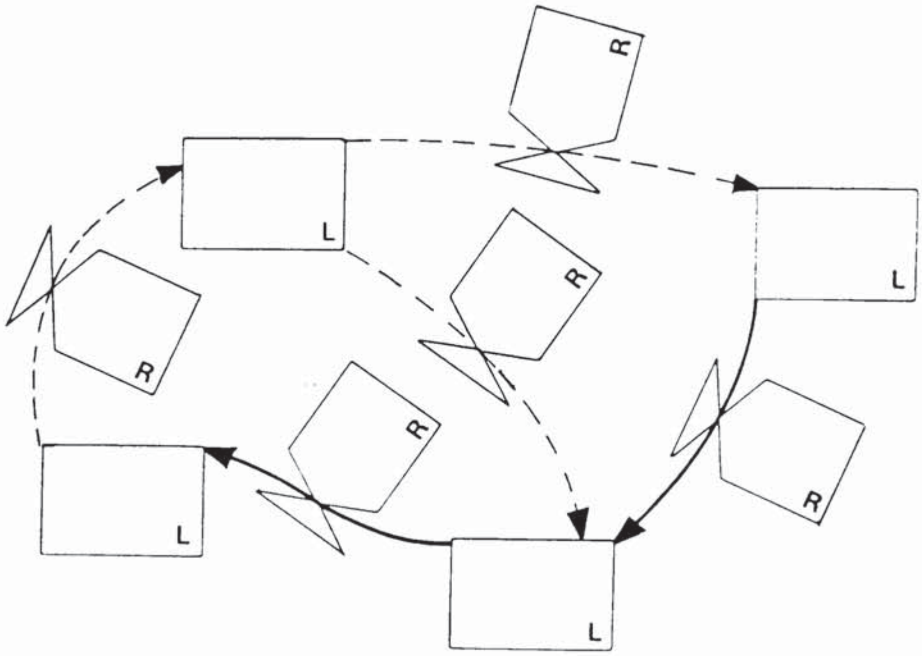

FIGURE 4.3 Interaction of Rates and Levels

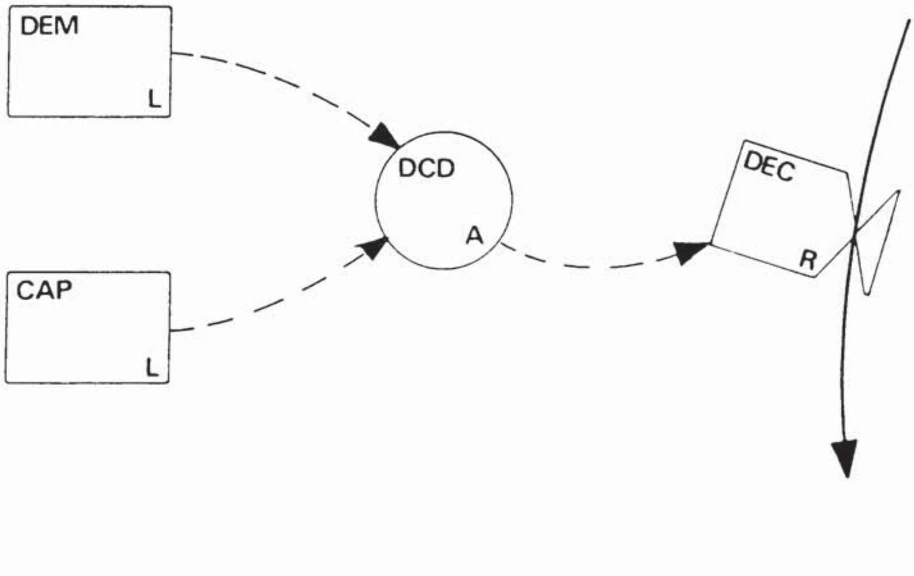

FIGURE 4.4 Auxiliaries

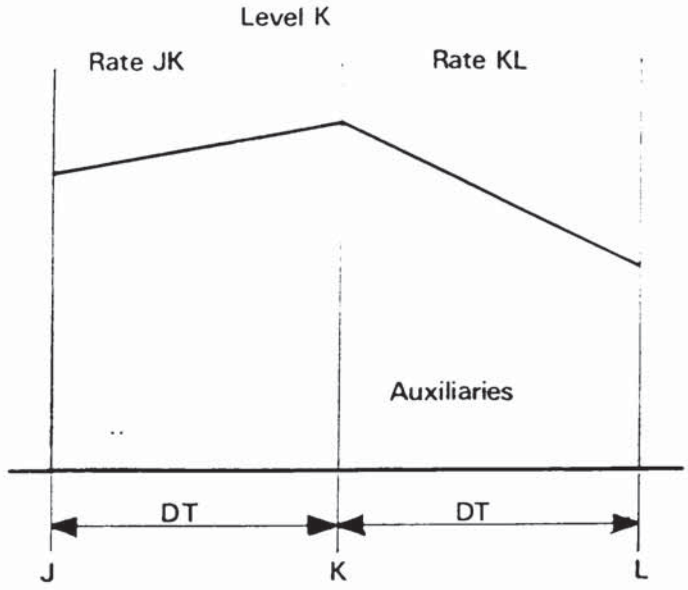

FIGURE 4.5 Treatment of Time in DYNAMO

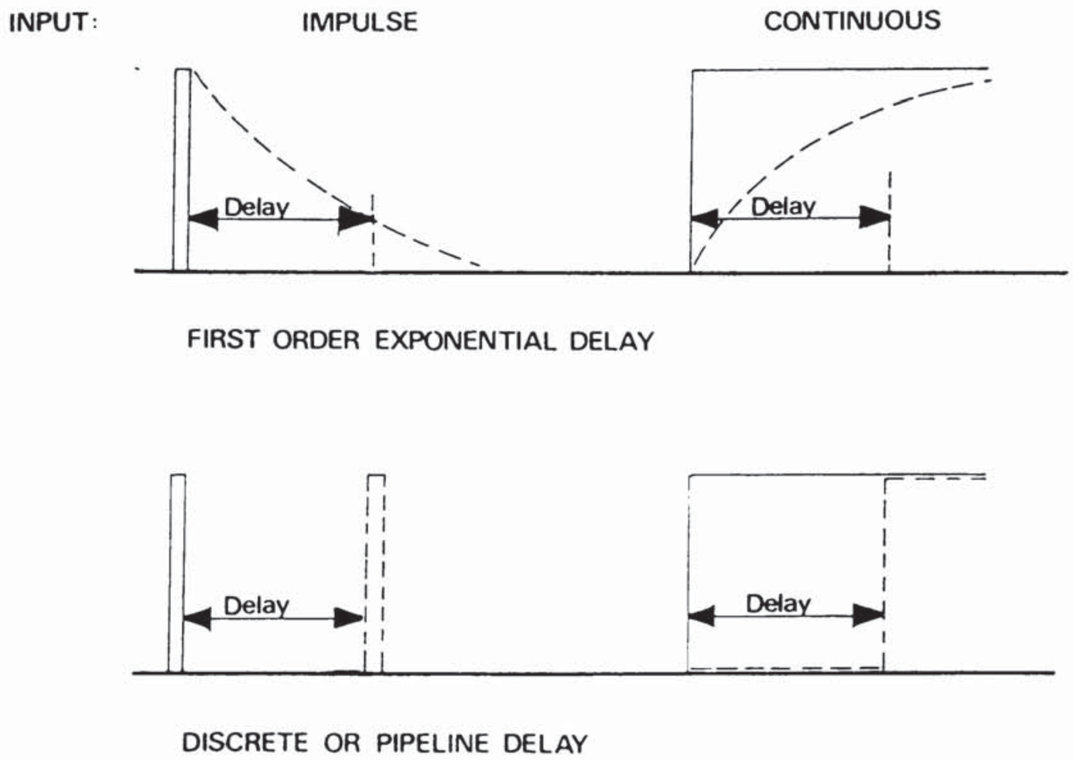

FIGURE 4.6 Two Types of Delay

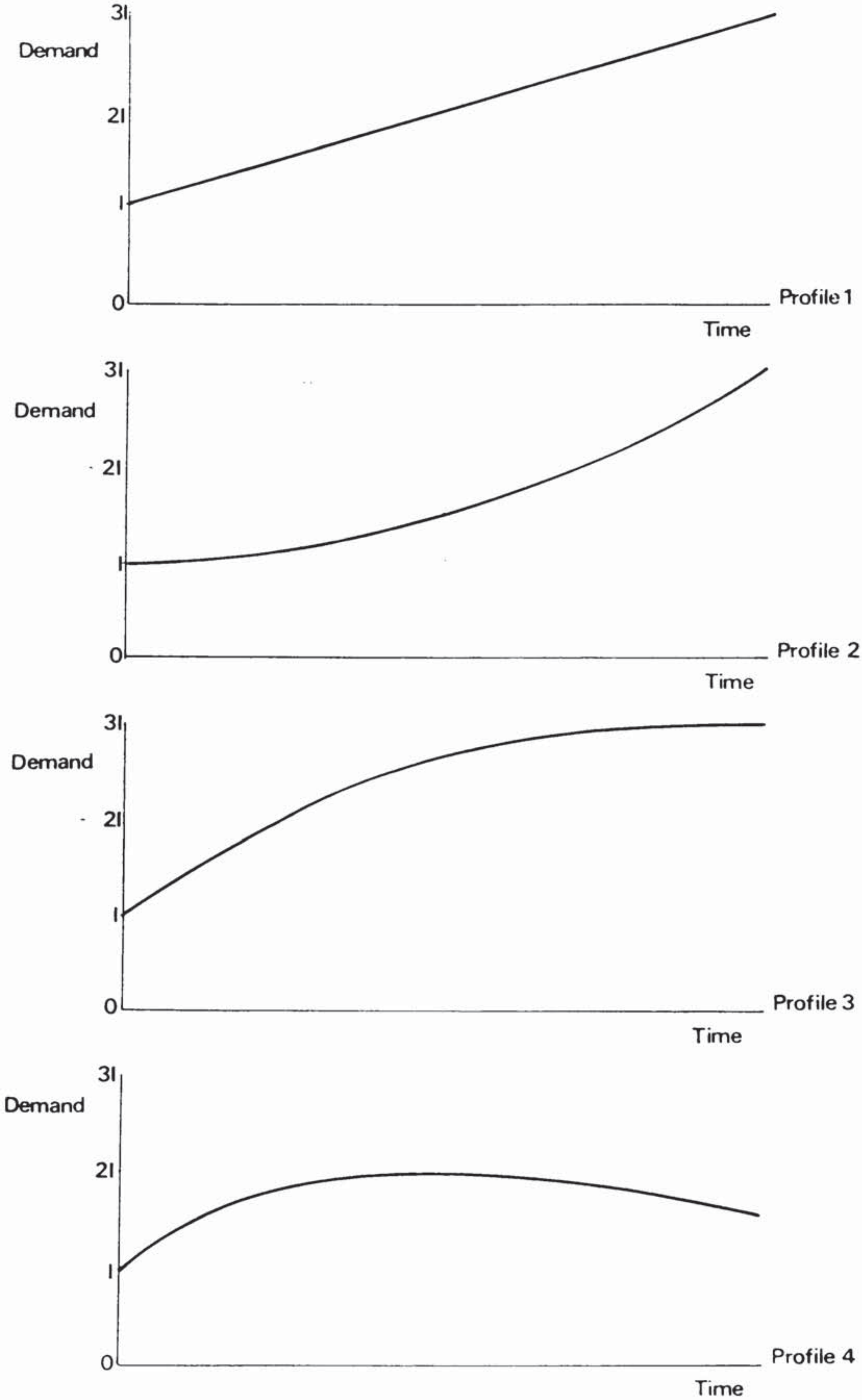

FIGURE 4.7 Demand Profiles for TRAIN

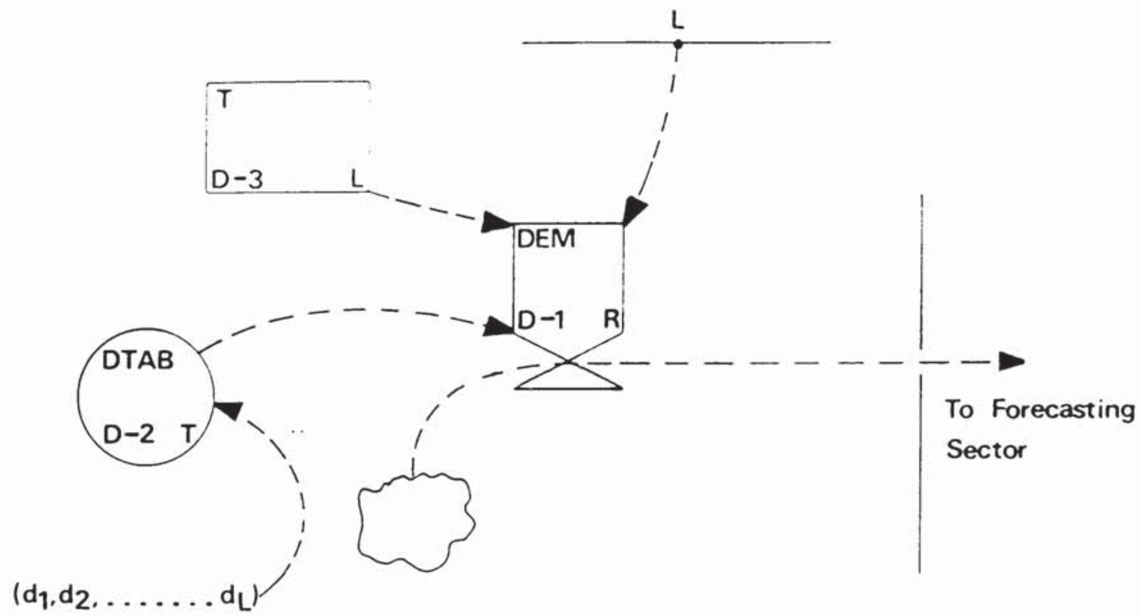

FIGURE 4.8 Exogenous Input of Demand Profiles

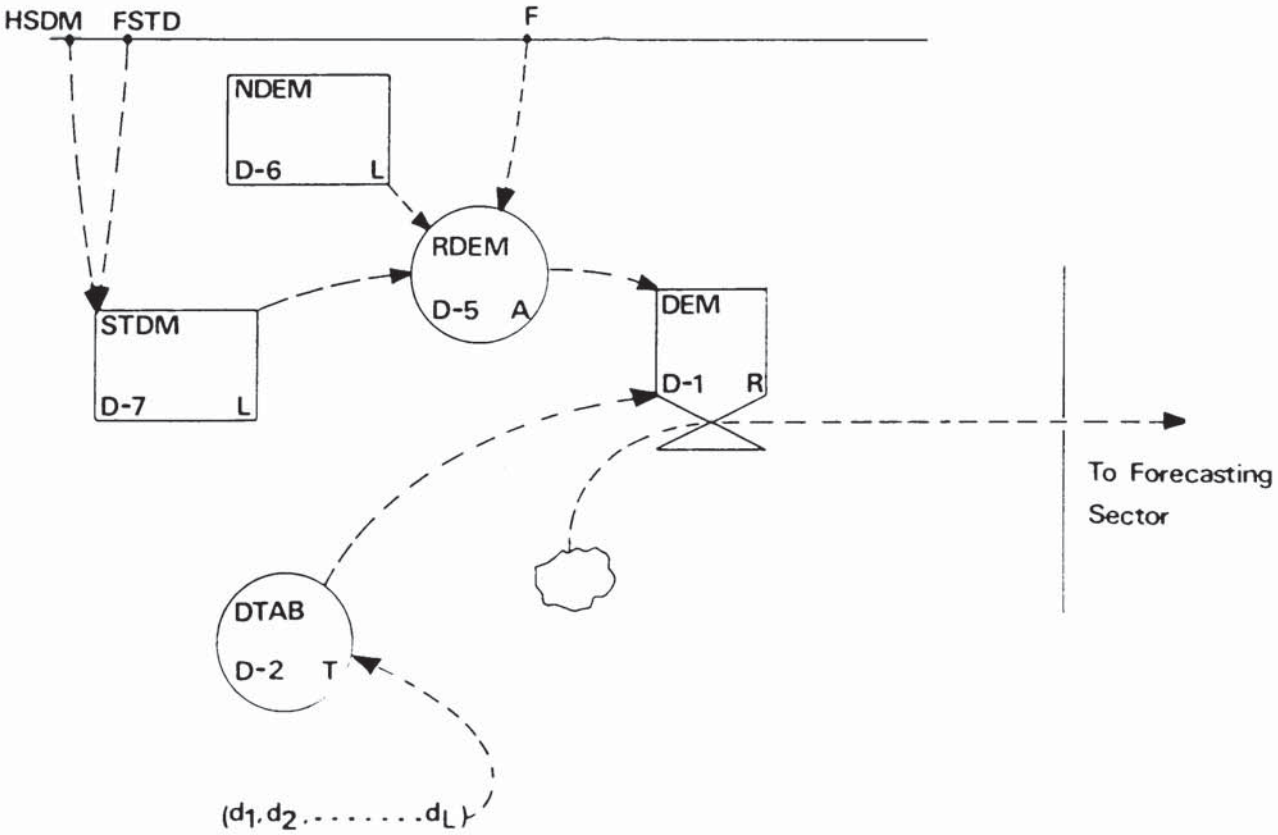

FIGURE 4.9 Random Fluctuation in Demand

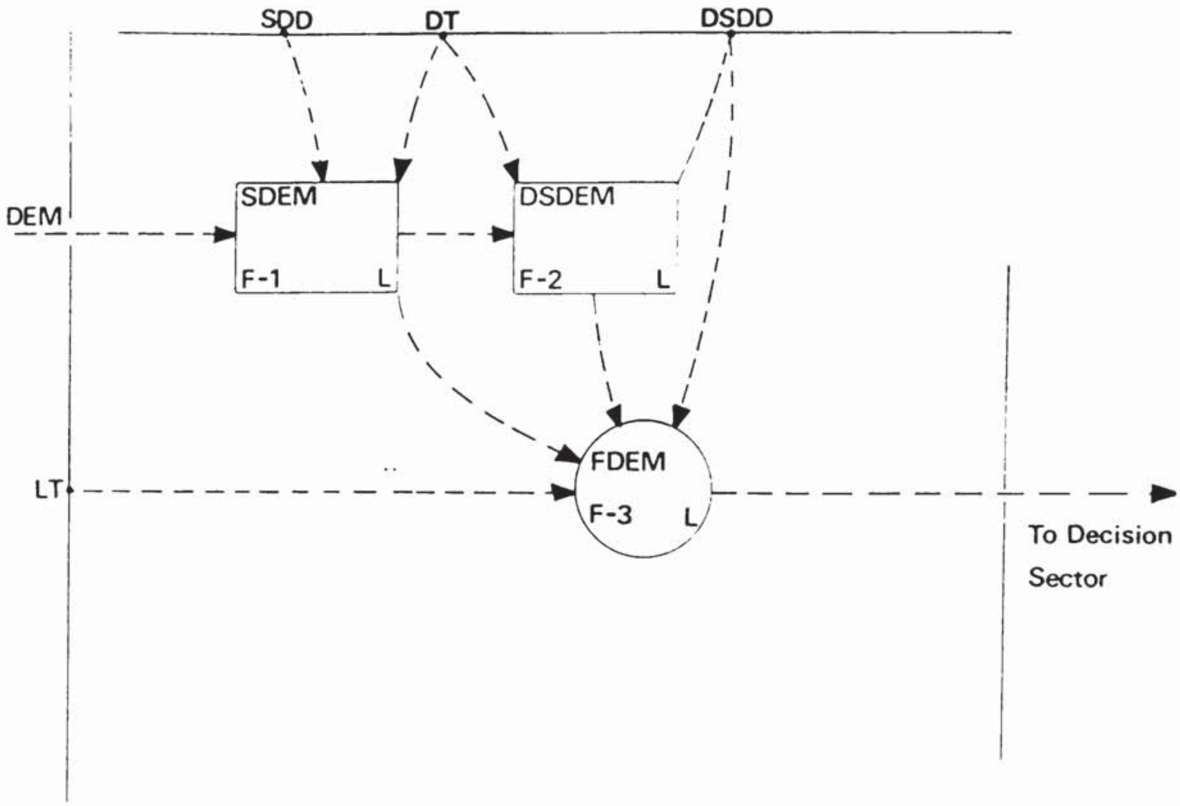

FIGURE 4.10 TRAIN - The Forecasting Sector

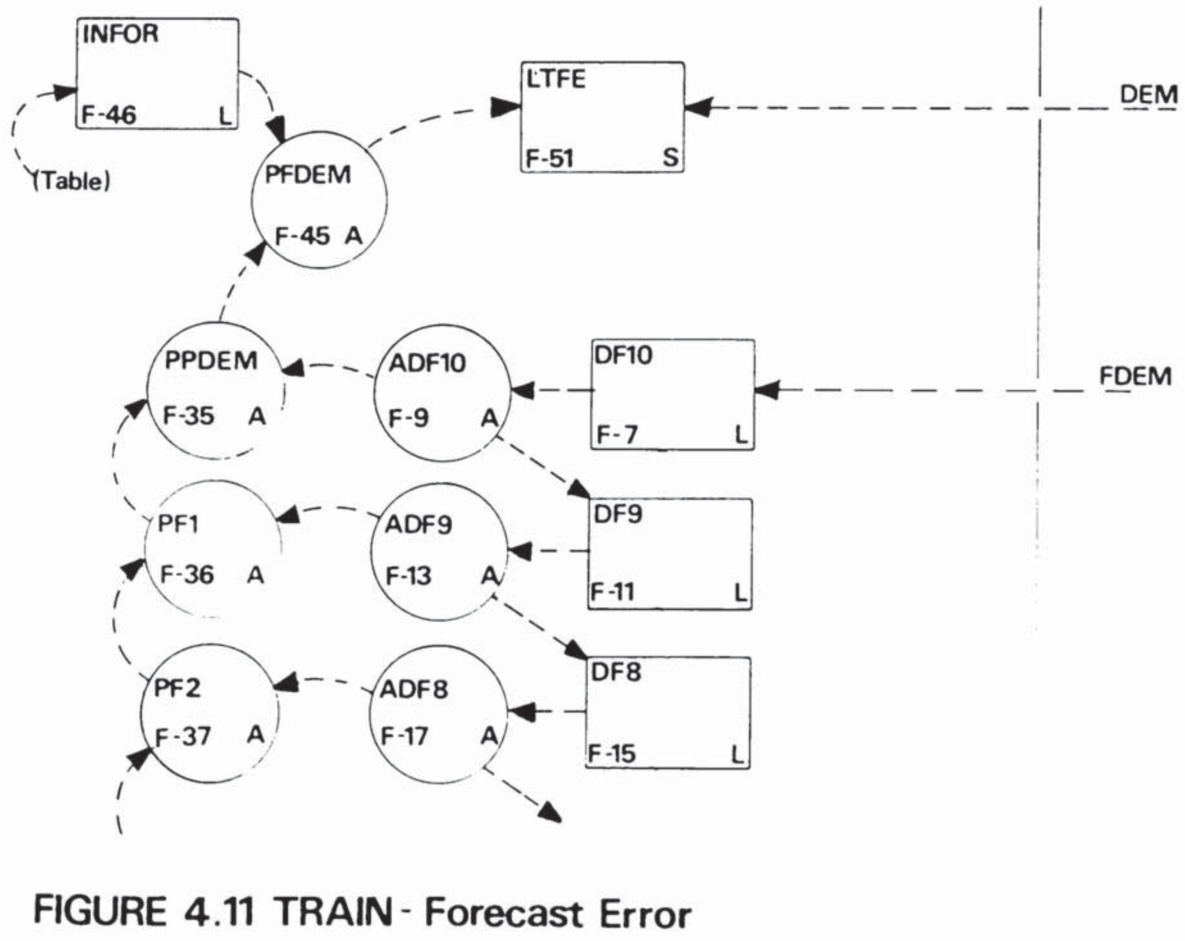

FIGURE 4.11 TRAIN - Forecast Error

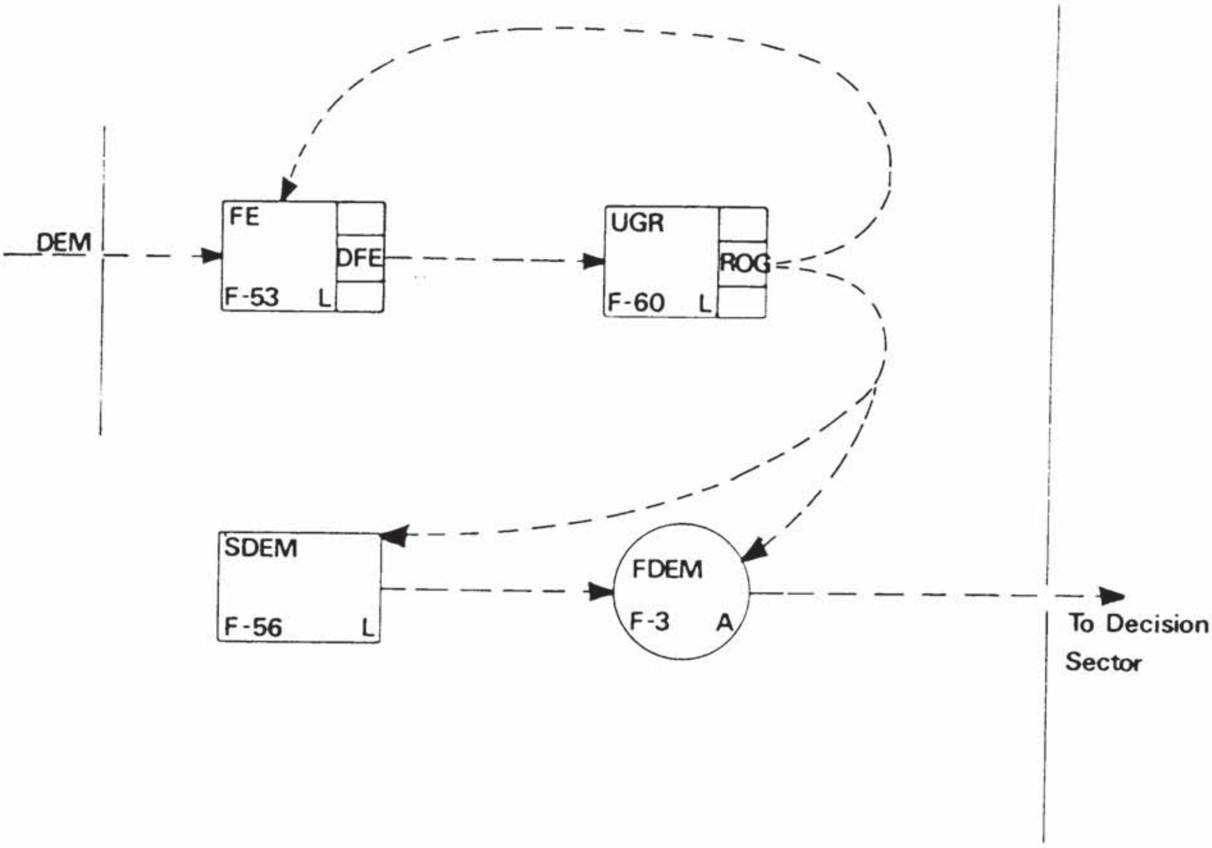

FIGURE 4.12 TRAIN - Holt's Forecasting Method

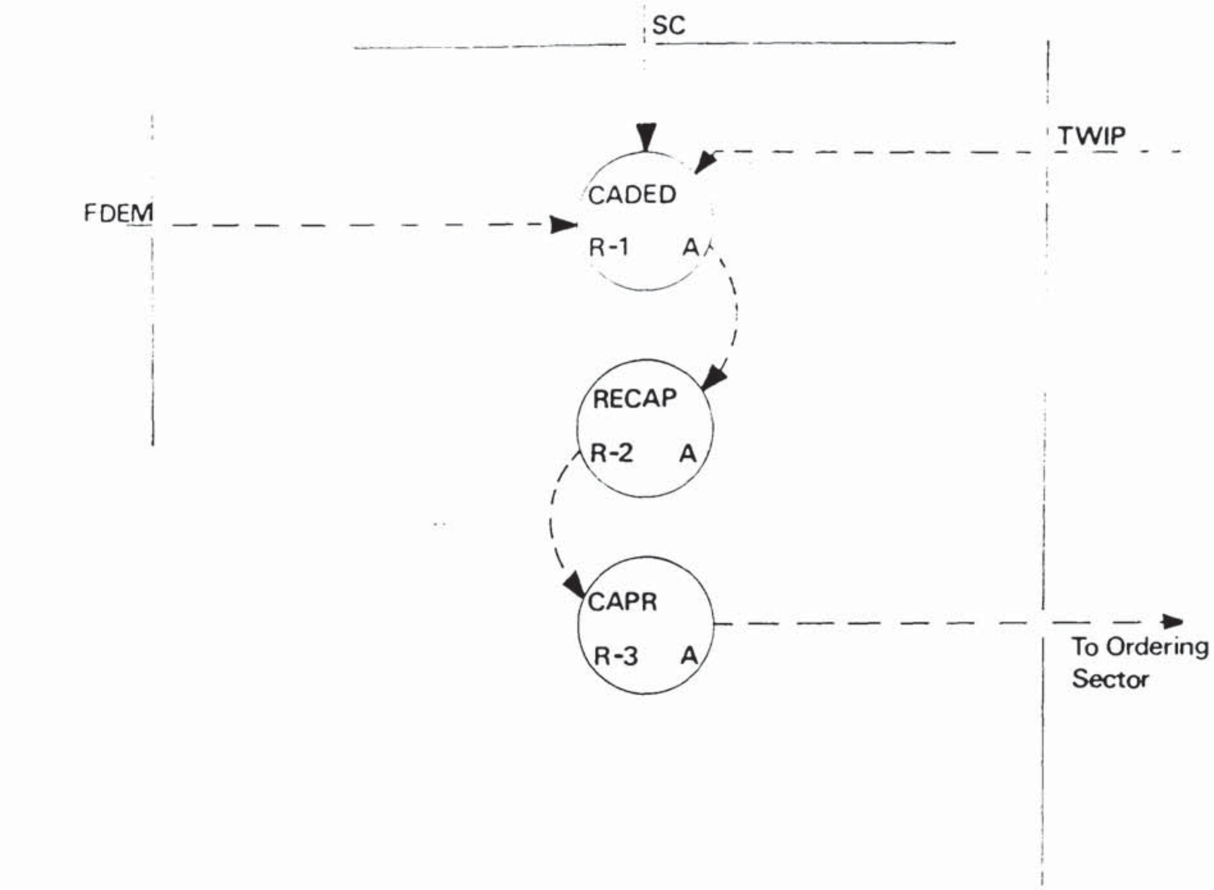

FIGURE 4.13 TRAIN - The Decision Sector

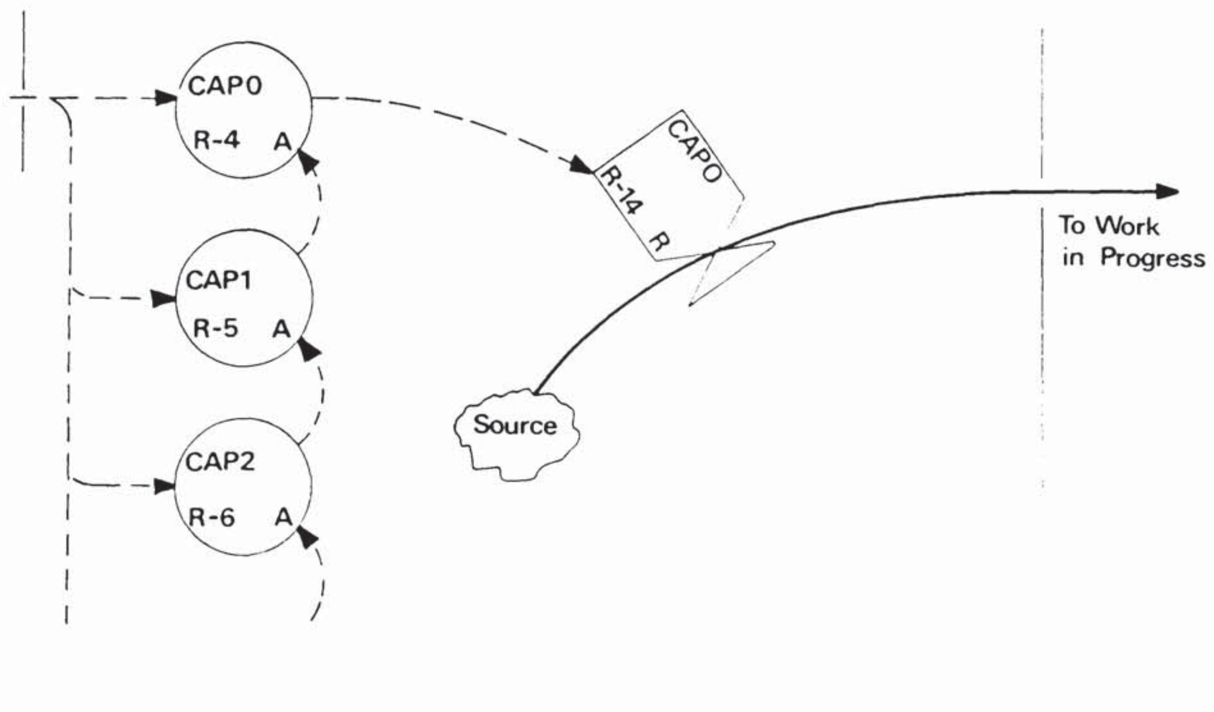

FIGURE 4.14 TRAIN - Whole Units for Ordering

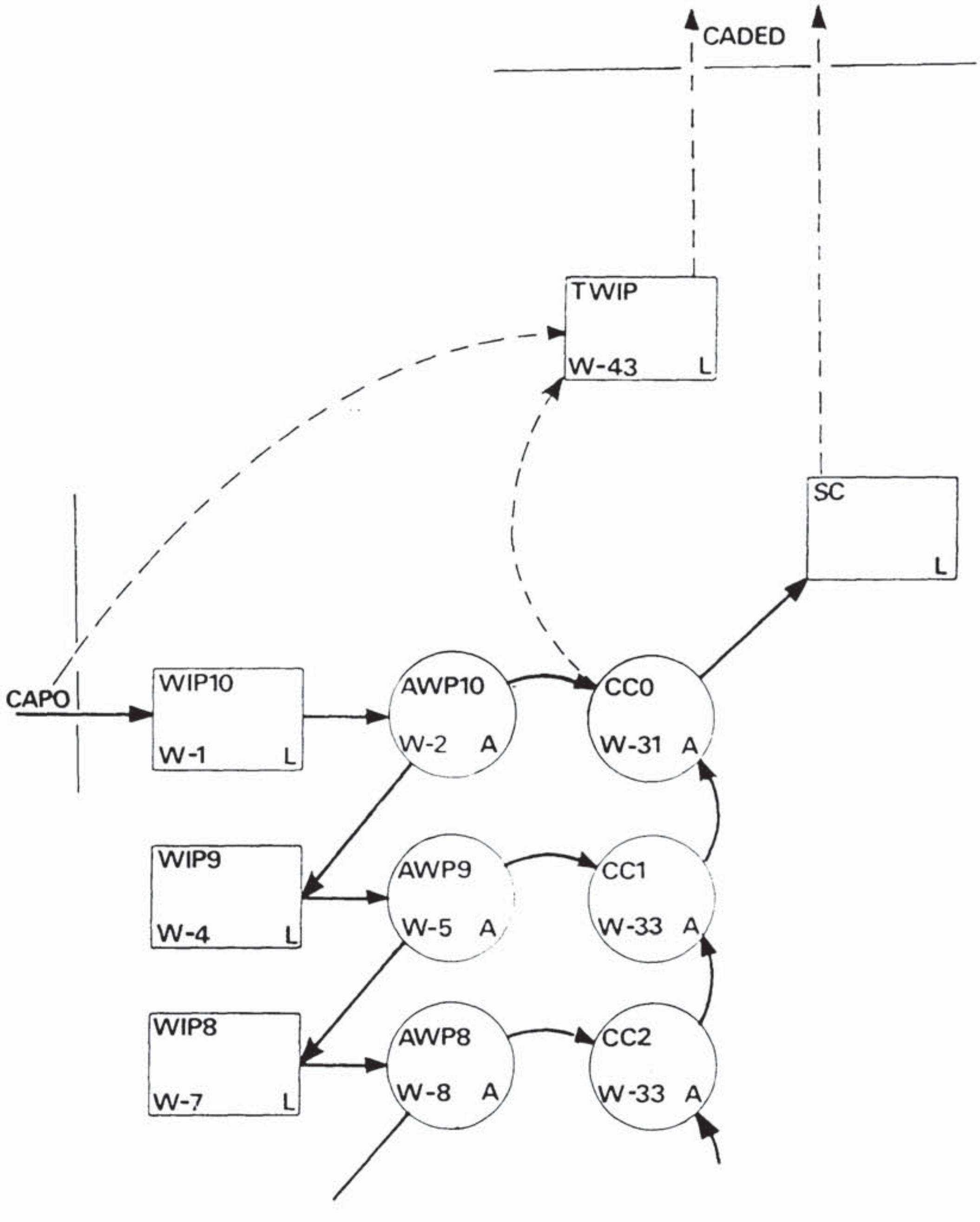

FIGURE 4.15 TRAIN - Work in Progress

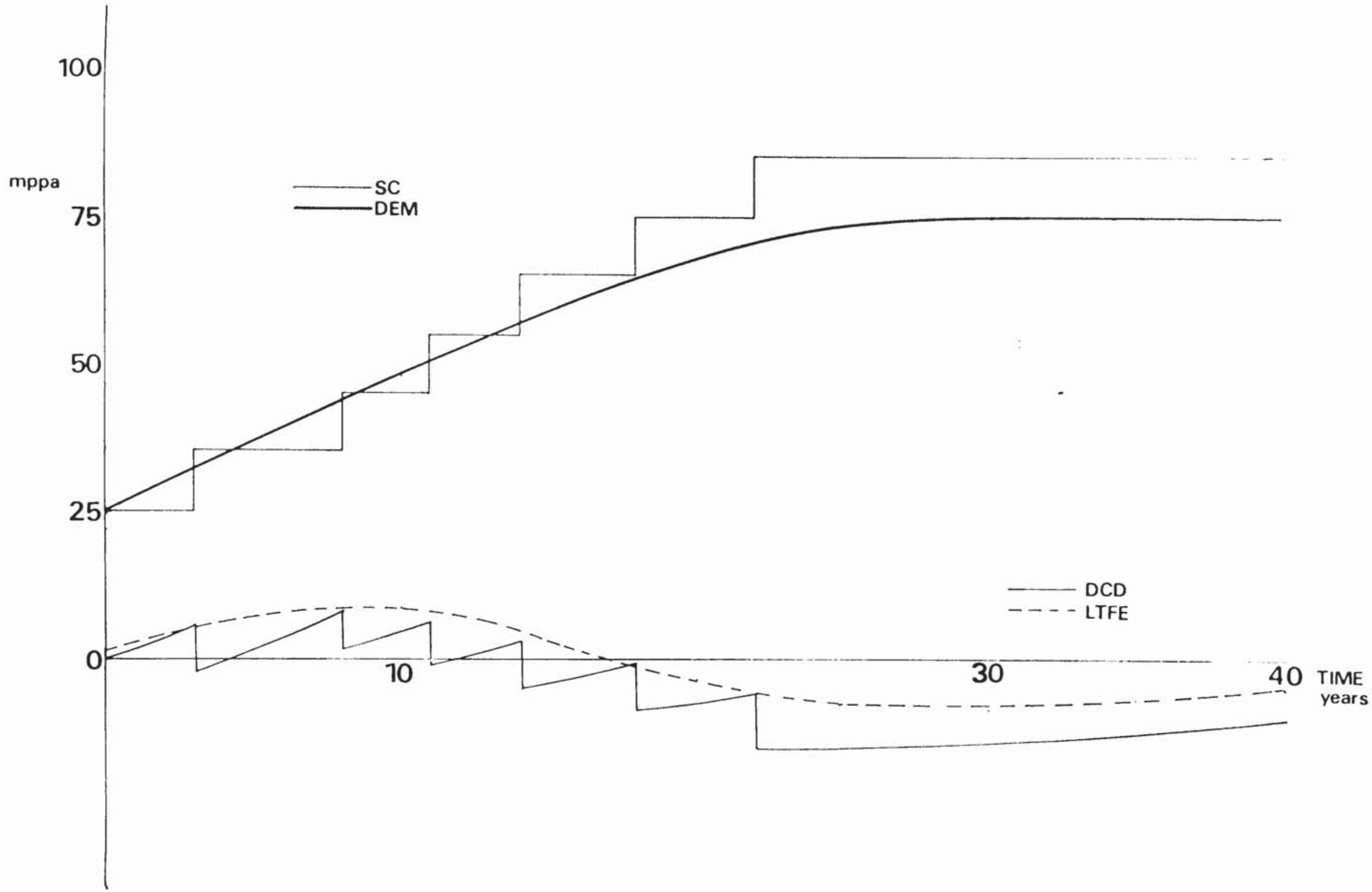

FIGURE 4.16 TRAIN - Example of Output - Strategy 1

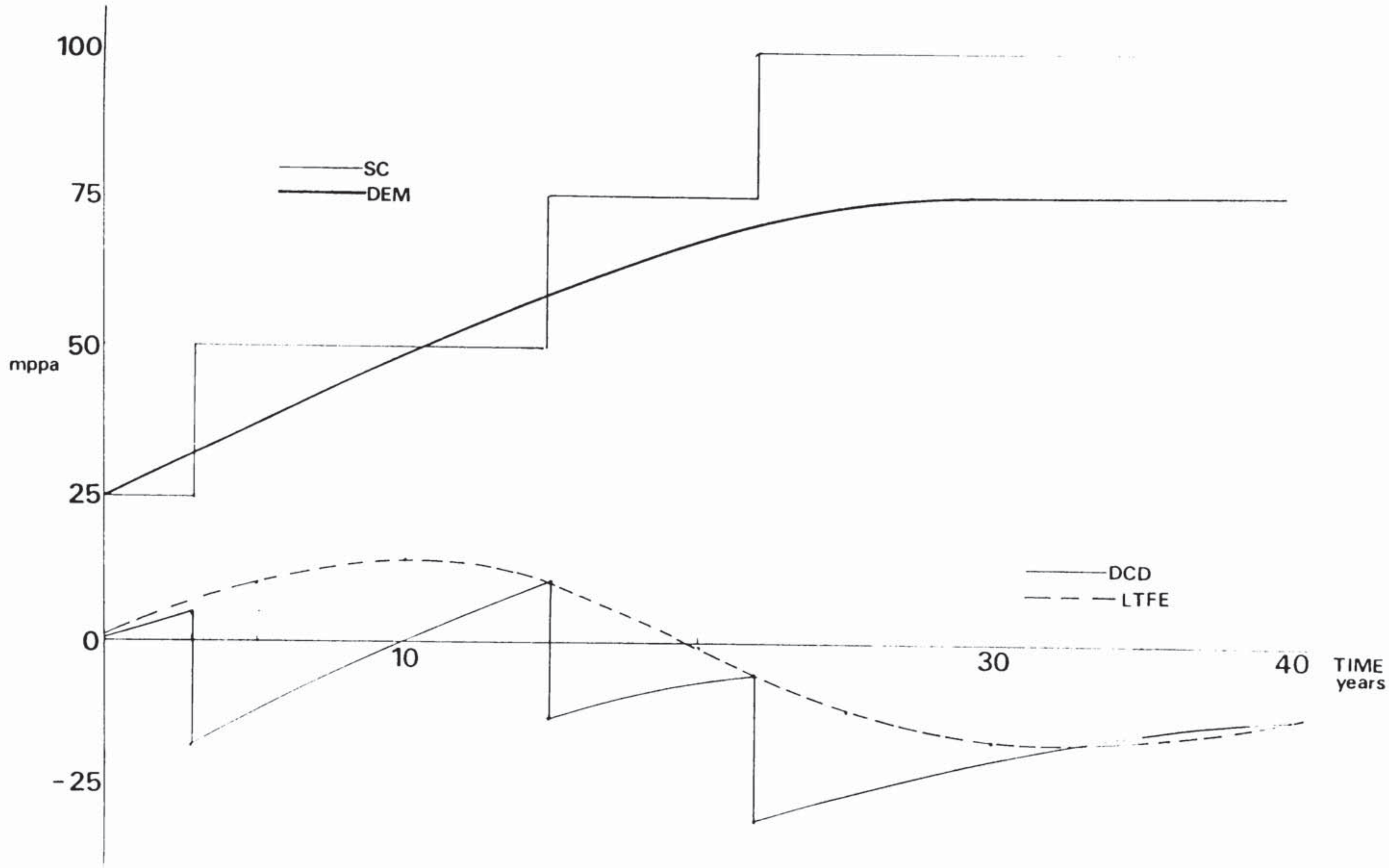

FIGURE 4.17 TRAIN - Example of Output - Strategy 2

CHAPTER 5

CASE STUDY ONE : AIRPORT PLANNING FOR LONDON

5.1. THE HISTORICAL CONTEXT

The Need for A Third Airport to serve London

5.1.1. The controversy surrounding the expansion of airport capacity to serve London can be traced back to the Second World War. Heathrow, a military airfield opened in 1943 became London airport in 1946. From that time onward there was concern over the availability of capacity to support Heathrow. This concern eventually became institutionalised as the third London airport issue. Stansted, the choice for the third site in 1986 was a possible site even in those early days of civil aviation.

5.1.2. Before the end of the 1940's a second airport to support Heathrow was deemed necessary, the two main alternatives being Stansted and Gatwick. In 1953, Gatwick was confirmed as London's second airport following a public inquiry which allowed the minimum investigation of alternatives. Like Heathrow, it was not the ideal site for a major international airport and:

> '...had either site been evaluated by the rigorous criteria of the 1960's or 1970's there is little chance that it would have passed the test.[1]

5.1.3 However it was to become apparent during future investigations into a third site that the planning issues surrounding airport development were rarely considered more important than the economic and political aspects of airport location. Unlike road planning, which developed from the disciplines of highway engineering and town and country planning, airport development lacked an institutionalised professional base. Thus it was not until the late 1970's that responsibility for London's third airport passed to the Department of the Environment and then in the 1980's the Department of Transport. Previously, airports had been considered a Trade and Industry matter.

5.1.4 This emphasis is confirmed by the next significant event following the choice of Gatwick for the second site in 1953. An inter-departmental committee was formed in 1961 to consider a third London airport:

> '....of its fifteen members, eight were officials from the Ministry of Aviation, five others represented air traffic in one way or another, one represented ground transport, and there was a sole representative from the planning division of the Ministry of Housing and Local Government'.[2]

The committee found that Stansted was the only suitable site for a third London airport and that it should be developed, as the capacity at Heathrow and Gatwick would be insufficient to accommodate demand by 1973.

5.1.5 It was as a result of this committee's findings that the problem of airport development became crystallised as the

Third London airport issue. They were significant because they precipitated fierce opposition from residents in the Stansted area and resulted in increasing participation from interested groups.

5.1.6 As a result of public pressure, the Government was forced to hold a public inquiry into the Stansted proposal. The inspector, faced with competent submissions from objectors was unable to find in favour of Stansted. Although the need for a new airport was not questioned, Stansted was not considered the best location on planning and environmental grounds.

5.1.7 However, the Government re-affirmed its commitment to Stansted in the White Paper of 1967.[3] The need for a new airport was now considered urgent and further investigation of alternatives would cause further delay. Thus the emphasis was on aviation matters and expediency of construction which favoured Stansted while other issues such as regional planning, the role of provincial airports and environmental impact, all aired in the inspector's report, were regarded as less important. These issues were to be raised again in future inquiries.

5.1.8 The White Paper did little to diminish criticism from objectors and local MP's. Public concern increased as the original proposal for two runways at Stansted considered by the public inquiry because a four-runway airport in the White Paper. Additionally, Anthony Crosland assumed responsibility for the Board of Trade shortly after publication of the White

Paper. He had been critical of the Government's approach to the third London airport issue and preferred a more rigorous appraisal of the problems than that undertaken at a local public inquiry. Such an appraisal was to be undertaken by the Roskill Commission.

The Commission on the Third London Airport

5.1.9 The Brief given to the Roskill Commission was:

> "To enquire into the timing of the need for a four-runway airport to cater for the growth of traffic at existing airports serving the London area, to consider the various alternative sites, and to recommend which site should be selected'.[4]

The commission was also directed to make extensive use of the techniques of cost-benefit analysis in its assessment.

5.1.10 This brief has been criticised for prejudging the issues, particularly that of need:

> 'The issue was captured from the start: all subsequent discussion took for granted that a new airport would sometime be built'.[5]

More specifically, the brief appeared to rule out expansion at existing airports (both in London and any of the provinces), subsequent growth in air traffic would be transferred to the new airport.

5.1.11 The report of the Roskill Commission has been reviewed in many other analyses and does not bear repetition here. The most important issues in the context of infrastructure development were the two contained within the brief: the timing of the need (as expressed through forecasts of demand and assumptions regarding capacity) and the assessment of the alternative sites through the application of the cost-benefit techniques. The Commission employed a working party to provide extensive technical support. It was responsible for the forecasting of traffic demand as well as the application of the evaluation techniques.

5.1.12. At the time of the commission's investigations, air travel was still confined to a minority of the population with business travellers dominating the market. However, the commission recognised that air travel would become more common and this could be quantified by a 'propensity to fly'. The main variables determining an increase in the propensity to fly were increases in income (assumed to be 3% p.a. in real terms), economic growth and increases in population with a saturation level of six flights per person per year within each category of user. These factors were used to generate levels of passenger demand. Given estimates of the important factor of aircraft capacity, passenger demand was converted to air traffic movements. Comparison of air traffic movements with the capacity of available runway space would generate an optimum time for development of the new airport.

5.1.13. This brief description of air traffic forecasting does not reflect the many assumptions necessary. Economic growth, aircraft capacity and runway capacity all require such assumptions. It was the issue of aircraft capacity that eventually caused problems for the Roskill Commission's findings. Runway capacity too is open to interpretation, being dependent on air traffic control improvements and also the proportion of the day during which the runway is at peak capacity. The consequences of demand exceeding capacity are an increase in congestion and therefore an increase in costs. The optimum timing for a new airport was deemed to occur when these congestion costs exceeded the costs of bringing forward construction. The commission considered that this situation would occur in 1980 and recommended that year as the opening date for the third London airport.

5.1.14. The timing of the need was not totally dependent on the aggregate forecasts of demand. This aggregate was first distributed between the various existing airports. The timing of the need obviously depended on this distribution, the more attracted to the existing London airports, the sooner the need for a third. The model used to carry out this distribution of traffic was of the gravity type, similar to that described in chapter 1 in the context of urban transport planning. This model covered a wide area, including Manchester in the north and Bristol to the west, although the midlands airports such as Birmingham were not considered important and not included.

5.1.15. It follows that the choice of site for the new airport will be dependent to some extent on the effect it will have on the distribution of traffic. This was determined by the accessibility defined for the catchment area of each site. Thus if Foulness had been chosen for the third London airport, extra traffic would be generated at Manchester and Luton, as the catchment area of the London airports would shift eastwards, so increasing that of provincial northern airports. Hence the third London airport must be considered a national investment rather than being uniquely dedicated to London.

5.1.16. The commission began with a long list of 78 possible sites for the third London airport. These were initially ranked according to their impact on noise pollution, defence and surface access. This list was then successively reduced to a medium list, a short list of six and finally a short list of four, the assessment becoming more rigorous at each stage. The final list consisted of the three best sites, Cublington in Bucks, Northampstead Herts, and Thurleigh in Bedfordshire. In addition, Foulness was included because it was considered a unique solution. Stansted was ranked ninth, and so was not included even though it fared better than Foulness which was ranked thirteenth.

5.1.17. Give Stansted's prominence in previous and subsequent assessments, it might have been expected to perform better in the evaluation. Its low ranking was perhaps due to the fact that the presence of existing airport facilities carried no weight in the ranking of alternative sites. The twenty factors used in the final assessment are shown in Table 5.1, which gives a comparison of the four sites with the favoured site (Cublington) attributed an aggregate cost of zero. The aggregate costs of the other three sites were given relative to the cost of Cublington. Presented in this form the appraisal was one of cost effectiveness which compared the relative merits of each site rather than an analysis of absolute costs and benefits.

5.1.18. One of the most eminent members of the commission, Sir Colin Buchanan dissented from the choice of Cublington and hence the final report.[6] He regarded the location of the third London airport as a planning rather than an economic issue and he was sceptical of the cost-benefit approach. He re-affirmed his view that on planning grounds, Foulness was the only suitable site. The commission did not consider the planning aspects sacrosanct but a factor to be assessed with any other.

5.1.19. In terms of political decision-making, the Buchanan disclaimer proved to be extremely important. The perceived split within the commission was much publicised and Maplin, as Foulness became known, gained substantial public support to add to that of a planning profession already committed to it. As a result the government chose to reject the findings of the commission and in April of 1971 declared Maplin the site of the third London airport.

5.1.20. Following the general election of 1970 a conservative government came to power and the instigators of the Roskill Commission were in opposition. While the government pressed ahead with legislation to develop Maplin and supporting services, the opposition gradually adopted a position which rejected Maplin, and concentrated on developing existing airports, with the possibility of a new airport on a much smaller scale than that envisaged in the brief to the Roskill Commission.

5.1.21. This parliamentary opposition gained further credence in 1973 when the oil crisis intervened and a more pessimistic vision of the future emerged. All of the factors determining future air traffic demand (e.g. incomes, economic grants) were subjected to revision and resulted in much lower traffic forecasts. In addition, the increase in oil prices forced airlines to reduce fuel consumptions and increase the load factors of aircraft, which in addition to the introduction of wide-bodied jet airliners, produced an even larger drop in air traffic movements.

5.1.22. Thus in 1973, forecasting suddenly became much more important than before. Previously there had been a consensus in support of the Roskill Commission recommendation that a new airport would be required in 1980. In 1974 the Department of Trade published a review of the Maplin project[7] containing the revised forecasts and the project was abandoned.

5.1.23. The revised forecasts of air traffic deferred the need for a decision on a third London airport and in the years following the abandonment of Maplin, allowed a comprehensive analysis of the airports strategy for Great Britain, a task never previously undertaken. The results of these studies were published in 1975[8] and 1976[9] for London and the regions respectively. In 1978 a White Paper on 'Airports Policy'[10] was finally published together with a further review of air traffic forecats. The resulting policy was inconclusive as it listed possible future options as:

1. a major expansion of an existing airport
2. the development of an existing military airfield
3. the construction of a new airport.

5.1.24. These essentially left all future options open with the exception of the development of Maplin, the decision to reject this solution was re-affirmed. Existing airports were now considered capable of dealing with existing demand and a new airport was not required immediately. In particular, there was no perceived need for a new airport outside of South East England.

5.1.25. The rejection of a new airport was possible because of the way in which existing sites had been able to cope with increases in traffic. Since 1973, passenger throughput rather than air traffic movements had determined capacity and the White Paper confirmed proposals for a fourth terminal at Heathrow and a second at Gatwick to meet new passenger demand.

5.1.26. To advise the government on future decisions relating to airport development the government instigated the Advisory

Committee on Airports Policy (ACAP) in 1978. In addition, a Study Group on South East Airports (SGSEA) was formed to examine the needs of the London area. The results of all of the studies from 1974 onwards were presented in chapter 2 as they concentrated primarily on the infrastructure aspects of airports. In the reports of these studies the cost-benefit approach to evaluation was conspicuously absent. This reflected not only a more sceptical view of that technique, but also a less certain view of the future and misgivings over the particular risks associated with large scale projects, which cost benefit analysis could not encompass.

5.1.27. One year after the White Paper of 1978, the ACAP published its report.[11] Its view on air traffic demand was that the existing capacity of the London area airports would be exhausted by the late 1980's and the government was once again requested to confirm that future demand would in principle be met by adequate capacity and decide upon a site for a third airport. The lead times of planning and construction were such that land safeguarding and acquisition was needed immediately. ACAP gave no preference to any of the six short-listed sites given in the report of the SGSEA also published in 1979.[12] This new short list was arrived at through a procedure similar to that of the Roskill Commission in that one site was chosen from six identifiable sub-regional areas around London. The six sites chosen were:

1. Hoggeston (nr. Cublington) Bucks.

2. Yardley Chase, Beds.

3. Langley, Herts/Essex.

4. Stansted, Essex.

5. Maplin, Essex Coast.

6. Wilingale, Roding Valley.

5.1.28. Significantly, Stansted was present as too was Maplin which by this time had been formally rejected by Government on two occasions. The sites were assessed in terms of resource costs for three factors, site acquisition and preparation, construction and surface access. Stansted had by far the shortest lead time (8 years) and Maplin by far the longest (17 years). On capital costs, Stansted was the cheapest by some margin due to the presence of an existing airport at the site, although it was the second most expensive to expand beyond 25 mppa. (see chapter 2). Maplin was not the most expensive; Yardley Chase required a greater initial investment, but it was considered the cheapest to expand beyond the initial commitment of 25 mppa, reflecting the available land on the Essex coast and the constraints on the inland sites, particularly Stansted.

5.1.29. When Stansted emerged the favourite from the short list an airport was already in operation at the site. This gave it low initial costs and a shorter lead time that would allow its development to meet the deadline of 1988 as prescribed. In 1982, Michael Heseltine the Secretary of State for Environment ordered a new inquiry, initially into the development of

Stansted as the third site. Shortly after the beginning of the inquiry, its terms of reference were broadened to include any other alternatives put forward to the inspector Graham Eyre QC. These included a fifth terminal at Heathrow and another coastal site, this time on the River Severn at the Western end of the M4.

5.1.30. Once again the interested parties including the British Airports Authority, (whose planning application to expand Stansted was actually the subject of the inquiry), local commerce and objectors, the planning profession and provincial consortia were motivated to submit evidence. Once again the planners in the shape of the Town and Country Planning Association (TCPA) quickly became disillusioned at the apparent indifference to planning issues which for them pointed to a coastal site.

5.1.31. After three years, the inspectors report was published in 1985[13] recommending a two-runway airport at Stansted. Nicholas Ridley, Secretary of State for Transport which was now responsible for air travel accepted the reports findings and confirmed the development at Stansted.

5.2 AIRPORT PLANNING FOR LONDON - ANALYSIS

Forecasting

5.2.1. The future demand for air travel in SE England has been subject to numerous forecasts since a third London airport was first mooted. These forecasts are shown in Figs. 5.1 and 5.2.

The overall trend has been to reduce estimates, while actual demand has suffered two decreases, firstly following the 1973 energy crisis and secondly during the economic recession of the late 1970's. Given these effects on actual demand, it is to be expected that economically derived forecasts will be reduced in the light of less optimistic forecasts for the main parameters of economic growth, fuel price and incomes.

5.2.2. However, the decrease in forecast demand was gradual rather than immediate. Each successive forecast between 1974 and 1983 exhibited slightly lower estimates. The reason for this lies in the method used to derive the forecasts. Air traffic demand consists of three components, UK international traffic, Foreign international traffic and domestic traffic. The two international componenents are further divided into busines and leisure traffic. In 1975, the distribution of traffic between these categories at the 4 London airports was as shown in Table 5.2. Overall, business traffic accounted for 19% of the total and domestic traffic 14%.

5.2.3. In 1979 the ACAP report included a series of sensitivity tests on air traffic forecasts undertaken for the Committee by the Air Traffic Forecasting Working Party (ATFWP). In the first case fuel prices were increased by a maximum 33%. This resulted in a reduction of the 1985 forecast of 0.8 mppa (1%). The forecast for the year 2000 was reduced by 8.8 mppa (7%).[14] There are two reasons why the changes are so small. The sensitivity tests were applied only to international traffic and as business traffic is assumed insensitive to the cost of travel, one third of the total traffic was unaffected by the changes. In addition,

> 'fuel and oil costs in 1978 only represented a little over a fifth of total airline costs.'[15]

Together with further assumptions regarding the increased fuel efficiency of aircraft and increasing load factors as a result of the increase in fuel prices, the effect of these increases was partially annulled.

5.2.4. A similar effect was observed when the sensitivity to economic growth, as expressed through GNP was tested. GNP was assumed to grow at a lesser rate than for Western Europe as a whole, which in turn exhibited lower growth rates than the rest of the world. Furthermore the increase in GNP was assumed to fall from 2.25% and 2.75% in 1977-80 to 1.25% and 2.25% in 1996-2000 for low and high growth respectively.[16]

5.2.5. Forecast economic growth for the period 1977-80 was further reduced to 1.0% (low) and 1.5% (high) as the economic recession of that period became apparent. These later figures were applied as a sensitivity test to the forecasts for ACAP resulting in maximum changes to the forecasts of -3.1 mppa (5%) in 1985 and 0.65 mppa (5%) in the year 2000.[16] Given such low levels of growth the small impact of any change was to be expected. The changes in fuel price and GNP were not allowed to reinforce each other. Thus the high fuel prices could not co-exist with low economic growth.

5.2.6. Whereas the effect of sensitivity testing of the forecasts was minimal, its impact on the timing of the need for a new airport was even less apparent. It did not alter ACAP's conclusion that a new airport would be required by the end of the 1980's. This was a similar conclusion to that reached by previous assessment, particularly that of the Roskill Commission which concluded that the opening of the new airport could only be deferred by a maximum of two years.

5.2.7. Hence, because there have been a series of relatively small revisions in forecasts, the effect on the need for investment has been negligible. However, from Figs.5.1 and 5.2, it is apparent that the effect of these changes in aggregate has been to defer the need by approximately 10 years. The Roskill Commission concluded a third airport would be required by 1980 when passenger demand would be 56 mppa. Latest forecasts indicate that this level of demand will not be reached until 1987 or 1995 for high and low growth respectively.

5.2.8. The apparent insensitivity of the issue to changes in forecast may explain why there was until recently little dissent over the timing of the need. Buchanan's disclaimer over the findings of the Roskill Commission concerned only location, he accepted the section of the report concerning forecasting. Yet at the 1982 inquiry into Stansted he stated that the existing airport system could accomodate foreseeable traffic growth.[17]

5.2.9. Alternatively, forecasts of capacity at London airports have not changed at all since the Maplin Review of 1974. Passenger throughput has remained the determinant with 38 mppa the maximum estimate for Heathrow with four terminals and 25 mppa for Gatwick with a second terminal.

Infrastructure Issues

5.2.10. The history of the third London airport provides a pertinent comparison of large and small scale solutions to a transport planning problem. The 'single site' approach characteristic of the major political and planning efforts required large commitments because of the inflexibility of the infrastructure involved. The high capital costs of the engineering works at a new site and the construction of airport facilities necessitated guaranteed funding for such projects.

5.2.11. The long lead times of design, decision-making and construction made the project extremely sensitive to uncertainty. This became apparent in the early 1970's when the main determinant of infrastructure needs changed within a period of three years. The Roskill Report, published in 1971 determined capacity requirements on the basis of air traffic movements or runway capacity and the decision to develop Maplin in part reflected this definition. By 1974 and the abandonment of Maplin, the passenger throughput of terminals had become the determinant of airport capacity. The infrastructure requirements of the airport system changed substantially in a period much shorter than the lead time of even the smallest airport developments.

5.2.12. The consequences of the abandonment of Maplin illustrated the inability of the planning process to re-orientate large scale infrastructure projects once environmental changes or 'shocks' became apparent. Smaller scale initiatives would also have been compromised by the introduction of wide-bodied jets, but with two important differences. Such initiatives would be susceptible to re-orientation, particularly if located at an existing airport and notwithstanding that, the costs of error not only in financial terms, but also with respect to planning, administrative and political effort, would be less substantial.

5.2.13. The development of smaller scale initiatives compares favourably with the experience of the third London airport. Although the extension of Gatwick and Heathrow airports can be viewed as projects justified in terms of demand indigenous to their own catchment area, the need for them became more important once the third London airport was delayed. Should a new airport still be considered necessary, it would be on a much smaller scale than originally envisaged.

5.2.14. The Terminal 4 (T4) development at Heathrow was first mooted in the mid 1970's. The public inquiry was held in 1978 with the inspector's decision in favour announced in December 1979. Final government approval was given 1981.[18] Some design and initial construction work had already been undertaken, but the majority occurred from 1981 onwards. Completion of the project in 1985 gives a lead time of four years for construction, seven overall. Although this was slightly longer than originally envisaged, the further delay was accommodated during the construction phase in order to keep down costs. Runing some 25% over budget at one point, design changes were made which enabled the original quotation of £200m to be met. This achievement was reported to be due to the use of contractors to 'manage' the project from start to finish.[19]

5.2.15. T4 was in fact a major construction project. Although it was an extension of Heathrow airport, it was located some distance from the original site and required all of its own ancilliaries. However, in terms of surface access, itself a major infrastructure investment, it involved an expansion of existing facilities through the extension of the London Underground and provision of new road links to nearby major routes. In this respect, extension of existing facilities required much less supporting infrastructure than new airports which may require whole new road and/or rail links to locations up to 40 miles from London. Indeed this may be the most important difference between the two approaches. T4 now carries 8m passengers p.a. which is equivalent to the first phase of the expansion of Stansted, although Stansted also requires runway capacity.

5.2.16. With hindsight, the analysis of the Roskill Commission, which attached no weight to existing facilities, gave new sites an advantage and discounted the benefits that expansion at existing airports can bring. The developments at Heathrow and Gatwick since the mid-1970's may be considered a poor relation to a new third airport in planning terms. However, in terms of infrastructure development, initial expansion of existing facilities was shown to have a greater efficacy in meeting the future needs of air travel than construction of a major new airport.

Policy and Decision-Making

5.2.17. The history of the Third London airports appears to typify an incompatibility between large scale technical planning and political decision-making. However, the issues important in the decisions have been shown to be economic and political rather than those concerning planning. The exception was Maplin, which has long been the favoured site of the planning profession. Since this proved a failure in economic and political terms, being expensive and partly as a result of that expense, divisive politically, planning considerations have been even less important in subsequent decisions.

5.2.18. Of the two major issues of need and location, the former has generally been subject to consensus. There may have been arguments as to what form the expansion should have taken e.g. a new site or expansion of existing sites, but this is primarily a problem of location. Rarely has there been serious dissent over forecasts of air traffic since the forecasts of the Roskill commission were shown to be in error. Thus there has been little opportunity for a positive policy with respect to demand management other than in terms of location and more efficient handling of traffic at a local level (e.g. improved

ATC). This is in contrast with urban transport systems where there are several competing modes of transport and where positive policies may vary the distribution of traffic and reduce the need for infrastructure.

5.2.19. Thus, the primary issue of airport development in South East England was that of location. Furthermore the planning aspects of location have been shown to be only one input to the decision-making process, rather than the comprehensive framework within which decisions are made. In terms of location, economics and politics appear to have been the major factors influencing airport decision-making. Stansted is the cheapest alternative for a new third London airport and this is undoubtedly one of the reasons why it has been finally chosen. The political aspects of the issue embrace not only this economic viewpoint but also environmental issues, those of the various vested interests and of regional policy. Major developments such as airports always attract strong local opposition and none was more vociferous than at Stansted.

5.2.20. However there were also local interests which desired expansion to boost local employment. Similarly there were economic and political interests from the north of England who wanted airport expansion further north as part of a regional policy to reduce the north-south economic imbalance. The airlines, particularly British Airways wanted further expansion at Heathrow as it was not in their interests to extend their resources to a third site. The airport operators

(BAA) were the proponents of Stansted and the planning profession desired development at Maplin.

5.2.21. Clearly, with so many powerful vested interests involved, location was the key issue. With so many interested parties, a long protracted decision-making process is to be expected. This is reflected in the length of time taken for the Roskill Commission (1967-1971) and the recent Stansted inquiry (1981-1985) to publish findings. With the political changes that could occur in such a period, and which did occur in the case of the third London airport, lengthy investigations will probably founder.

5.2.22. Compared with the inquiries into the third London airport, that for Terminal 4 at Heathrow took only one year to complete. Location was not an issue, the inquiry was considering only expansion at Heathrow and only four issues; traffic generation of the new terminal, noise, employment implications and landscaping. All of the questions surrounding inquiries into new sites which consider the distribution of resources, were outside of the brief.

5.2.23. It is apparent that large scale developments imply not only greater risk in terms of economics and infrastructure, they also imply a much greater scale and lead time of the decision making processes. Whether decision-making on airport development generally could proceed on the T4 model remains open to question. That inquiry was similar in many respects to those for trunk roads in England (see chapter 6). At such inquiries, questions of policy relating to the development of the entire system are deemed inadmissable; only objections specific to the function of the individual project are acceptable. The strategic issue is then one of the policy framework used to co-ordinate individual developments. This is a matter for government and more generally how it formulates policy on scientific and technical matters.

5.3 BASIC MODEL OF AIRPORT CAPACITY

5.3.1. The TRAIN model developed in chapter 4 was not designed to comprehensively simulate the behaviour of transport systems. Given the disjointed development of British airports, calibration of a model to past historical circumstances, even if it were possible, is unlikely to be useful for projecting future developments.[20] Political and locational issues have been shown to be as important as technical factors in the planning of a third London airport. Such externalities can not form an integral part of a model. although their impact may be tested through the specification of input.

5.3.2. TRAIN is a very generalised model as the particular situation to which it is applied determines the form of input data. The mechanism internal to the model could be applied to a wide variety of situations and problems. Here, the Basic Model will be utilised to obtain general information concerning the infrastructure of airports. This will be achieved by observing the effects on model output brought about by variations in the input parameters which define the form of infrastructure implemented to meet demand. It will be assumed for the purpose of this exercise that system capacity is determined by passenger throughput at airport terminals.

5.3.3. The Basic model runs undertaken were similar to that used in the example given in chapter 4. Profiles of demand formed exogeneous inputs to which the model responded by building capacity. The form of this capacity was dependent on the input parameters which defined the investment policy for each run. These parameters were the input capacity (CAPU) and Lead time (LT) of the investment and the safety factor used in the decision algorithm.

5.3.4. The four demand profiles given in chapter 4 were used to test the performance of the models. Together with variations in the three input parameters the number of possible 'runs' of the model was far in excess of that necessary. As such profile 2 (exponential) was chosen as the basis for comparison. The most extensive combinations of lead time and unit capacity were undertaken using this profile. For the remaining profiles (1, 3 and 4) a more selective schedule of runs was undertaken. The combinations of lead time and unit capacity used are shown in Table 5.3.

5.3.5. The more selective schedule still consists of 13 runs, which may be considered excessive. Those combinations of LT and CAPU which may be considered internally 'consistent' are represented by the diagonal in Table 5.3 and show a directly proportional relationship between the two parameter. However, by keeping one parameter constant, while the other varied, it was possible to ascertain the relative impact of each parameter on the output of the model i.e. it will show which of increasing scale or increasing lead time has the greater effect on the relationship between demand and capacity. This would not have been apparent from runs where the values of both parameters were increased in unison.

5.3.6. In addition to those runs outlined above a further four were undertaken for all demand profiles. The safety factor in the decision function was varied from zero (the base case) to +10%, +50%, +100% and -10% of unit capacity. A positive safety factor indicated the ordering of more capacity than required as a hedge against future uncertainty. As a sensitivity test a negative safety factor was also tested. These four extra runs were undertaken for a lead time of five years and a unit capacity of 10 mppa.

5.3.7. The schedule of demand profiles used is given in Table 5.4. For the basic profile 2 (i.e. without any random elements), the total matrix of runs given in Table 5.3 was used. For all other profiles, the more select series of runs was undertaken. Forrester's forecasting method[21] was generally used although Holt's method[22] was used for a series of runs using profile 2 with random noise. Any variation due to the smoothing and forecasting procedures in each method could then be ascertained.

5.3.8. The initial conditions of the run were as for the example in chapter 4. Demand and capacity were equivalent in 25 mppa at the beginning of each run. The run length has 40 years with a 10 year pre-run to allow the forecast error algorithm to stabilise. This pre-run is omitted from the results that follow.

Demand Profile 1

5.3.9. Linear growth provided the most uniform demand profile and correspondingly a highly regular pattern of system development. Figure 5.3 plots the demand curve together with system capacity for investments with a capacity of 10 mppa and a lead time of five years. The Demand-capacity difference (DCD) and the forecast error (LTFE) for each time period are also shown. LTFE is constant, which reflects the linear nature of demand and negative as the smoothing process used in forecasting produces a smoothed demand which is slightly lower than actual demand.

5.3.10. Table 5.5 gives a summary of the total difference between demand capacity (DCD) for each simulation run undertaken. DCD is shown as under/over capacity for combinations of LT and CAPU. When CAPU is constant at 10 mppa, under capacity increases with increasing lead time while over-capacity decreases. When LT remains constant at 5 years and CAPU is varied, the reverse situation occurs with under-capacity decreasing and over-capacity increasing with increasing unit capacity.

5.3.11. When both LT and CAPU increase in unison, (represented by the diagonal in Table 5.5), the absolute demand-capacity difference (total DCD irrespective of sign-TDCD) increases with increasing unit size. The smallest value of TDCD occurred for the smallest units (LT=2, CAPU=5) and the largest value for the longest units (LT=5 and CAPU=25).

Demand Profile 2

5.3.12. Model output for demand profile 2 with a lead time of five years and unit capacity of 10 mppa is given in Fig. 5.4. The exponential growth causes an increase in LTFE over time. However the relatively flat profile of demand during the early stages of the run results in greater over-capacity during that period which diminishes as the simulation progresses.

5.3.13. A more extensive series of runs was undertaken for this profile giving a complete matrix of results as shown in Table 5.6. Overall trends in the variable DCD are similar to those observed for profile 1. If LT remains constant, increasing CAPU results in decreasing under-capacity and increasing over-capacity. This pattern occurs in reverse which CAPU remains constant. When both LT and CAPU increase together, so does TDCD.

5.3.14. The complete matrix of results given in Table 5.6 allows a comparison of the relative impact of the parameters LT and CAPU on the absolute demand-capacity difference (TDCD). Both the smallest and largest values of TDCD occur for a lead time of 2 years. The minimum value corresponds to a CAPU of 5 mppa and the maximum to a CPU of 25 mppa. It appears that increasing CAPU has a far greater impact on DCD than increasing LT.

Demand Profile 2 With Random Noise

5.3.15. The first two demand profiles tested consisted of smooth curves. The profile of forecast demand based on smoothed demand was therefore correspondingly regular. A more irregular demand profile was obtained by applying a random element (defined in table 5.4.) to the demand level of profile 2 at each time period. The resulting model output for an LT of 5 years and a CAPU of 10 mppa is shown in Fig. 5.5.

5.3.16. The smoothing process in the forecasting algorithm should remove the perturbation in demand caused by the presence of these random elements. However, the forecasting procedures of Forrester failed to achieve this. Hence smoothed demand and therefore forecast demand exhibited corresponding variations, resulting in the fluctuating forecast error shown in Fig. 5.5.

5.3.17. The results obtained through incorporating the random elements into profile 2 are given in Table 5.7. Although the more random demand profile produces some discrepancies in the pattern of results, the overall trends are similar to those for the smooth profile. Table 5.7 also shows the increased tendency to overcapacity under random demand conditions together with lower levels of under capacity.

5 3.18. Increases in CAPU for a constant LT produced greater absolute differences in demand and capacity than for the smooth profile. However, the effect of increasing LT produced similar results to those without random demand. The value of TDCD for the Lead time of 10 years was the lowest for all the runs with a CAPU of 10 mppa. Hence increasing the short term fluctuation in demand and hence forecasting, did not alter the impact of increasing lead time on model output. However, the level of TDCD when both LT and CAPU increased together was between 20% and 53% greater than for the smooth profile.

Demand Profile 2 with Random Noise (Holt's Forecasting Method)

5.3.19. A further series of runs was undertaken for Demand Profile 2 using the forecasting method derived by Holt. These runs were undertaken because of the poor smoothing of random demand achieved by Forresters method. They therefore provided a sensitivity test on the forecasting method.

5.3.20. However, Holt's method did not improve the smoothing and forecasting of demand. The trends in DCD were similar to those observed using Forresters method, whilst overall levels of DCD, generally showed little variation (Table 5.8). It would appear that the results are reasonably insensitive to the forecasting algorithm.

Demand Profile 2 with Step Function

5.3.21. An alternative method of disturbing the demand profile is to use a step function. This function was employed to induce a sudden drop in demand of 10 mpps at time period 20 for demand profile No.2. The model output for a lead time of 5 years and a CAPU of 10 mppa is shown in Fig. 5.6. The results of all runs incorporating this function are given in Table 5.9. The overall pattern is similar to that caused by use of the random noise function. There is a greater tendency to over-capacity and the effect of increasing CAPU appears to be much greater than increasing LT.

Demand Profile 3

5.3.22. Model output for Demand Profile 3 is shown in Fig. 5.7. Although LTFE and DCD are high at the beginning of the run, they decrease over time as the logistic demand curve approaches its saturation level and the growth rate is reduced.

5.3.23. The results of all runs under this demand pattern are given in Table 5.10. With the exception of those runs where CAPU was 20 mppa, the results are similar to those of previous profiles, but with much lower levels of DCD. The reason for this lower level of DCD may be explained by the shape of the demand curve. Demand profiles 1 and 2 exhibited constantly increasing demand over time. However in profile 3, the demand stagnates as it approaches 75 mppa. If the capacity of the system has reached 75 mppa, then there is little difference between the two variables in the latter stages of the run and hence TDCD is small.

5.3.24. The exception occurs when CAPU is 20 mppa. All the other unit capacities are factors of 75 mppa, the final demand. However to reach this level of capacity, three 20 mppa must be ordered during the run which results in a capacity of 85 mppa. This results in an extended period of over-capacity and explains the higher levels of DCD obtained for these runs.

Demand Profile 4

5.3.25. Model output for a single run under Profile 4 is given in Fig. 5.8 and the results for all runs are given in Table 5.11. They show greater levels of DCD than for profile 3 but the overall trends are similar. Greater over-capacity is to be expected when the level of demand decreases for part of the run. For a CAPU of 20 mppa, the effect on DCD was similar to that obtained using profile 3 and in this case it also affected those runs where CAPU was 10 mppa. Neither of these values of CAPU are factors of the total capacity required during the run and this creates much higher values of DCD.

The Effect of Forecast Error

5.3.26. The extent to which system capacity differs from demand is dependent on forecast error. The greater the error, the greater the potential level of the variable DCD. Forecast errors will depend on the form of demand profile and on the lead time necessary for forecasting. Table 5.12 contains the ratio of TDCD to the total forecast error for each of the runs undertaken using demand profile 2.

5.3.27. Table 5.12 gives an indication of the results that would be obtained if the forecast error was constant during each run. The ratio TDCD/LTFE is a measure of the difference between demand and capacity for each limit of forecast error. It is apparent from these results that as lead time increases, the TDCD/LTFE ratio decreases. Conversely, this ratio is observed to increase with increasing unit capacity. As LTFE is constant for each lead time, regardless of the value of CAPU, it follows that the effect of increasing CAPU has a significant impact on the ratio as it did on DCD alone. Comparison of these ratios with the values of DCD in Table 5.6 confirms this. Although LTFE increases with lead time, the variation in TDCD/LTFE is small for low unit capacities, but becomes much greater as CAPU increases.

5.3.28. In Table 5.13 the TDCD/LTFE ratios for the four demand profiles are compared for lead times and unit capacities which increase in unison. The apparently inconsistent results (particularly for demand profiles 3 and 4) may be explained by the conflicting trends described above. Increasing lead time tends to reduce the ratio, while increasing unit capacity causes significant increases.

5.3.29. For profiles 1 and 2, the ratio increases with unit size and so smaller units would be preferred. For profiles 3 and 4 the situation is more complex. The higher values of TDCD/LTFE when CAPU is 20 mppa are consistent with previous results as are those for the 10 mppa unit under profile 4. However, small units exhibit high ratio values under these profiles. This is due to the low forecast error consistent with a lead time of 2 years, together with the high level of DCD for profiles 3 and 4.

The Effect of Safety Factors in Decision Making

5.3.30. Safety factors are often used in predicting future demand as a hedge against uncertainty. The effects of under-capacity may be considered so serious that a situation where capacity fails to meet demand cannot be tolerated. Electricity generation is one area where they are often used but a form of safety factor is also used in transport forecasting.

5.3.31. The effect of incorporating safety factors into the decision algorithm of the Basic Model is shown in Table 5.14. The tests were carried out using the four demand profiles and investments of 10 mppa capacity and a 5 year lead time. The safety factor was expressed as a percentage of the unit capacity, i.e. a factor of 10% is equivalent to 1 mppa, with positive factors indicating the ordering of more capacity than the forecasts suggest is required.

5.3.32. As the safety factor increases so the level of under-capacity decreases but the level of overcapacity increases rapidly. Zero under-capacity was only achieved for all four demand profiles when the factor was +100%. For demand profile 2 the absolute value of DCD was lower when the factor was -10% (ordering too little capacity) than for a factor of zero. The overall level of under-capacity is generally low for all the positive safety factors.

5.3.33. In the base runs (safety factor =0), the decision algorithm seeks to avoid under-capacity at every time period and using large units of capacity will therefore result in over capacity for the great majority of time-periods. Hence there is already a built-in safety factor within large units of infrastructure. If small levels of undercapacity can be tolerated explicit safety factors serve only to substantially increase the level of over-capacity present within the system.

Summary of Results

5.3.34. The results obtained from the Basic Model of Airport Capacity may be summarised as follows:

1. Independently increasing the lead time and unit capacity of infrastructure investments increased the difference beween capacity and demand within the system.

2. As Lead time increased, the level of under-capacity observed also increased while the over-capacity present in the system decreased.

3. As the unit capacity of investments, increased, the level of over-capacity increased while the level of under-capacity diminished.

4. Over-capacity was much more prevalent than under-capacity.

5. The relationship between demand and capacity was much more sensitive to the unit capacity of investments as opposed to their lead time.

6. Short term perturbation of demand greatly increased the level of over-capacity within the system, particularly at high unit capacities.

7. The results were relatively insensitive to the forecasting method used.

8. The difference between demand and capacity varied significantly with the demand profile used. The presence of any saturation level or long-term decrease in demand gives added importance to the choice of unit capacity.

9. Using a ratio of TDCD/LTFE as a proxy for constant forecast error, the level of DCD diminished with increasing lead time and increased with unit capacity under conditions of continually increasing demand. When demand stagnated or decreased, DCD was minimised only for selected unit sizes and no

proportional relationship with lead time or unit capacity was apparent.

10. High safety factors are necessary to completely remove the presence of under-capacity in a system, even under smooth demand profiles. They significantly increase the levels of over-capacity under all demand profiles.

5.4 EXPANDED MODEL OF AIRPORT CAPACITY

5.4.1. The basic TRAIN model has provided information on the general characteristics of airport infrastructure, but it does have limitations. In particular, it assumed that airport investments could be treated as homogeneous units of capacity. To assess scenarios related to the case study of the third London airport, greater sophistication is required.

5.4.2. Given the simplicity of the basic model, there are three main areas where it may be expanded. These are the demand and forecasting sub-model, the decision algorithm and the capacity submodel. Expansion of the demand elements would greatly increase the amount of data required, while variation in the forecasting algorithms has been shown to have relatively little effect. The decision algorithm although currently simplistic, would require more extensive research if it were to more accurately reflect the past history of airport decision-making processes. The value of calibration to such historic processes is also uncertain.

5.4.3. The capacity sub-model is more easily modified and given the limitations of the Basic Model, it was here that further development was undertaken. The case study showed that the total capacity of the London airports system has been determined by either terminal or runway capacity. Therefore, the capacity sub-model was disaggregated in order to represent this situation.

5.4.4. Disaggregation was easily achieved by simply repeating the whole of the capacity sub-model within TRAIN. One such submodel was devoted to terminal capacity and one to runway capacity. Each capacity model was treated independently, with its own lead times, unit capacities and decision algorithms. Demand remained aggregated and decisions to develop either runways or terminals were simulated in an identical manner to those in the basic model, except that it has the individual capacity of each element that determined the ordering of new investment.

5.4.5. The total capacity of the whole system was then given by:

TSC.K = MIN (SCR.K, SCT.K)

where SCR = the current capacity of runways.

SCT = the current capacity of terminals.

TSC = the effective capacity of the whole system, equivalent to either SCR or SCT, with the lower value being chosen.

5.4.6. This expanded model may be tested under two scenarios important to the case study:

1. The construction of a new airport to meet forecast demand.

2. The expansion of existing airports to meet forecast demand.

In the first scenario new runway and terminal capacity will be required, while in the second, it is assumed that sufficient runway capacity is available at existing airports and only new terminal capacity is required.

Specification of Input

5.4.7. The input parameters defining the form of infrastructure are given in Table 5.15. Lead times and unit capacities of investments are obviously dependent on locational factors which cannot be simulated within the model. The input parameters therefore represent an average of those given in the report of the Study Group on South East Airports (SGSEA) which were detailed in chapter 2. The Lead time for runways may be considered excessive, but it is on the expansion of runways that investment decisions are most dependent because of the potential scale of future operations implied.

5.4.8. The initial conditions for Scenario 2 were similar to those used in the Basic model. Runway capacity was set at 25 mppa indicating not so much the total capacity available, but a limit to expansion at existing airports. Terminal capacity has increased to 30 mppa to represent the situation apparent in the 1960's when runway provision was the determinant of the total capacity of the airports system. For scenario 2, the initial runway capacity has increased to 75 mppa, indicating the combined capacities of two runways at Heathrow and one at Gatwick.[24]

5.4.9. Demand profiles 2 and 3 were used to test the two scenarios. Profile 2 represents a situation where the expected increase in demand is delayed but is very sharp when it arrives. Profile 3 simulates the situation where demand is rising sharply at the beginning of the run, but where the growth rate diminishes with time. Further runs incorporating a positive step function were also undertaken to simulate a sudden boom in demand (as opposed to the sudden decrease analysed in the Basic model). A further run under both demand profiles incorporated a safety factor equivalent to the capacity of one terminal for scenario 1.

5.4.10. Model output for both scenarios is illustrated in Figs. 5.9 and 5.10 (Profile 2) and Figs. 5.11 and 5.12 (Profile 3). The results for all the runs are summarised in Table 5.16.

5.4.11. Under Demand Profile 2, the levels of DCD attained are generally low for both scenarios indicating a good fit between demand and capacity. Scenario 2 is marginally inferior but this may be explained by the initial value of terminal capacity which dictates total capacity. At 30 mppa it is 5 mppa greater than the initial demand which increases only slowly at the beginning of profile 2 and hence gives rise to overcapacity. In terms of total DCD the step function has a similar impact on both scenarios with scenario 2 again displaying a greater tendency to overcapacity. The use of a safety factor for scenario 1 had a significant impact on the level of DCD although it did not completely eradicate under-capacity.

5.4.12. Under demand profile 3, the total level of DCD for scenario 2 was similar to that apparent under profile 2. However, scenario 2 produced higher levels of DCD and the tendency to operate at under capacity was again apparent. These trends were confirmed when the step function was incorporated into the demand profile. The effect of the safety factor under profile 3 was less marked than under profile 2. Under-capacity was not significantly reduced and the increase in overcapacity was similarly minimal.

Summary of Results

5.4.13. Under demand profile 2 both scenarios exhibited low levels of DCD with scenario 2 achieving slightly lower demand-capacity differences. This marginal superiority may be attributed to initial level of terminal capacity and it was maintained when a positive step function was introduced to the demand profile. However, scenario 2 displayed a greater tendency to under-capacity within the system. Use of a safety factor in the decision algorithm greatly increased the level of overcapacity present in the system.

5.4.14. Under demand profile 3, scenario 2 achieved notably lower levels of the variable DCD. Again scenario 2 displayed a greater tendency to under-capacity. The use of a safety factor in decision making was less significant than for profile 2.

5.4.15. The results outlined above are consistent with the historic development of the airports system to serve London. When demand was forecast to increase sharply (demand profile 2) as it was during the period of the Roskill Commission evaluation, a large new airport such as that proposed for Maplin may be considered advantageous. In more recent appraisals of airport requirements, rapid growth in demand has already occured and the forecasts of future demand are being reduced. Such trends are consistent with Demand profile 3 and indicate an expansion of existing airports to be more effective in meeting demand. Although Stansted is considered a choice for a new airport, some basic facilities were already in place and the proposed development is much smaller than previously envisaged particularly for Maplin.

5.5 CONCLUSIONS

5.5.1. The historical development of the airport system to serve London has been described and the policy, forecasting and infrastructure aspects analysed. A simulation model (TRAIN) was employed to provide further information on airports infrastructure.

5.5.2. The economic and political implications of the location of a new, third London airport were shown to be the most important factors in investment decisions. However, such factors are related to the form of infrastructure employed to meet demand. Investment at Maplin was perceived to be of a greater scale than that required at Stansted, which in turn was perceived to be greater than that required at existing airports.

5.5.3. The treatment of the issues was consistent with that of the traditional transport planning process described in Chapter 1. Investment decisions were a response to changes in the demand for air travel. Early appraisals of these demand changes were partial, considering only aviation matters. Although a broader approach such as that employed by the Roskill Commission foundered, the demand satisfaction approach had not been discarded. The forecasting processes employed illustrate the importance of the economics of travel and hence appraisals are still market-led.

5.5.4. Transition to a more interventionist policy has not occurred, unlike the situation in urban transport planning.[25] Restraint of air traffic was rarely an issue at all and redistribution of traffic to regional airports did not receive sufficient support to make it a viable proposition.

5.5.5. The absence of a strong policy on airport size and location has created significant problems for the public inquiry. It was originally designed to assess local planning applications, with reference to government policies where necessary.

However, the absence of such a policy for airports has resulted in the inquiry itself adopting a significant role in the policy-making process.

5.5.6. The inadequacy of the local public inquiry is further illustrated by the large number of well-prepared objectors who submit evidence. It is difficult to evaluate each individual case against the quasi-objective economics of demand satisfaction as they concern such diverse aspects as environmental impact and regional development. Appraisal of such issues would be much less difficult if coherent policies and objectives were available for reference.

5.5.7. If policy objectives were clearly stated, the matrix-based evaluation methodology described in chapter 3[26] would clearly be of great use. The evidence submitted by interested parties could then be evaluated against policy objectives. If the evidence was requested so that a policy could be recommended, then a commission of the Roskill format would be appropriate. However, such a commission would not recommend any individual location. That decision would be dependent on a subsequent local inquiry. This would probably be more satisfactory than the current situation which strongly resembles the disjointed incrementalism described by Lindblom. Power appeared to be distributed amongst many groups and allegiance did not respect party-political boundaries. However, because it has a non-incremental issue it required many years before a politically acceptable solution could be constructed.

5.5.8. The non-incremental nature of the issue was partly due to the infrastructure of airports. Large scale developments at new sites are not only politically difficult to implement themselves, but they also require supporting infrastucture in the form of surface access. The modelling undertaken in this chapter has shown that the scale of investment also has a significant impact on the efficiency of the airports system in terms of matching demand with capacity. This was far more important than the lead time of such developments.

5.5.9. These findings were consistent with the research reviewed in chapter 2 where the economics of smaller scale developments were considered superior. The concept of lead time management introduced in chapter 2 was also found to be important in minimising the delay associated with large scale projects. The management of the Terminal 4 development at Heathrow through the specific appointment of contractors minimised the delay that often occurs when large numbers of groups are employed on one project.

CHAPTER FIVE

REFERENCES

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3. GB Board of Trade (1967)
4. GB House of Commons (1968)
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12. GB Department of Trade (1979b)
13. Guardian (1984)
14. GB Department of Trade (1979a) App.3 Table 1
15. ibid, App.3 para. 7
16. ibid, App.3 Table 2
17. Financial Times (1982), p.9
18. Glidewell (1979)
19. New Civil Engineer (1984), p.6
20. See Coyle (1983), p.363
21. See Appendix C
22. See Appendix D
23. See Table 2.23
24. See Table 2.14
25. See Ch.6
26. Para.3.4.9

	Cublington		Foulness		Nuthampstead		Thurleigh	
	High time values	Low time values	High time values	Low time values	High time values	Low time values	High time values	Low time values
Row 1 Airport construction	18		32		14		0	
2 Extension of Luton	0		18		0		0	
3 Airport services	23	22	0	0	17	17	7	7
4 Meteorology	5		0		2		1	
5 Airspace movements	0	0	7	5	35	31	30	26
6 Passenger user costs	0	0	207	167	41	35	39	22
7 Freight user costs	0		14		5		1	
8 Road capital	0		4		4		5	
9 Rail capital	3		26		12		0	
10 Air safety	0		2		0		0	
11 Defence	29		0		5		61	
12 Public scientific establishments	1		0		21		27	
13 Private airfields	7		0		13		15	
14 Residential conditions (noise, off-site)	13		0		62		5	
15 Residential conditions (on site)	11		0		8		6	
16 Luton noise costs	0		11		0		0	
17 Schools, hospitals and public authority buildings (including noise)	7		0		11		9	
18 Agriculture	0		4		9		3	
19 Commerce and industry (including noise)	0		2		1		2	
20 Recreation (including noise)	13		0		7		7	
Aggregate of inter-site differences (costed items only) high and low time values	0	0	197	156	137	128	88	68

Differences from lowest-cost site (£ million discounted to 1982)

TABLE 5.1 COSTS AND BENEFITS OF THIRD LONDON AIRPORT SITES

Source: GB Commission on the Third London Airport (1971)

International Traffic				Domestic Traffic	Total
UK		Foreign			
Leisure	Business	Leisure	Business		
9.2	2.5	10.2	3.0	3.9	28.8

TABLE 5.2. CATEGORIES OF DEMAND AT LONDON AREA AIRPORTS 1975 (mppa)

LT (years)	CAPU (mppa)				
	5	10	12.5	20	25
2	(x)	(x)	x	x	x
4	x	(x)	x	x	x
5	(x)	(x)	(x)	(x)	(x)
8	x	(x)	x	(x)	x
10	x	(x)	x	x	(x)

Note: x indicate those runs undertaken for profile 2

○ indicates those runs undertaken for all other profiles

TABLE 5.3. BASIC MODEL OF AIRPORT CAPACITY - LEAD TIMES AND UNIT CAPACITIES TESTED

DEMAND PROFILE	FORECASTING ALGORITHM
1	Forrester
2	"
2 + Noise[1]	"
2 + Noise[1]	Holt
2 + Step Function[2]	Forrester
3	"
4	"

Notes:

1. Demand perturbed each time period by a normally distributed random number between -5 and +5 mppa.
2. Demand perturbed by a negative step of 10 mppa at year 20, i.e. mid-way through the run.

TABLE 5.4 BASIC MODEL OF AIRPORT CAPACITY - SCHEDULE OF DEMAND PROFILES

LT (years)	CAPU (mppa)				
	5	10	12.5	20	25
2	38/13	19/94			
4		38/63			
5	75/0	38/63	30/105	23/258	15/340
8		94/19		56/171	
10		132/6			53/228

Total Under/Over Capacity per run (millions of passengers)

TABLE 5.5 BASIC MODEL OF AIRPORT CAPACITY - DEMAND PROFILE 1

LT (years)	CAPU (mppa)				
	5	10	12.5	20	25
2	29/42	15/142	12/196	7/396	5/512
4	75/28	37/105	27/159	17/345	9/468
LT5	90/26	45/103	34/155	25/333	9/468
8	157/21	100/78	74/119	49/278	36/419
10	194/13	129/58	108/91	61/229	39/347

Total Under/Over capacity per run (millions of passengers)

TABLE 5.6 BASIC MODEL OF AIRPORT CAPACITY - DEMAND PROFILE 2

LT (years)	CAPU (mppa)				
	5	10	12.5	20	25
2	38/71	8/211			
4		24/167			
5	53/61	28/151	19/260	15/418	2/630
8		55/149		18/401	
10		45/128			31/435

Total Under/Over capacity (millions of passengers)

TABLE 5.7 BASIC MODEL OF AIRPORT CAPACITY - DEMAND PROFILE 2
WITH RANDOM NOISE

LT (years)	CAPU (mppa)				
	5	10	12.5	20	25
2	43/59	10/202			
4		32/147			
5	87/46	34/135	31/201	23/425	4/590
8		58/130		25/392	
10		52/121			34/416

Total Under/Over Capacity per run (millions of passengers)

TABLE 5.8 BASIC MODEL OF AIRPORT CAPACITY - DEMAND PROFILE 2 - WITH RANDOM NOISE - HOLT'S FORECASTING METHOD

LT (years)	CAPU (mppa)				
	5	10	12.5	20	25
2	24/97	11/219			
4		212/180			
5	64/77	29/178	20/251	12/390	18/536
LT					
8		67/147		32/350	
10		69/118			42/439

Total Under/Over Capacity during run (millions of passengers)

TABLE 5.9 BASIC MODEL OF AIRPORT CAPACITY - DEMAND PROFILE 2 - WITH STEP FUNCTION

LT (years)	CAPU (mppa)				
	5	10	12.5	20	25
2	83/30	24/76			
4		51/56			
5	101/19	66/47	57/47	36/197	28/175
8		132/40		79/262	
10		174/36			61/96

Total Under/Over Capacity per run (millions of passengers)

TABLE 5.10 BASIC MODEL OF AIRPORT CAPACITY - DEMAND PROFILE 3.

LT (years)	CAPU (mppa)				
	5	10	12.5	20	25
2	5/97	8/255			
4		19/238			
5	45/93	27/235	23/122	18/535	15/177
8		63/211		40/498	
10		92/210			49/531

Total Under/over Capacity during run (millions of passengers)

TABLE 5.11 BASIC MODEL OF AIRPORT CAPACITY - DEMAND PROFILE 4.

LT (years)	CAPU (mppa)				
	5	10	12.5	20	25
2	0.93	2.06	2.74	5.3	7.08
4	0.8	1.11	1.45	2.82	3.73
5	0.76	0.97	1.24	2.34	3.12
8	0.78	0.78	0.85	1.43	1.99
10	0.75	0.68	0.72	1.05	1.39

$$\text{Ratio} = \frac{\text{Absolute Difference Between Demand and Capacity (TDCD)}}{\text{Total Lead Time Forecasting Error (LTFE)}}$$

TABLE 5.12 BASIC MODEL OF AIRPORT CAPACITY - DEMAND PROFILE 2 - TDCD/LTFE RATIOS

LT (years)	CAPU mppa	DEMAND PROFILE			
		1	2	3	4
2	5	0.68	0.93	1.54	1.80
4	10	0.80	1.11	0.88	3.11
5	12.5	0.90	1.24	0.71	1.29
8	20	1.00	1.43	1.50	3.09
10	25	1.00	1.39	0.56	2.72

$$\text{Ratio} = \frac{\text{Absolute Difference Between Demand and Capacity (TDCD)}}{\text{Lead Time Forecasting Error (LTFE)}}$$

TABLE 5.13 BASIC MODEL OF AIRPORT CAPACITY - TDCD/LTFE RATIOS

SAFETY FACTOR	DEMAND PROFILE 1	2	3	4
-10%	63/38	73/41	91/44	35/216
0	38/63	45/103	66/47	27/235
+10%	19/91	33/141	61/104	17/246
+50%	0/225	3/221	15/237	/289
+100%	0/428	0.458	0.382	0.608

Total Under/Over Capacity per run (millions of Passengers) for LT = 5, CAPU = 10

TABLE 5.14 BASIC MODEL OF AIRPORT CAPACITY - EFFECT OF SAFETY FACTORS

PARAMETER	SCENARIO 1	SCENARIO 2
Runways		
Lead time (Years)	10	-
Unit Capacity (mppa)	25	-
Initial Capacity (mppa)	25	75
Terminals		
Lead time (Years)	6	6
Unit Capacity (mppa)	12.5	12.5
Initial Capacity (mppa)	30	30

TABLE 5.15 EXPANDED MODEL OF AIRPORT CAPACITY - INPUT PARAMETERS

SCENARIO	DEMAND PROFILE					
		2			3	
	A	B	C	A	B	C
1 (New Airport)	85/41	38/258	146/31	124/39	98/97	199/216
2 (Existing Airports)	58/83		97/92	74/49		159/217

Total Under/Over Capacity per run (millions of passengers).

Key:
A - Basic Profile
B - with safety factor
C - with step function

TABLE 5.16 EXPANDED MODEL OF AIRPORT CAPACITY - RESULTS FOR TWO INVESTMENT SCENARIOS

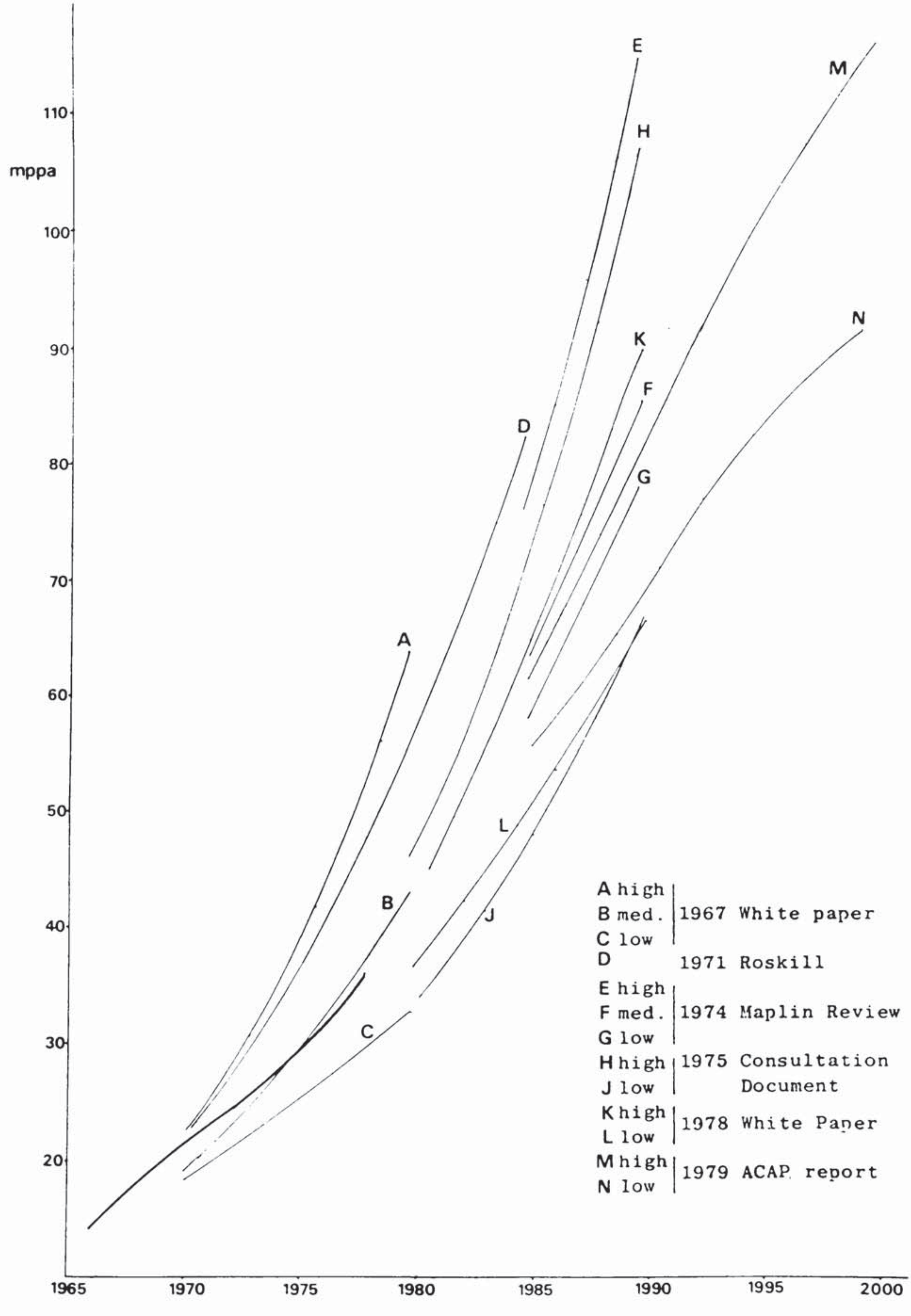

FIGURE 5.1 London Area Airports - Forecasts of Passengers pa

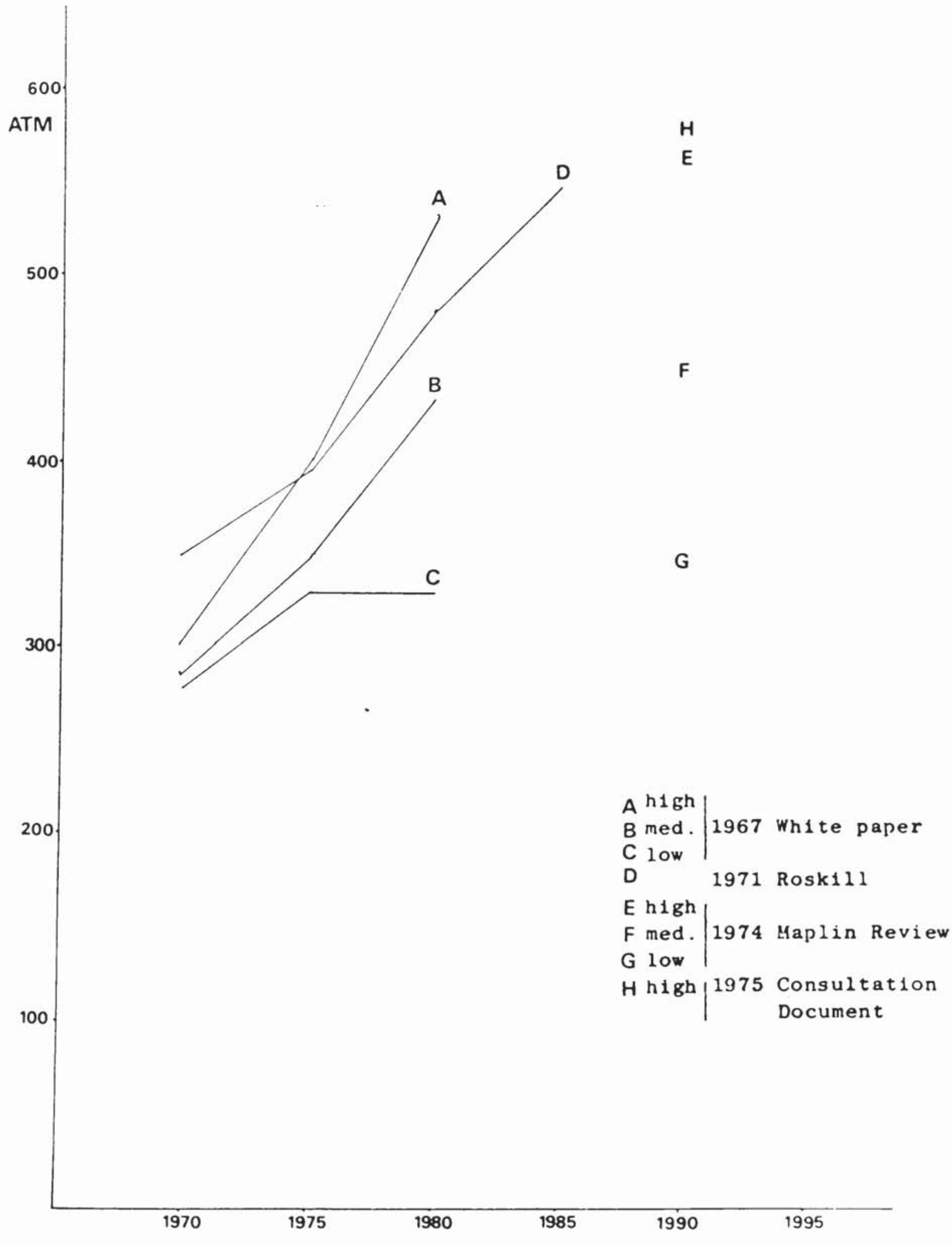

FIGURE 5.2 London Area Airports Forecasts of Air Traffic Movements pa

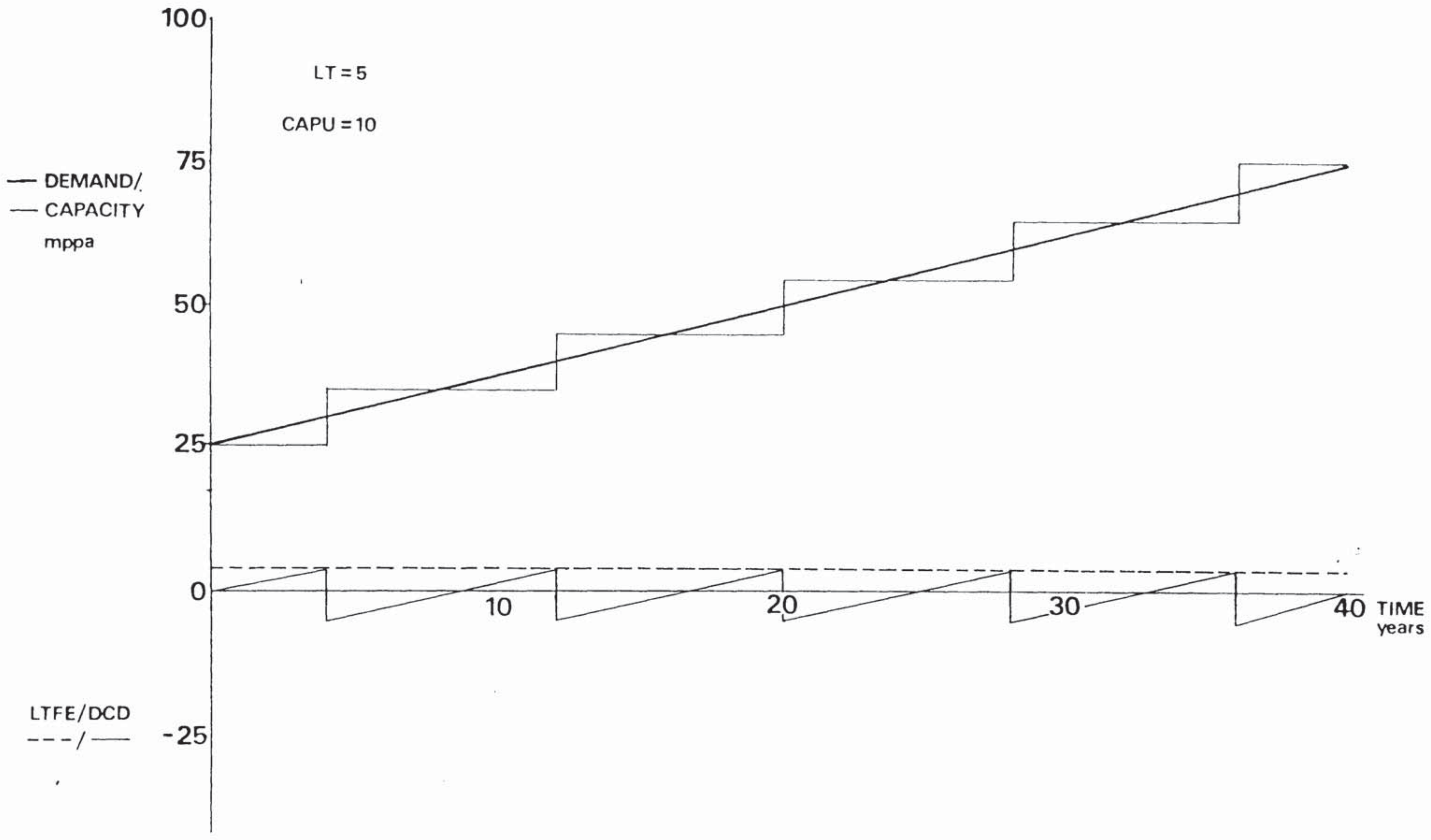

FIGURE 5.3 BASIC MODEL OF AIRPORT CAPACITY – DEMAND PROFILE 1

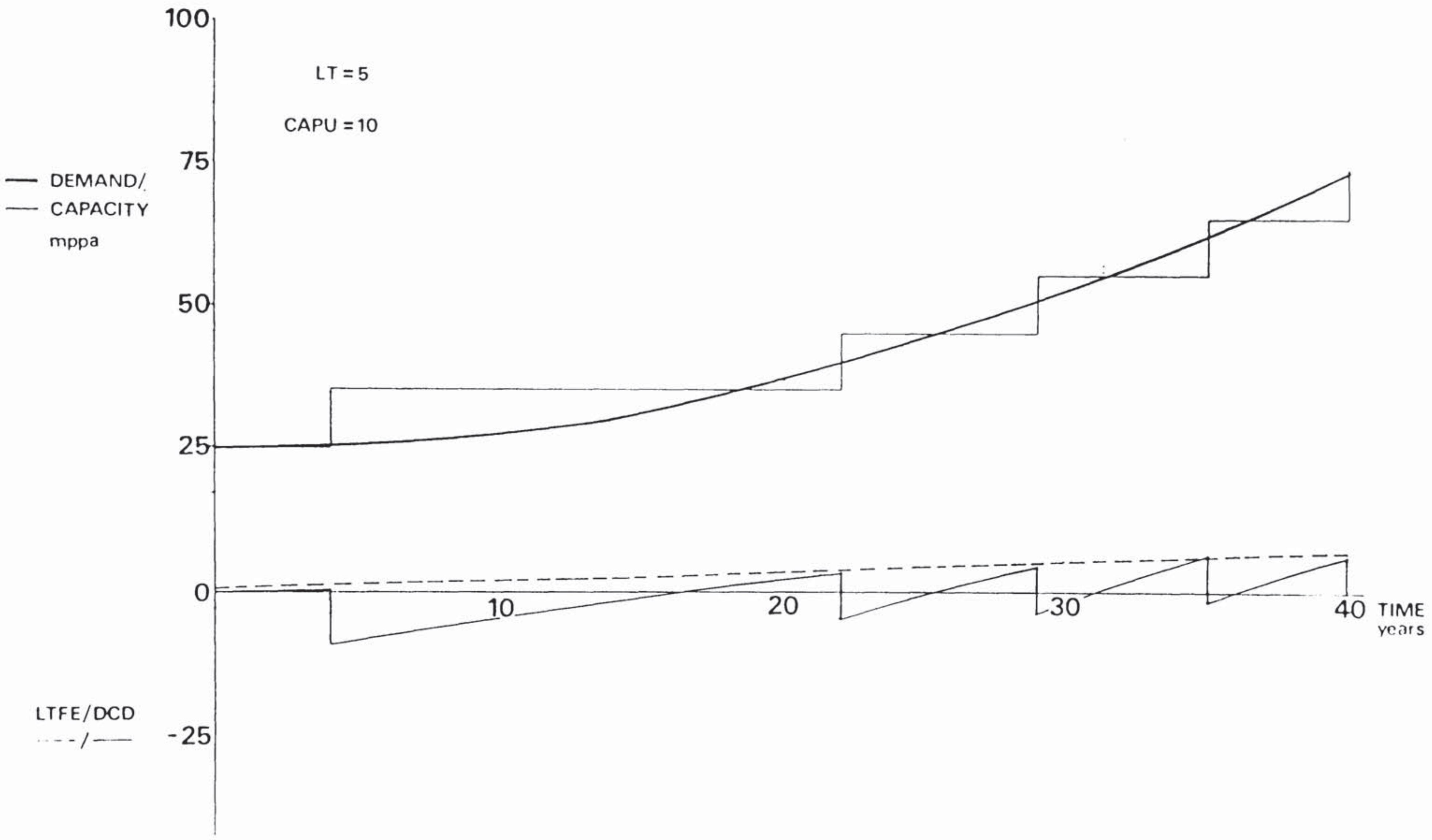

FIGURE 5.4 BASIC MODEL OF AIRPORT CAPACITY – DEMAND PROFILE 2

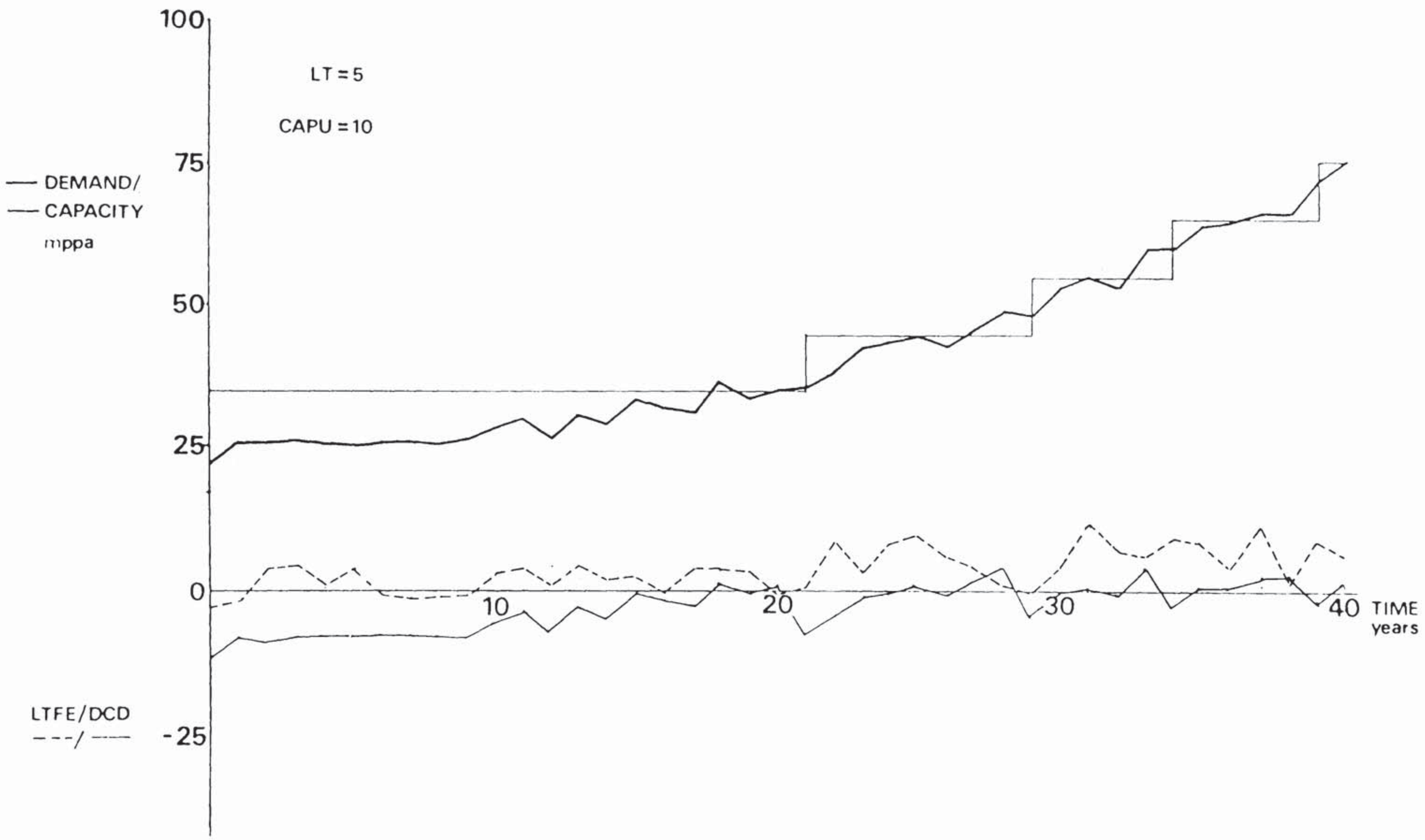

FIGURE 5.5 BASIC MODEL OF AIRPORT CAPACITY – DEMAND PROFILE 2 WITH NOISE

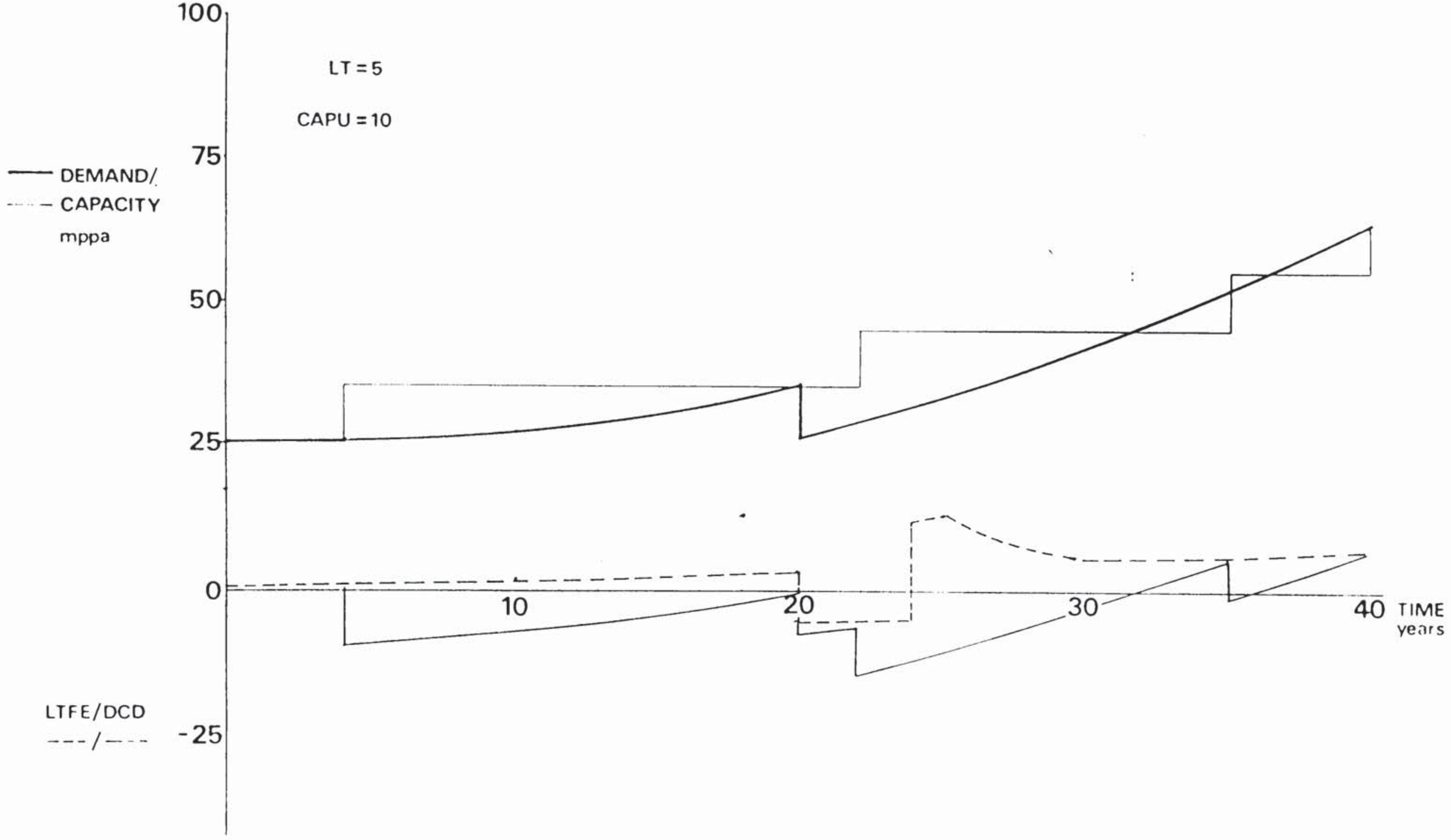

FIGURE 5.6 BASIC MODEL OF AIRPORT CAPACITY – DEMAND PROFILE 2 WITH STEP FUNCTION

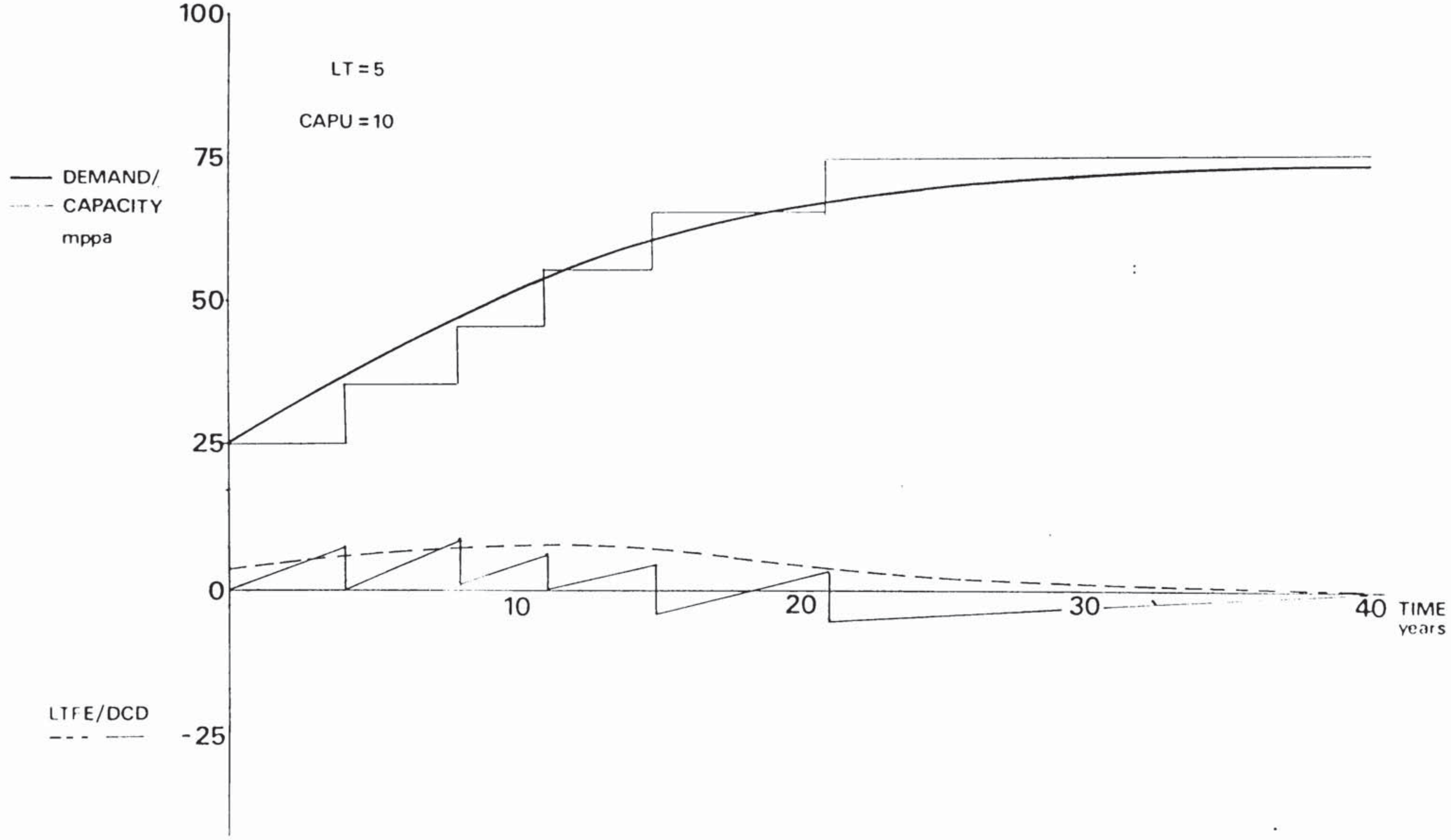

FIGURE 5.7 BASIC MODEL OF AIRPORT CAPACITY – DEMAND PROFILE 3

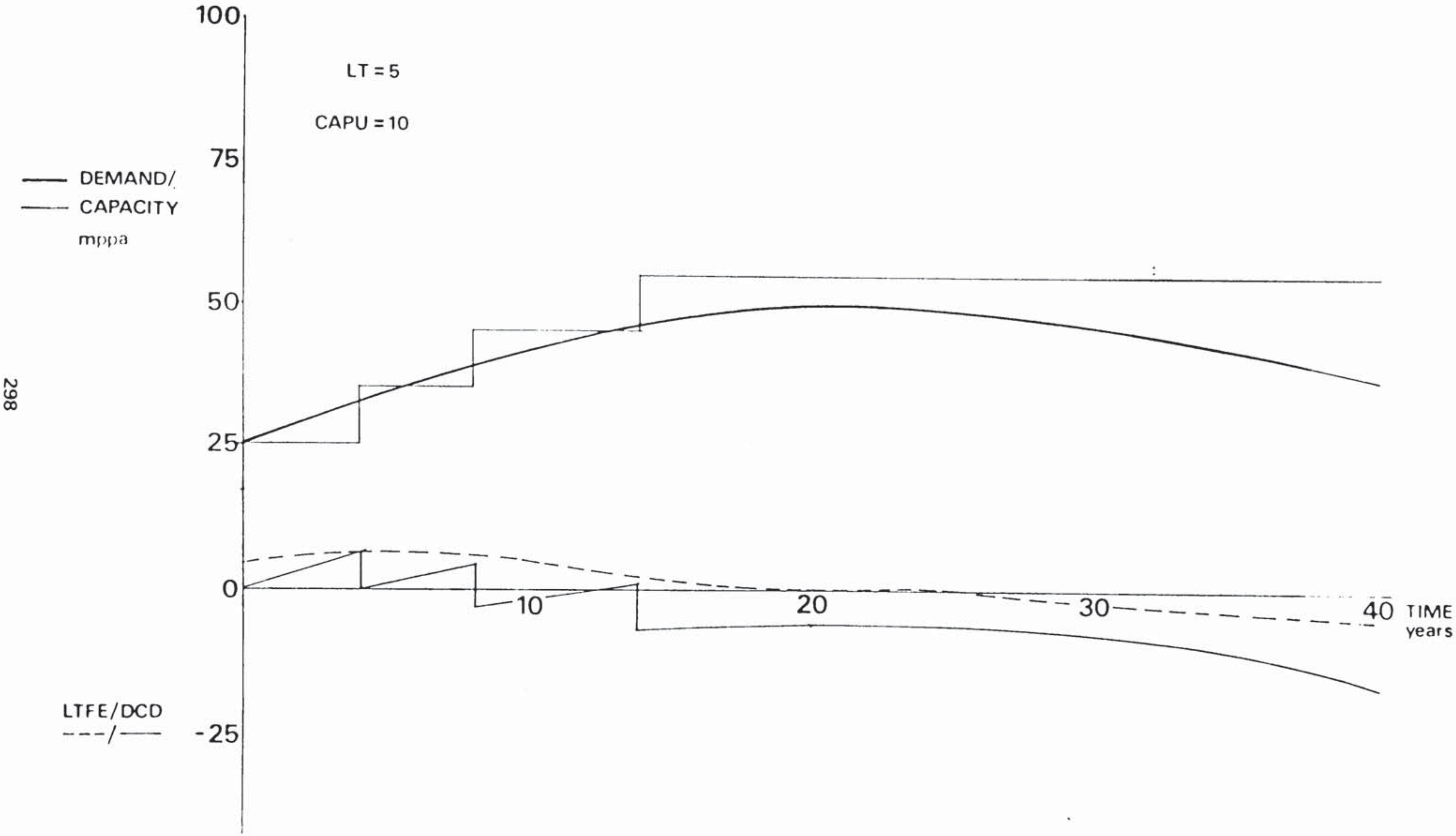

FIGURE 5.8 BASIC MODEL OF AIRPORT CAPACITY – DEMAND PROFILE 4

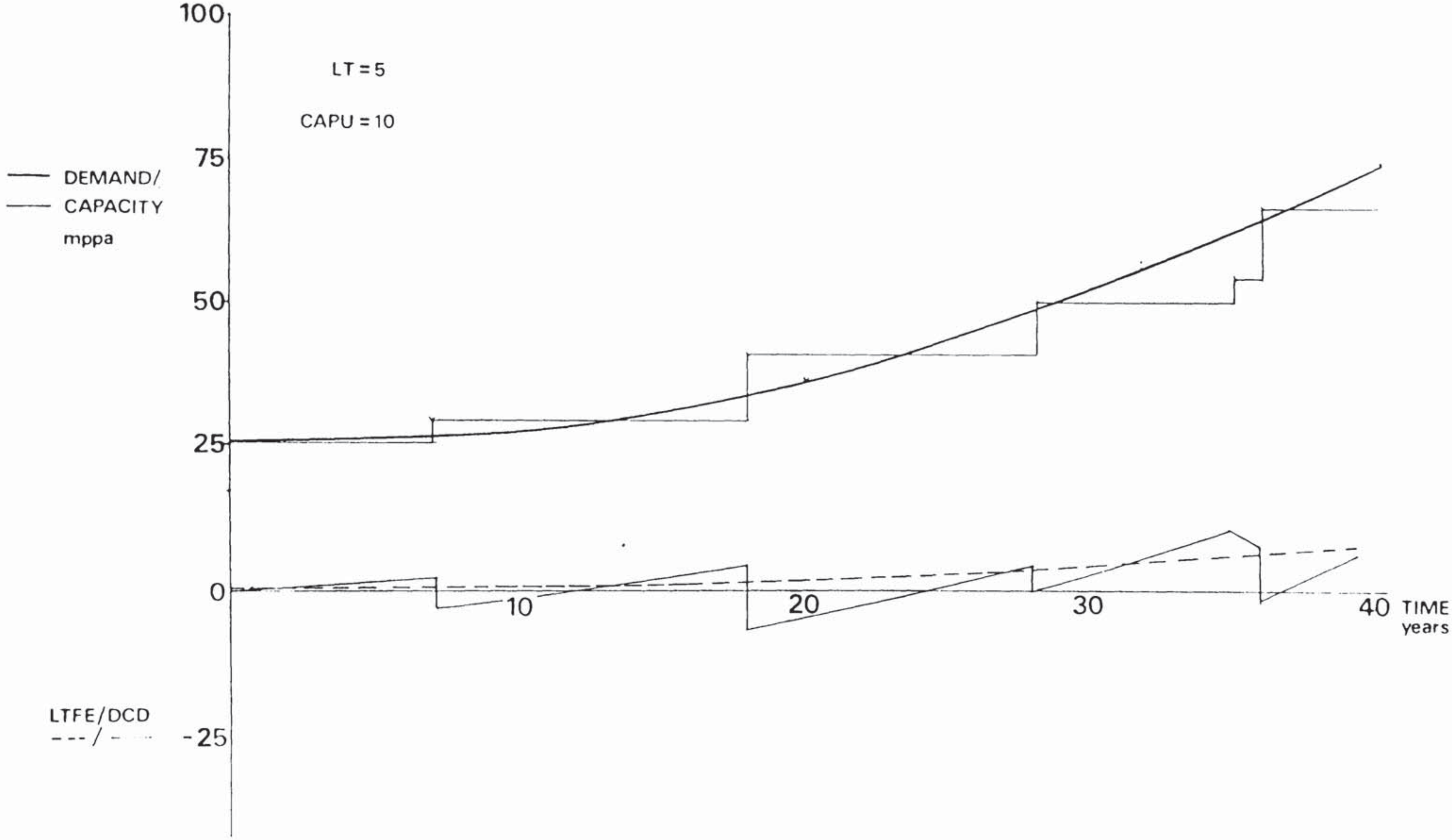

FIGURE 5.9 Expanded Model of Airport Capacity - Profile 2 - Scenario 1

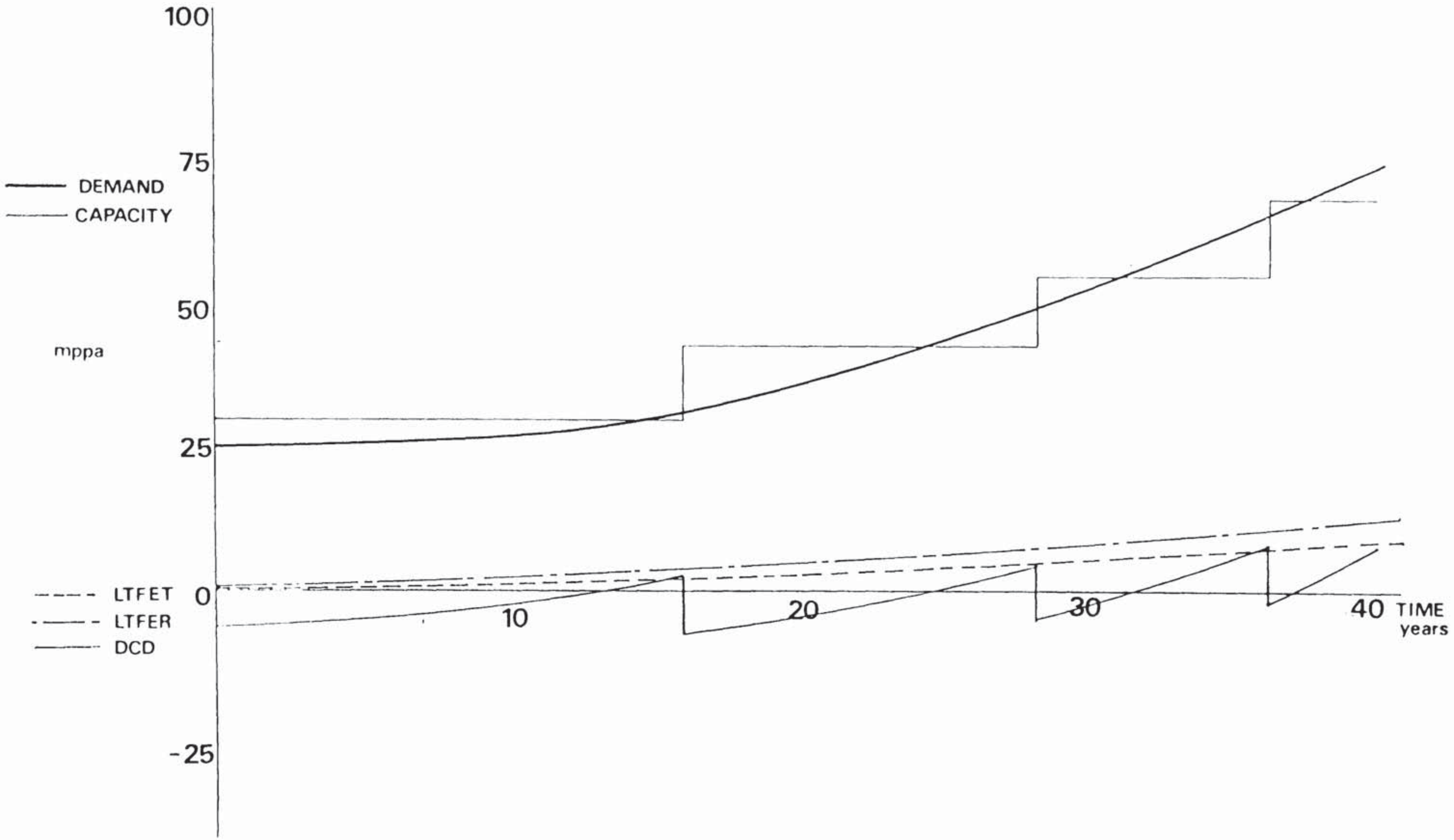

FIGURE 5.10 Expanded Model of Airport Capacity - Profile 2 - Scenario 2

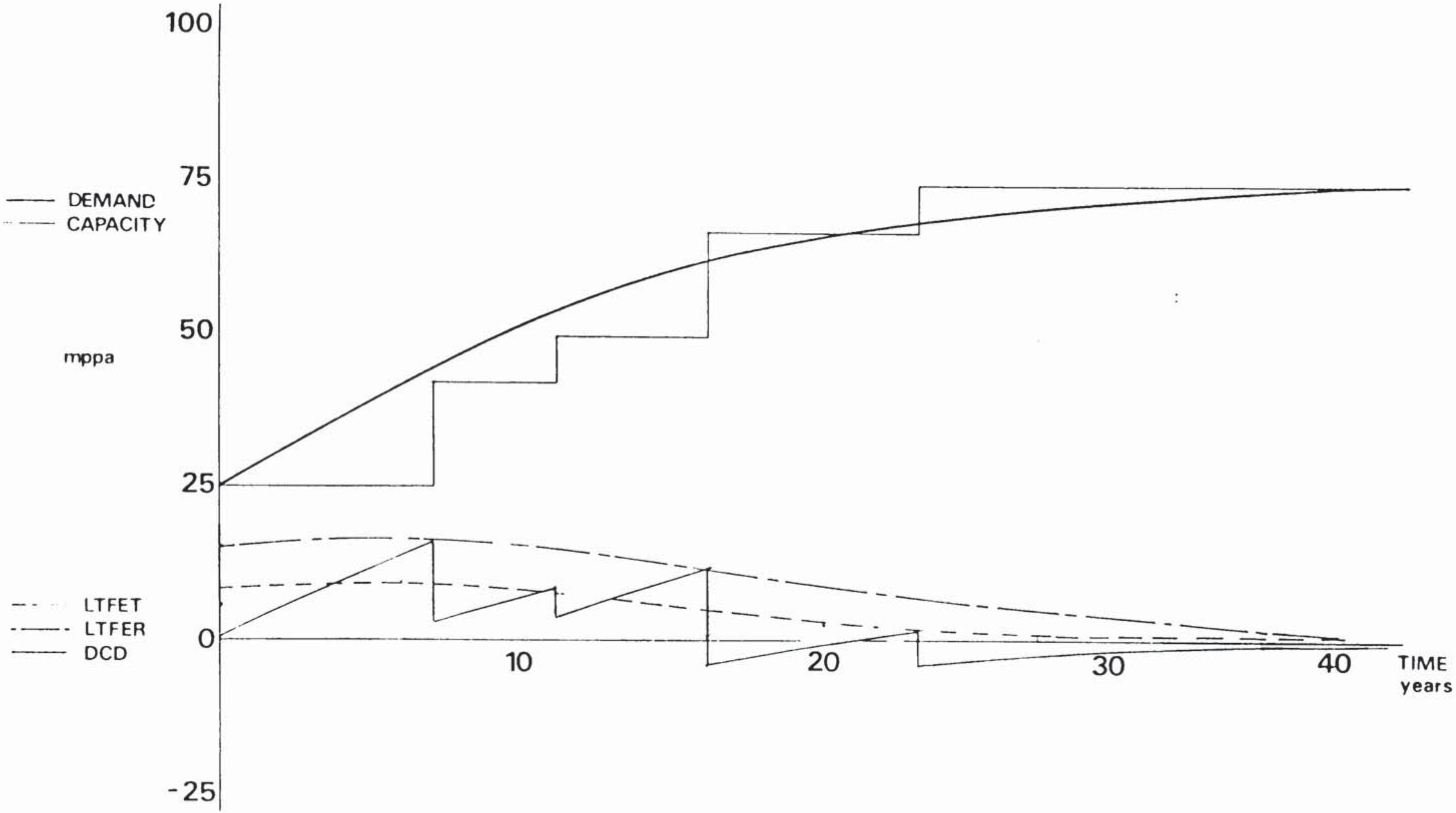

FIGURE 5.11 Expanded Model of Airport Capacity - Profile 3 - Scenario 1

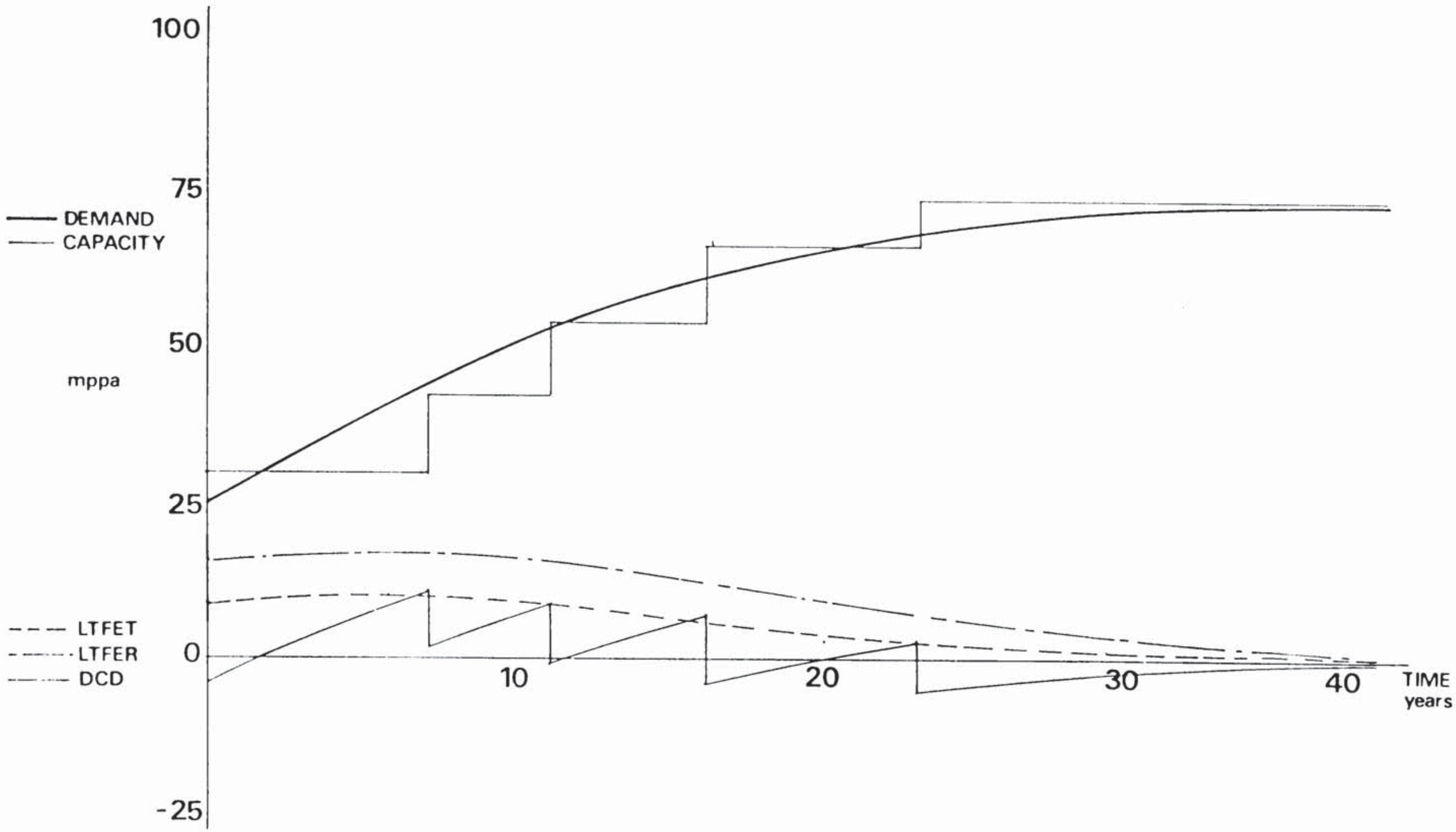

FIGURE 5.12 Expanded Model of Airport Capacity - Profile 3 - Scenario 2

CHAPTER 6

CASE STUDY TWO - ROAD PLANNING FOR GREATER LONDON

6.1 HIGHWAY APPRAISAL IN URBAN AREAS

6.1.1. This second case study is primarily concerned with the planning of the strategic road network in Greater London. However, roads in London cannot be considered in isolation from other parts of the transport system. Public transport is more important in the capital than in any other city in Britain and it assumed greater significance as the difficulty of implementing major road schemes in the urban environment became apparent. Comparisons with the approach adopted in other cities will highlight the extent to which London is a unique case. In addition, integration with the national road network is an important factor. Trunk roads have increasingly encroached on metropolitan areas as the major inter-urban schemes have been completed. Yet the planning constraints differ from those affecting urban road schemes.

6.1.2. During the 1960's and 1970's urban road building was only one element of the rational comprehensive planning adopted by metropolitan authorities. However, it was the most tangible aspect of such planning because of the urban definition given by the road network. As such it received greater prominence than other parts of strategic plans and because of its great cost attracted more of the available resources. This was particularly apparent in London where the planned orbital motorways, or ringways, attracted most objection at public consultation and subsequent inquiry into the Greater London Development Plan (GLDP). It is the plans for the Ringways and their legacy that will form the focus for the case study.

6.1.3. In contrast, inter-urban road building has always been the responsibilty of the Department of Transport who manage the trunk road network. Their partial approach concentrates on the design of a road (dictated by traffic engineering) and its immediate environmental impact. This is followed by a cost-benefit analysis, which although a part of an assessment framework, is still the most important aspect of evaluation. In urban areas, the potential for road schemes to achieve agreed policy objectives is of much greater significance. However, as the major inter-urban shemes are completed and trunk roads now penetrate much further into the conurbations, the use of techniques developed for inter-urban roads is of greater significance in the urban context.

6.1.4. A comparison of these two approaches will be important beyond their impact on physical schemes. In chapter 3 the importance of scale in the administration and management of transport programmes was illustrated. The two approaches to roadbuilding are examples of the decentralised policy orientated, comprehensive planning of the local authorities and the more centralised, partial approach of the civil service. The latter has received greater responsibility following the local government reorganisation of 1985.

6.2 THE HISTORICAL CONTEXT

6.2.1. The nature of the road system in London is heavily influenced by its historical development. Despite some changes during the 20th century, the predominantly radial network of routes can be traced back to Roman times. The straight and direct bearing of these routes reflected the pedestrian mode of travel which they served. As London expanded, the land available between the radials was gradually covered by buildings. The deficiencies in this form of network were not to come to light until the advent of motorised transport. The effect was to concentrate traffic from what was a very large area into a very small city centre where the radial routes converged.

Road planning in London has thus concentrated on re-orientating the structure of the road network to suit the needs of motor vehicles.

6.2.2. During the 19th century the great majority of travel was undertaken on public transport. The railway network was supplemented by the underground from 1863 and by a network of tramways from 1869. Although the London County Council (LCC) was formed in 1888, the traffic problem in the capital, considered more acute than elsewhere, was seen as the responsibility of central government. Following the introduction of motorised vehicles a Royal Commission on London Traffic was appointed in 1905[1]. Although they heard evidence on many radical solutions, the Commission concluded that the problem was a lack of co-ordination. As a result, a London Traffic Branch was formed within the Board of Trade in 1907.

6.2.3. The London Traffic Branch inaugurated a Road Fund to finance road construction from vehicle and fuel tax. However, the Government resisted explicit intervention until 1919 when the Ministry of Transport was formed assuming the powers of the Traffic Branch. The lobby for a co-ordinated programme of road expansion was strong;

> 'the future must be saved from the costly and ugly blunders which isolated action in the past has bequeathed to us and which we inherit today much to our regret'[2].

Such sentiments are still apparent in more contemporary debate on transport in London.

6.2.4. However, the new Ministry took little decisive action. In 1926 the Treasury gained powers to retain revenue collected for the Road Fund and in 1929 a Royal Commission on Transport rejected the need for motorways within London. Ameliorative measures such as the Prevention of Ribbon Development Act of 1935 were designed to attack the cause of the problem: development activity along arterial roads generated local traffic reducing the speed of the faster through traffic. The Highway Development survey of 1937[3] described in chapter resulted in proposals from the Ministry of Transport for orbital roads and roundabout junctions to aid this through traffic.

6.2.5. The movement of vehicular traffic on roads continued to be the primary transport issue. However, the railways and the underground together with London's buses still catered for the greater majority of travel. Emphasis on public transport was negligible partly because of the lack of co-ordination (the Ministry of Transport was responsible for roads but not public transport) but also because there was little technical input to planning. Hence analysis of underlying travel patterns rather than vehicular movement was not undertaken. Government committees continually rejected the need for such Travel Surveys.[4]

6.2.6. The impact of the Barlow Commission and the plans of Abercrombie were described in chapter 1. Abercrombie and Forshaw were greatly influenced by the control of traffic in cities abroad, particularly the United States. This heavily influenced the road network contained within the County of London Plan (Fig. 6.1.). Its objectives were stated as;

1. The improvement of traffic circulation.

2. Separation of fast long distance traffic from that of a local nature.

3. A reduction in the number of accidents.

4. Maintenance of existing communities free from through traffic.[5]

A potential hierarchy of routes for longer-distance and local traffic still dominates the issue of London's road in the 1980's.

6.2.7. The authors answered expected criticism within the plan itself. In response to future uncertainty, they considered their plan as flexible as any laissez faire approach. The role of the planner was to ensure that short term projects were in themselves complete, yet fell into line with the long-term plan;

> 'Thus if there are any unforeseen modifications of the later stages, the earlier are not vitiated.[6]

The plan was therfore considered to be evolutionary and corrective in the organic tradition.

6.2.8. The road network for the Greater London Plan (Fig. 6.2) extended that of the County Plan and reflected a more detailed analysis of traffic problems. There were now 12 objectives for the road plan including such diverse aspects as grade-separated junctions, precincts, car parks and cycle tracks.[7] The influence of Alker Tripp was increasingly apparent. Abercrombie believed planning to be a fusion of art and science, but it appeared that the supposedly scientific aspects were becoming increasingly dominant, a trend that was to continue. Ironically, when a more technical analysis of traffic was undertaken, several of Abercrombie's assumptions were discovered to be mistaken. The level of through traffic was disovered to be far lower than supposed while local trips provided most of the traffic on the roads.[8] His belief that further research would give greater precision to the plan based on underlying principles that were timeless has proved to be incorrect.

Development Plans

6.2.9. In 1947, the Town and Country Planning Act required that each county produce a Development Plan. The first such plan produced by the LCC was published in 1951.[9] It was subjected to a public inquiry in 1955 before statutory acceptance in 1960. It incorporated Abercrombie's road plans (including a fifth 'E' ring added in 1947) although the LCC was only responsible for that area contained approxiatey within the 'C' ring. The remainder of the road network was under the jurisdiction of the Ministry of Transport. This divided responsibility caused confusion and conflict and in 1950 the 'A' ring was dropped after disagreement between the two agencies over cost.

6.2.10. The delay experienced by the LCC Development Plan gives an impression of procrastination over the traffic issue in London. In fact the immediate post-war period was one of reconstruction, particularly of housing which took precedence over roads. In addition the New Towns programme was underway and this too diverted resources from London and its road network.

6.2.11. Public transport was still a separate issue, although British Rail (following nationalisation in 1947) encouraged commuting long distances into London, especially from the south east. This contradicted the spirit of the new town ethos which advocated a shift in employment as well as population. Thus a lack of co-ordination between transport authorities was still apparent.

6.2.12. In 1957 the Ministry of Transport established the Nugent Committee to consider again traffic problems in London. On this occasion the recommendation for a metropolitan inventory of travel resulted in action when the LCC instigated the London Travel Survey (LTS) in 1960.[10] Consultants were appointed to undertake the survey, predominantly covering car.use. The Buchanan report of 1963 tended to reinforce the car-orientated approach, although it emphasised the great costs of accommodating motor vehicles in the urban environment.[11]

6.2.13. The costs of new roads would be nowhere greater than in London. It was at this time the concept of road-pricing was first aired.[12] In a congested traffic environment, a direct charge for the use of roadspace would result in the optimum distribution of traffic through market mechanisms. The difficulty of measuring the usage of roadspace meant that this idea was not pursued at the time.

6.2.14. The first volume of LTS published in 1964 detailed only the collection of information during the survey without offering solutions. It highlighted the extensive use of public transport (90% of all work trips) and the importance of local traffic (only 0.2% of trips passed through London)[13]. The desire for orbital routes such as the north circular road was low, they were used for short sections of trips to switch between radial routes. This information contradicted preconceived notions concerning through traffic and the need for orbital movement. However when the Greater London Council was formed in 1965 it immediately announced plans for an inner motorway box. This occurred prior to the publication of the second, analytical volume of LTS which advocated two further orbital routes to complete a streamlined Abercrombie plan - 3 ringways plus improved radial access. This plan appeared to maintain an inertia insensitive to analysis.

6.2.15. LTS used demographic projections to predict the population of London in 1981 and together with forecasts of car ownership and usage, to predict the level of car journeys. This future matrix of trips was assigned to a series of road networks based on varying intensities of the ring and radial plan. Each assignment was evaluated in operational and economic terms, with the 3-ring plan considered the best.
The forecast of population proved to be a key factor. The success of the new town programme resulted in a continuing decrease in London's popultion - the opposite to that assumed by the GLC, although it attempted to reverse the decline.

6.2.16. Stage 3 of LTS, although published only in summary form, analysed the increasingly important issue of public transport in much greater detail. The conclusions of this report provided a substantial input to the Greater London Development Plan

(GLDP). Consequentially the relationship between public transport and highway investment was superficially considered in the GLDP. However, the proposals for the primary road system (the ringways) remained intact, as it was supposed that decreased congestion resulting from road building would benefit buses as well as private cars. The impact of road building on modal split and the release of suppressed demand were not sufficiently understood at that time. Public transport patronage was considered insensitive to roadbuilding, with quality of service and travel times the determinants of use.[14]

6.2.17. The road network was the main feature of the GLDP. Its benefits were stated to be:

1. Relief of existing road from longer-distance traffic.

2. Easier orbital movement.

3. Improved access from London to the national motorway system.[15]

The programme for investment in the plans remained uncertain as did the commitment to public transport. Hall cited three reaons for these uncertainties.

1. LTS was undertaken as a response to a traffic problem.

2. LTS utilised American techniques unsuited to British public transport.

3. The GLC held no responsibility for London Transport until 1969.[16]

6.2.18. The GLDP was published in 1969 and subjected to a public inquiry between 1970 and 1972. Unusually for such an inquiry a panel of assessors was appointed similar to those of the Commission on the Third London Airport. Sir Frank Layfield QC was appointed inspector and chairman of the panel which heard 28,392 objections from 19,997 objectors. 75% of them were concerned with transport and this was reflected in the report of the inquiry published in 1973.[17]

6.2.19. The GLC was severely criticised during the inquiry because of its rigid commitment to the road plan. However it became apparent that the GLC no longer considered it inevitable, but that it was their desired objective:

> 'The core of the problem of transport in London is how to persuade people to use the mode of transport which both satisfies their demand for movement and avoids conflict with the other objectives of the plan. The forecasts are not however inevitable, they represent merely the outcome of the assumptions made.'[18]

6.2.20. Legislation in 1968 required that Development Plans be regarded as structure plans which required alternative strategies for future development. However they were difficult to discern within the GLDP. The shortcomings of the plan were summarised by the panel as:

1. It was over ambitious - policies cannot alter settled population trends.

2. There was inconsistent treatment of substance:

   1. The knowledge of roads was far greater than that for public transport

   2. It concentrated on policies it had the power to implement e.g. concerning roads.

3. Failure to relate information to policies - the GLC chose political reasons and presented them as inevitable.

4. Failure to relate policies to aims, aims were never clarified.

5. Failure to present aims in meaningful terms.

6. Failure to distinguish between strategic and local planning material.[19]

6.2.21. The effect of these criticisms on the road plan may be gauged from Figure 6.3. The recommended road network retained Ringways 1 and 3, but rejected Ringway 2. However, the north circular road which would have formed the northern section of Ringway 2 was already in place and further improvement of this route was suggested. In relation to the road network, the conclusions of the Layfield Panel may be considered a compromise, but with the emphasis on roadbuilding solutions retained.

6.2.22. For the duration of the Layfield inquiry, the Labour Party in London campaigned for the abolition of the Ringway plans and improved public transport. When they obtained control of the GLC in 1973 the objectives of the campaign were realised.

Although the technical arguments had prevailed at the public inquiry, the political debate resulted in rejection of large scale road plans. Land safeguarded for many of the routes was sold, so that plans of such a scale would be difficult to implement in the future.

6.2.23. The attempts of the Labour administration to improve public transport between 1973 and 1977 were not as successful as those implemented in the 1980's. Financial difficulty precluded any real improvement and when the Conservative Party returned to power in 1977, roadbuilding returned to the agenda. In 1977, the report of the Advisory Committee on Trunk Road Assessment[20] chaired by Sir George Leitch, was published. The assessment framework, detailed in a subsequent report,[21] was to be important in relation to highway appraisal in London.

6.2.24. The Leitch framework was intended for use in rural areas and as such, its use in urban assessment was problematic. However, the North Circular Road (NCR) in London was a trunk road and the Department of Transport proceeded to use the framework to evaluate improvements, as recommended by the GLDP panel of inquiry. This created intense conflict between the GLC and the DTp when the Labour Party returned to power in 1981. The use of unconstrained traffic forecasts and cost benefit analysis in the London environment were questioned at public inquiries while the measures of environmental impact, developed for rural application were too insensitive to changes in the well-developed urban fabric.

6.2.25. In 1984 the DTp appointed consultants to assess the traffic problems of four areas of metropolitan roads in the inner London area. These GLC roads were to become trunk roads upon the abolition of the GLC in 1986 and three of them covered those areas where ringway 1 and the southern section of ringway 2 were once proposed (Fig. 6.4.). The DTp had by this time virtually completed construction of the outer-orbital, the M25, although its alignment was further from London than the previous Ringway 3. Travelling for most of its length outside the GLC, it met with little opposition and was constructed very easily. The GLC supported the scheme as it provided a potential by-pass for heavy commercial traffic which previously passed through inner and central London.

6.2.26. Meanwhile the GLC had introduced controversial measures to improve public transport. The cheaper fares and the introduction of integrated tickets for all modes of public transport were successful as patronage increased and traffic levels in central London were marginally reduced. The conflicts between this policy and the major road improvements of the DTp were one of the issues which led to the abolition of the GLC in 1986. To assist the DTp in its new role as highway authority for all major routes in London, SACTRA was reformed in 1985 to recommend techniques for highway appraisal in urban areas.

6.3 HIGHWAY PLANNING IN GREATER LONDON - ANALYSIS

Traffic Forecasting

6.3.1. The history of road planning in London related above has shown forecasting traffic in metropolitan areas to be a complex task. There are a number of factors which influence forecasts over and above those affecting the urban centres of small towns. Similarly, traffic forecasting in such towns is more complex than in the inter-urban situation. Inter-urban road planning, like airport planning considers only one travel mode in forecasting, with little competition and a captive market. In metropolitan areas there is direct competition for some trips from well developed public transport services. The additional factors which directly affect the relationship between modes include the availability and cost of parking, levels of traffic congestion, the distribution of employment and services etc.

6.3.2. It would appear that many of these factors were either ignored or their importance unrecognised when the ring and radial system of motorway standard roads was devised. Unfortunately, this strategic road plan gained its own inertia which rendered much of the analysis of travel irrelevant. Abercrombie viewed the increasing car ownership in the USA is a trend which would inevitably be repeated in Britain and particularly in London where much of the nation's wealth was concentrated. This was an intuitive assumption.

6.3.3. The London Travel Survey was designed to provide more technical support for road planning. LTS was partial in its approach and failed to recognise neither the scale of the infrastructure required for its unconstrained projections of traffic growth, nor their environmental impact. It was at this stage that the principal technical error in forecasting occurred. Population forecasts during the early 1960's did not anticipate the decline in national growth that was subsequently to occur. In addition, migration from London was encouraged by the creation of new towns, such as Harlow, Stevenage, Bracknell and Crawley which were located around London.

6.3.4. Even if projections of car ownership were correct, the shortfall in expected population would result in less cars and less traffic than originally surmised. The reduction in population resulted in a subtle shift of policy concerned at the migration from London the GLC position began to suggest that the ringways were a means of regenerating the inner-city areas, a long standing aim.

6.3.5. Further analysis of traffic in London undertaken in later stages of LTS suggested that congestion would always be present, particularly in the central area, no matter how great the capacity of the road system. In 1963, Traffic in Towns[22] had shown that restraint of traffic in central urban aras was inevitable, because the scale and cost of roads to satisfy unrestrained demand was prohibitive. These conclusions were reinforced by the report of the GLDP inquiry in 1973[23]. In the 10 years following that report, more research has been carried out on the role of parking policy and the importance of public transport provision in relation to road use.

6.3.6. The case-study of highway planning in London reflects the very slow learning process that has occurred in traffic forecasting. Gradually over a number of years, the impact of an increasing number of factors has been encompassed. This learning process is still continuing with the possibility of road building itself generating enough traffic as self justification of the need for roads an increasingly important issue.

6.3.7. One conclusion is however clear. Unrestrained forecasts of road traffic in metropolitan areas are invalid. There are too many factors in the control of (often different) policy-makers for this to be the case. Major strategic road schemes such as the ringways are examples of positive approaches to policy objectives in much the same way as the Zeitgeist and visionary plans of the early transport planners described in chapter 1.

6.3.8. The fact that the ringway plans were announced in 1965 prior to the publication of the results of LTS further supports this position. In the event, the reports of the studies were used to justify the plans rather than provide information for the generation of alternative schemes.

6.3.9. It is apparent that the forecasts of traffic in London were not the most important aspect of the GLDP (75% of objections concerned the strategic or policy aspects of transport rather than technical issues). Just as the London airport issue was dominated by the politics of location, so the ringway plans were the result of the powerful engineering and planning professions, together with the visions of local politicians. There was little consensus over traffic forecasts but ultimately, they were not essential to the future of roadbuilding in London at the strategic level. Strategic road plans are matters of policy, not a rational response to travel trends. The shortcomings of the infrastructure options chosen for London, and of the policies designed to achieve them will now be examined.

London's Transport Infrastructure

6.3.11. It has been shown that the transport element of the GLDP was not a rational product of forecasts of car traffic, but a part of a much larger plan which represented the aspirations of politicians and professionals alike. The plan was in many respects a comprehensive one, relating travel to housing, employment etc. although the absence of any detailed analysis of public transport detracted from its completeness (The GLC was not responsible for London Transport at that time). It may also have been internally rational and consistent given the aims of decision-makers, but in relation to patterns of travel and community preferences it was not an objective response.

6.3.12. That strategic plans of this nature represent the values of decision makers does not diminish the importance of the development of the road network. In chapter 5, the real issue was how best to develop London's airport system, not should there be a third London airport. For roadbuilding in London the question is not whether the ringways should be built, but how the development of the network should proceed. The question is complex and will be dependent on the (often conflicting) policy objectives discussed later in this chapter. It is the infrastructure aspects that will be examined here.

6.3.13. The structural configuration and scale of development are the principal issues concerning the road network. Consideration of the question of scale will also give rise to implications for lead time, rate of development, cost and environmental planning.

6.3.14. In chapter 2, the short-comings of the ring and radial road network were exposed. It canalised traffic in a concentric manner giving rise to large-scale intersections near its centre illustrating how the structure of a network affects its scale. As a result costs are high and environmental intrusion at its greatest where development is at its most dense.

6.3.15. However, the radial routes which connect central London to the outer suburbs and then the provinces are a product of the development of the capital over many years and which are inadequate given the recent rapid rise in motor-vehicle use. Even though other forms may be more appropriate to London such as the plans of Mars and Proudlove,[24] it is unlikely that they could be implemented at this stage. Even at the GLDP public inquiry, the majority of objectors agreed that should major road building be necessary, the ring and radial form was the most logical. Given that it is inadequate, the question remains whether the centrally orientated nature of London's roads should be reinforced by the provision of high standard orbital routes.

6.3.16. The GLDP was a structure plan and as such was strategic rather than detailed. It was apparent however that the volume of trips to be accommodated on the road network implied infrastructure on a very large scale. The ringways were designed as dual-three lane carriagways with grade separated junctions built to motorway standard. The few sections of the ringways to be built (e.g. the East Cross Route) bear testimony to this. In key areas, the standard of road required resembled the freeways of the United States. The West Cross route at Earls Court was estimated to require 14 lanes of road to accommodate the predicted levels of traffic. The feasibility of implementing such schemes without causing severe environmental intrusion was seriously questioned at the GLDP inquiry.

6.3.17. The lead time of the GLDP road plan was estimated to be 40 years, considered too distant by the Layfield Panel. In addition the panel considered the validity of the GLC forecasting and traffic modelling procedures to be poor. The level of uncertainty was thus great not only in terms of traffic growth, but also because of the level of integration required in such a comprehensive network.

6.3.18. Over-riding this uncertainty, was probably the most important issue of cost. The East Cross route, a relatively small section of the entire network cost £50m, some 15% of the total GLC construction budget. The GLC clearly could not afford the level of capital investment implied by the plan. As many of the roads which they were considering were actually controlled by the Department of Transport, central Government has expected to meet part of the costs. The (now superseded) first year rate of return indicated 8%, 2% less than that officially required by the Treasury at the time.[25]

6.3.19. In 1963 the Buchanan report had indicated the substantial costs of incorporating major road developments into highly developed urban areas. By the standards applied to inter-urban roads many of the GLC proposals would have been regarded uneconomic. Economic evaluation continues to be one of the most contentious elements of road appraisal, because of the demarcation between factors which are included and those which are not.

6.3.20. The uncertainty over costs and benefits was exacerbated by that caused by the infrastructure itself. The traffic generation potential of roads particularly in urban areas implied that investment in roads could be self-fulfilling. Although more research on traffic generation has been undertaken since the GLDP inquiry it remains a controversial issue.[26] Even much smaller schemes such as the traffic management measures introduced in the central area where restraint was universally accepted as necessary were subject to an intense debate regarding their economic value.[27]

6.3.21. The Layfield panel considered this circular problem one of where to break into the vicious circle of generated demand which requires increased capacity, which in itself will create yet more demand unless restrained. The conclusions of the panel were that maximum restraint and utilisation of public transport should be sought prior to major capital investment in roads.

6.3.22. To summarise, the development of roads in urban areas is not a wholly rational technical process. It is heavily influenced by the policies and objectives of politicians, professional engineers and planners. There are a number of complicating factors such as public transport usage, traffic restraint and generation and parking policy which are administered by policy makers and will influence the level of traffic as the road network.

6.3.23. However the road network will continue to be improved. A minimum amount of road space is at least required for the movement of goods and other commercial and personal trips. Roads also have a limited life and changing patterns of land-use especially in outer areas will mean that improvements and some new roads will always be required. The questions remain at what scale should the network be developed, at what rate should this development proceed and how should schemes be evaluated?

London's Roads - Policy and Decision-Making

6.3.24. The GLC ringway proposals were a product of the Greater London Plan of 1944. Abercrombie's designs were rejected by the LCC in the 1950's because of potential intrusion into London's environment and the scale and cost of the supporting technical studies necessary. The orbital additions to the predominently radial road network were a product of Abercrombie's organic view of growth as applied to the metropolitan area. The LCC's initial reservations concerning the cost of transportation surveys were soon reversed when, based on the approach taken in North America, they announced the London Traffic Survey in 1959.

6.3.25. The new and large GLC instituted in 1965 primarily to deal with strategic matters, announced their intention to pursue ringways 1, 2 and 3 before the survey had reached its conclusion. It is therefore apparent that the road proposals ultimately contained within the GLDP were not a rational response to a detailed technical analysis, but a policy objective of that administrataion. It was also encouraged by the strong professional team of transport engineers and planners assembled at County Hall. However, it was not strictly a technocratic approach, more a product of the instinctive expertise of professional planners in the Abercrombie tradition.

6.3.26. One of the criticisms of the GLC put forward by the Layfield Panel was that the objective of the plan and the policies required to achieve them were never clearly defined. As a product of the intuitive and organic mode of planning, it is possible that the plan was itself the end rather than the means of achieving objectives. The panel stated that their report was an attempt to:

> 'establish links between on the one hand aims and aspirations and, on the other the policies needed to bring them about. Our basic criticism of the plan is that there are, too often, either no links between its aims and policies, or no policy at all to support a wholly desirable aim. We attempt not to recommend aims unless we can also recommend policies which are likely to achieve them. Where we are not able to do so we reject the aim, desirable though it may be as unrealistic.'[28]

6.3.27. The Layfield panel did not reject the concept of the ringway plans, as they recommended that two of the orbitals, 1 and 3, be constructed.

The third, ringway 2, was already partially in place in the form of the north circular road and the panel recommended it be upgraded. Thus the report of the inquiry was a compromise which favoured the concept of improving orbital movement by road.

6.3.28. Large scale plans such as those contained within the GLDP are the product of political and professional vision. Thus, if they are to be realised over a period of many years they require political consensus. A breakdown in consensus will put such plans in jeopardy and conversely, such plans may be viewed as being highly sensitive to political change.

6.3.29. In chapter 3, decisions concerning large scale investment of this sort were characterised as non-incremental. The work of American political theorists was examined and they rejected such decisions as being inefficient and inappropriate to a pluralist society. Such divisions would always attract opposing groups, involve protracted negotiation and often result in no action being taken. Lindblom in particular advocated disjointed incrementalism as an alternative method of decision-making.

6.3.30. However infrastructure by its very nature and roadbuilding in particular may not be susceptible to incremental processes. Their inflexibility means that there is little room for marginal adjustment other than in the scale of junctions and carriagway capacity. The inflexibility of road construction arises from the decision to build at all, as much as from the scale of construction. For a network of links, the need for integration etc reinforces and adds to this inflexibility.

6.3.31. Since the demise of the ringway plans roads have been constructed and built in London. The GLC itself, although committed to improving public transport has continued to construct new roads and improve existing ones. However the scale of these projects has been much smaller than that envisaged for the ringways. Hence where in the past dual three lane motorways would have been proposed, dual-two will now suffice. Such differences may be regarded as marginal, but they are a physical manifestation of two entirely different approaches to the problems of traffic congestions.

6.3.32. The first approach reflects the established view of catering for unrestrained traffic growth as a natural consequence of economic growth. The latter represents a concern over the consequences for those areas adjacent to a major road improvement which may suffer increased environmental intrusion due to increases in capacity. The traffic generation potential of roads in London is such that any new road space is immediately occupied by traffic (the 80% of commuters who use public transport reflects the level of suppressed demand). Such generated traffic may include undesirable change of mode from public transport, considered a less damaging and more efficient means of transporting people to the centre of a metropolitan area.

6.3.33. The two approaches also imply two methods of assessment. The first is a localised evaluation dominated by time savings for road users and the second is more orientated to policy and strategic planning goals. By implication, the latter reflects a greater concern for the strategic aspects of transport planning. Thus marginal differences in road construction may be more than just a product of compromise in an incremental mode of decision-making.

6.3.34. The earlier GLC plans also conformed to this strategic approach although they resulted in failure. However there have been strategic successes. The policy of public transport subsidy and ticketting integration within Greater London increased patronage and reduced car commuting by 6%. This may seem a small change, but in a complex urban environment it will have a significant impact on congestion. It further demonstrates the importance of marginal changes and their reflection of very different attitudes to policy.

6.3.35. Given the failure of earlier strategic initiatives and the success of the integrated public transport policies, the differences between the two approaches are potentially very important. The cheap fares policy required little capital investment and was implemented (and reversed) in a very short space of time in planning terms, although it was strategic in nature. Thus strategic initiatives are possible and maybe necessary in a complex environment such as London. Decentralised, marginal initiatives such as those prescribed by disjointed incrementalism may not be the necessary or appropriate alternative to large scale capital works.

6.3.36. It is apparent that in a complex environment such as London, strong and coherent policies are required to give direction to transport planning activity. Furthermore appraisal of transport schemes should be undertaken relative to such policies. Those schemes with large commitments to capital investment and/or extensive lead times are likely to prove problematic. Strategic policies which avoid these characteristics are more likely to succeeed.

6.4 MODELLING URBAN TRANSPORT NETWORKS

6.4.1. Models of multi-modal urban and inter-urban transport systems are potentially much more difficult to construct that those for airport development. Airport capacity may be reduced to relatively few discrete sites which makes it more susceptible to time-series analysis. There are two major difficulties for a continuous or dynamic model when roads and public transport facilities are considered:

1. The need for forecast traffic flows on each individual link in the network.

2. The effect of road provision on demand.

6.4.2. The first problem is considered the reason why the practical application of transport planning techniques has to date altered little.[29] Clearly for a model like TRAIN to project whole networks of roads, railways and bus-services would require substantial expansion of its scope and capacity. However, it was not designed for such comprehensive coverage. Indeed given that uncertainty in future demand can never be eradicated a simpler approach based on time series is possibly more sensible.

6.4.3. The second issue, that of the possible generation of traffic through roadbuilding is potentially susceptible to analysis via TRAIN. The presence of such an effect has mostly been disregarded by practitioners because of implications for policy and economics. However, recent work by the GLC has recognised the effect,[30] although the absence of a predictive mechanism for such generation prompted a rejection of road building as the only possible response. With the use of feedback and dynamic principles, the possibility for linking capacity to demand in a model such as TRAIN is more realistic.

6.4.4. However, such a feedback mechanism would require substantially more research. Again, such an approach over a large network would be prohibitively expensive. At the strategic level the commonly accepted method of analysis for both urban and inter-urban travel is now the 'corridor'. At such a level, a model such as TRAIN could be applied, particularly for the generation effects of infrastructure and the interaction between competing modes. The example that follows will not provide any validated results, but an illustration of the possible use of TRAIN.

6.4.5. The Basic model of TRAIN as described in chapter 4 was used to illustrate the effects of two different approaches to potential traffic congestion in an urban corridor. Given that the peak hour is more important than daily or even annual traffic flows, this time period was chosen for analysis. The model considered a dual carriageway road in a metropolitan area. The capacity of such a road may be considered to be 3000 veh/hr in each direction. A demand profile of the logistic type with a saturation level of 4000 veh/hr was used to test two alternative strategies.

6.4.6. These strategies were based on two alternative responses to congestion in urban areas. Strategy 1 involved addition of an extra lane to the contingency, ie conventional road-widening (a major scheme in an urban area) increasing the capacity to 4500 veh/hr and requiring 8 years to complete. Strategy 2 involved a series of traffic management measures to increase the capacity. The first, would involve junction improvements, (the major constraint on capacity) which would increase capacity by 1,000 veh/hr and require 3 years for completion. Should any subsequent expansion be required, improved public transport patronage would be necessary and a bus lane scheme may encourage a similar increase in capacity (assuming 1 occupant per private vehicle).

6.4.7. The model output for these two strategies is given in Figs. 6.5 and 6.6. The summary characteristics for both strategies are given in Table 6.1. Although strategy 2 has less spare capacity for the initial conditions described, road capacity is extremely 'lumpy' and so an initial capacity of 2500 veh was also tested. This was clearly more sympathetic to road building (strategy 1) which suffered far less spare capacity, although greater undercapacity as a result of the longer lead time. In practice demand would expand to fill any available road space and the spare capacity available would be minimal.

6.5 CONCLUSIONS

6.5.1. London has inherited a road network unsuited to the speedy movement of motor-vehicles. The ring and radial structure concentrated traffic at its centre where volumes are at their highest and conflicts at their greatest.

6.5.2. To re-orientate the network to a structure that could accommodate greater car-usage, such as the grid adopted in American cities would be very expensive, economically and environmentally:

> 'To preserve a certain worthwhile standard of environment, the amount of traffic that can be admitted depends upon the money that can be invested in physical alterations'.[31]

This 'law' as quoted in 'Traffic in Towns' remains the case today. The cost of land and environmental redevelopment in urban areas, particularly London is very high and contributes to the high overall costs and lower benefit-cost ratios of major urban road schemes.

6.5.3. Hence a re-definition of the London road network more favourable to car-usage, is unlikely to occur. Furthermore, the level of suppressed demand for roadspace is likely to ensure that any form of road network will be used to the limits of capacity. Investment in roads is a policy issue, not only because of this relationship between cost and accessibility, but also because it complicates the forecasting and evaluation procedures. Car usage in London will be partly determined by the roadspace provided and the alternative modes of travel available. In addition, cost-benefit evaluation procedures may exaggerate the benefits of road schemes by predicting improved traffic speeds which ignore the effect of suppressed demand or 'generated traffic'.

6.5.4. Traffic forecasting for urban areas needs to be policy sensitive if it is to acknowledge these effects of roadbuilding. The longitudinal methods outlined in chapter 3 are most likely to achieve this sensitivity, as they incorporate a temporal dimension absent from conventional cross-sectional modelling. This time dependent approach is more appropriate to forecasts of travel demand where changes in behaviour may occur as a delayed response to 'events' such as road and public transport improvements. The use of feedback in such a model offers a potentially powerful tool for predicting the generation effects of infrastructure investment.

6.5.5. Scheme evaluation allied to policy objectives, deemed to be more satisfactory than a traffic-functional/economic approach, is by definition strategic in nature. It implies a broader context for scheme appraisal which extends beyond local traffic effects. In itself this does not reflect a desire for comprehensiveness, but only the effects of scheme implementation in practice. The nature of urban congestion is such that relief at one point on the network may simply relocate the congestion elsewhere. Furthermore, major road improvements, particularly for radial roads reflect a desire to encourage commuter trips by private vehicle.

6.5.6. Such policies have been shown to be self-defeating as road users achieve little real benefit (excepting a possible change in mode) as congestion quickly re-asserts itself. Alternatively, strategic policies directed towards public transport improvement have been shown to achieve both increased patronage and reduced traffic congestion. Furthermore, the public transport systems in London, particularly the railways, have greater spare capacity than that available on the road system. Hence, policies that encourage public transport patronage are accommodated more easily than those that encourage car use.

6.5.7. The administration of strategic policy now proceeds on an ad-hoc basis since the demise of the GLC. The temporary nature of the administration of policies for transport which transcend localised areas, but which are not national issues reflects the uncertainty of how best to achieve responsive strategic planning:

> 'Although the present idea of a fluid planning operation which is constantly capable of redirecting itself has won widespread approval in governmental and professional circles, there are few examples of how such a process could be made operational'.[32]

6.5.8. The current situation separates major road investment and public transport from traffic control and other planning activity. The Department of Transport has assumed control of London Transport and all the principal roads in London. If they were to apply their standard trunk road appraisal techniques to road improvements in inner London, then some of the most important effects of transport schemes would be ignored. There would appear to be a need for some authority, responsible for strategic policies which can relate transport improvements to other planning activity. This will allow strong statements of strategic policy necessary for matrix-based assessment.

CHAPTER 6

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STRATEGY	INITIAL CAPACITY	
	2500 veh/hr	3000 veh/hr
1	25/34	88/13
2	7/81	44/3

Total Under/Over capacity per run (000's veh)

TABLE 6.1. TWO STRATEGIES FOR URBAN ROAD IMPROVEMENTS

- MODEL RESULTS

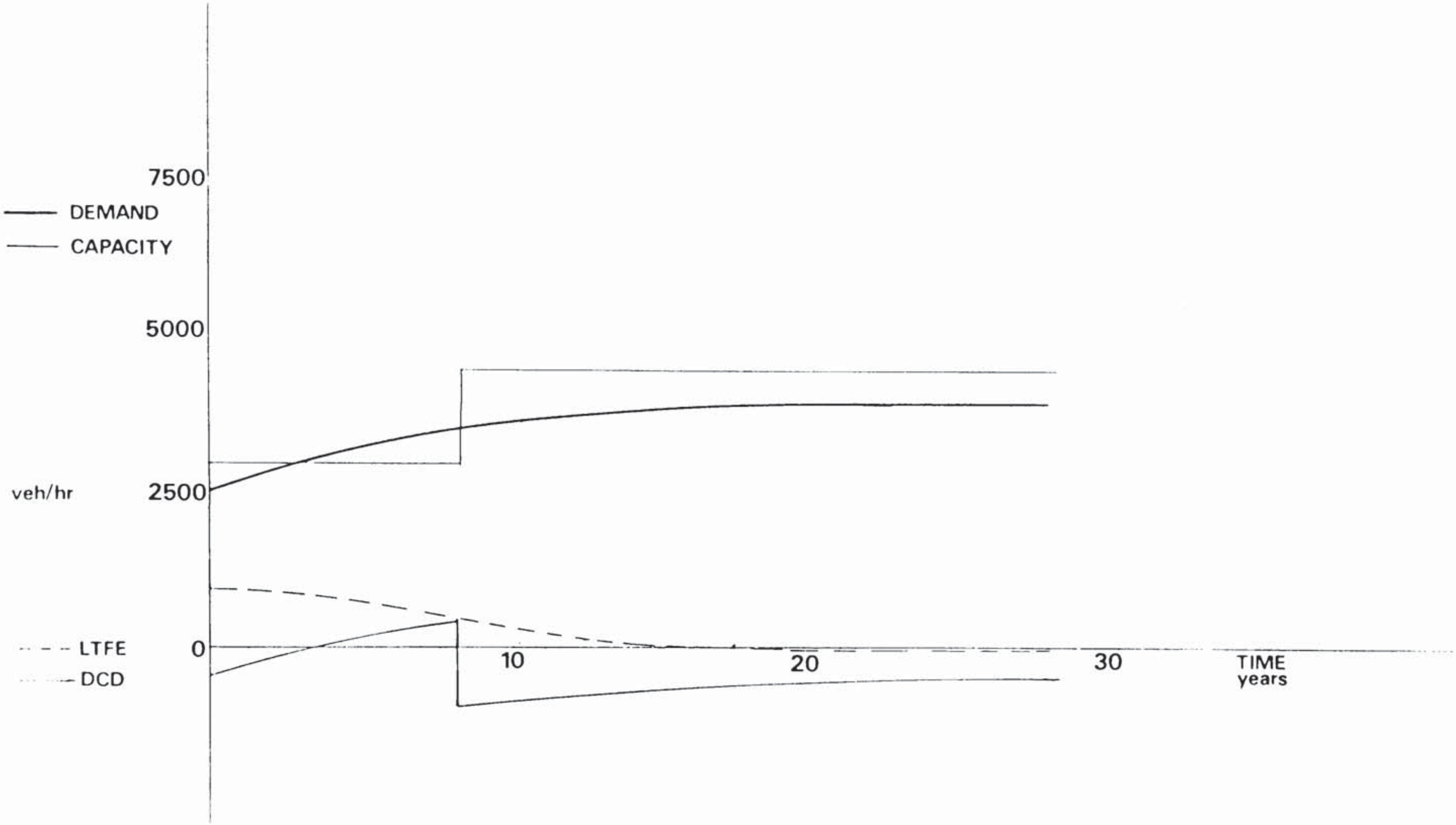

FIGURE 6.5 Urban Highway Corridor - Strategy 1

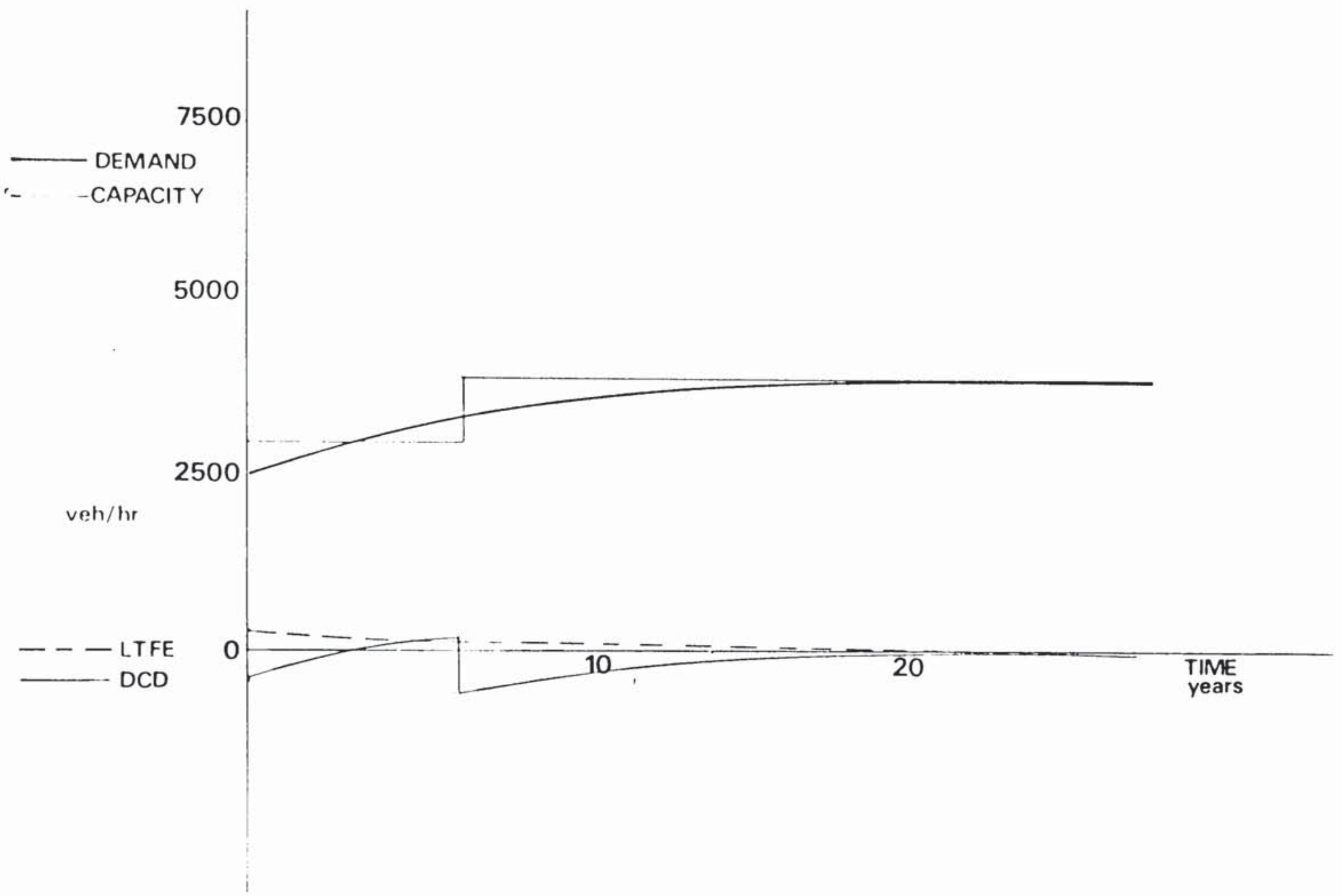

FIGURE 6.6 Urban Highway Corridor - Strategy 2

CHAPTER 7

CONCLUDING REMARKS

7.1 SUMMARY OF ISSUES

7.1.1. Chapter 1 described the coalition of planning ideas and practices which provided the framework for the evaluation of transport investments. The resulting transport planning process embodied a demand-satisfaction approach whereby rational analysis was the major determinant of policy. The assumptions of appraisal techniques together with the projects they supported were very sensitive to future uncertainties in travel demand and transport policy. Consequently, the evaluation of major schemes became protracted and conflictual.

7.1.2. In Chapter 2 those characteristics of transport infrastructure which promoted inflexibility were further investigated. Particular attention was given to the scale and lead time of transport projects, and for road networks the structural configuration. It was concluded that the efficacy of alternative investments could be evaluated only with reference to policy objectives. Furthermore, if large scale projects with long lead times were adopted, then accurate forecasting would be required.

7.1.3. Hence major construction projects required a policy consensus if they were to be successful. In chapter 3 the breakdown in this consensus was cited as the major reason for the failure of strategic transport planning initiatives. The techniques of transport planning that generated such projects also assumed a consensus through the aggregation of demand (forecasting) and values (evaluation).

7.1.4. Thus the current requirement is for strategic projects and policies which are feasible in a new planning environment consisting of a plurality in values that lacks consensus. Furthermore, such new initiatives would require a re-appraisal of techniques which embody a greater recognition of the uncertainty and diversity of travel behaviour. In essence they should be capable of reflecting potential changes in demand and values over time.

7.1.5 The conventional approach to these issues has concentrated on the forecasting and evaluation procedures. The construction of a series of future scenarios would provide a methodology that would establish which projects were robust to varying future conditions. This potential robustness was also sought during the evaluation phase when those projects which could maximise benefits and/or minimise disbenefit under a range of future conditions would be preferred. These techniques for dealing with uncertainty were described in Chapter 3.

7.1.6 It was also suggested in Chapter 3 that this approach ignored a significantly important aspect of uncertainty: the effect of the physical characteristics of the projects themselves. By concentrating on the forecasting and appraisal procedures, most research has failed to comment on the form, scale and structure of either complete strategies or individual projects. As a result, improvements to the methodologies have not necessarily improved the results of transport planning.

7.1.7 The approach adopted in Chapters 4, 5 and 6 assumed implicitly the continuing presence of uncertainty in forecasting and evaluation and the emphasis was on discovering which characteristics of transport projects most exacerbated the problems of this uncertainty. Then it would be possible to identify those projects which were most likely to be susceptible to re-orientation to new goals, objectives and environmental constraints in the future. It is likely that the choice of such projects would differ from that resulting from the application of existing techniques.

7.2 IMPROVING THE PROCESSES OF STRATEGIC TRANSPORT PLANNING

7.2.1. There are three areas related to the development of transport systems that may be subject to improvement. The problem was initially formulated as one of the constraints of inflexible capital investment that prevented the planning processes from responding to future changes in demand and policy, that always occur when uncertainty is present. However, the generation of projects more susceptible to realignment in the face of such changes also implies an improvement in modelling and evaluation techniques. Finally, improvements in these two areas will have implications for the policy and decision-making processes.

Transport Infrastructure

7.2.2. The investigation of the characteristics of transport infrastructure involved two distinct elements. The first consisted of the review of previous research on the infrastructure of roads and airports presented in chapter 2. The second utilised a simple simulation model developed in chapter 4. The review embraced many more characteristics of infrastructure than was possible using the model e.g. configuration, although the results of the model generally confirmed in detail certain aspects of previous research.

7.2.3. Research on road networks has been more extensive than that for airports. The Buchanan report first identified the need for solutions other than infrastructure to urban traffic problems. The incremental costs of a total roadbuilding solution for Newbury town centre as compared with a more partial redevelopment were shown to be far in excess of the benefits.

7.2.4. 'Traffic in Towns' concluded that no configuration of urban network could satisfactorily accommodate all traffic. However all other studies highlighted poor operational characteristics of the ring and radial structure, giving greater need for alternative approaches in British cities. If a re-orientation of networks is possible, a composite or linear grid is desirable. If not, policies other than roadbuilding should be pursued.

7.2.5. The under-utilisation of large, centralised systems was highlighted by Stone, in the context of road networks and for airports by Walters[2], and Doganis and Thompson[3]. As the capacity of individual investments increased, the capacity of the whole airport system was likely to show greater differences when compared with demand and for longer periods. The effect was compounded with increasing lead time.

7.2.6. The effects of large scale investments on the relationship between demand on capacity were confirmed by the empirical modelling undertaken in chapter 5. Lead time was found to be much less important in this respect. The results of this exercise were dependent on the form of demand profile, with large scale strategies performing better under certain conditions. However, the future profile of demand is one of the uncertainties that is unknown. The relationship between scale of investment and the difference between demand and capacity was not linear. The difference increased more rapidly than the scale of investment as it was a product of unit capacity and time.

7.2.7. One of the important differences between highway and airport infrastructure was the influence on demand. The presence of airport capacity was not considered to influence demand, but in congested urban situations, the level of suppressed demand implied that a strong generation of traffic was effected by increases in capacity. Hence the development of airports presents a less difficult modelling problem than that of highway improvements.

7.2.8. Over and above the preference for smaller scale infrastructure alternatives, it was apparent that there was no optimum form of transport system that provided a correct solution. Even a demand satisfaction approach based on conventional rationality will generate many alternative solutions.

Although costs and benefits will be evaluated during appraisal, it is apparent that alternative solutions reflect differences in policy. This is particularly important in road building where small differences in scale as expressed through carriageway and junction capacity may imply totally different policies.

7.2.9. Hence the role of policy in infrastructure development is very important, particularly if evaluation becomes less utilitarian. The choice of solution will become increasingly dependent on policy and this has implications not only for the role of policy itself but also for evaluation techniques.

Transport Planning Techniques

7.2.10. The application of transport planning techniques has been shown to be fundamental to the development of transport systems under uncertainty. Both forecasting and evaluation procedures employed in support of the case studies examined were shown to be inadequate without political consensus. Comprehensive analysis proved to be ineffective in the face of uncertainty engendered by a diversity of transport needs and a plurality of interested groups.

7.2.11. There are two possible responses to the loss of political consensus. The first involves an improvement or replacement of existing techniques such that they may better represent the diversity of needs and objectives. Alternatively, those transport authorities with executive power may seek to limit objections to planning procedures. There is:

> 'an extreme tendency to rigidity in the solution of any large or practical problem...... and any challenge to the conception of the problem is likely to meet with intense resistance'[4]

7.2.12. Although the structure of the public inquiry has altered little during the period examined, the second of these responses has been invoked, particularly in relation to transport in London. The ultimate result of GLC opposition to roadbuilding was to limit its power, firstly by removing executive control of London Transport and secondly by complete abolition of the authority.

7.2.13. The first response, the improvement of techniques, may be considered more positive. Research reviewed in earlier chapters has highlighted potential improvements in techniques which would better represent changes in demand and a variety of objectives in appraisal.

7.2.14. In forecasting and modelling, the aggregated projection of key variables based on the cross-sectional calibration and validation of traffic models was considered inappropriate. Such static techniques do not seek to explain behaviour only to describe it. Therefore they are unlikely to reflect changes in policy or values:

> 'The assumption that relationships can be extrapolated into different circumstances, such as new modes or changing social conditions is a very substantial one. In essence it is being presumed that spatial and circumstantial variation in behaviour can be used to predict temporal changes.'[5]

7.2.15. Time-series or longitudinal modelling was considered more likely to reflect such temporal changes. The Department of Transport in response to the recommendations of the Leitch Committee instituted a range of traffic forecasts based on low and high economic growth. However, they are still insensitive to a wide range of other factors including policy.

7.2.16. The development of behavioural and dynamic models of travel demand was considered more likely to be policy sensitive. However, although it is considered by modellers that they will substantially improve forecasting, particularly in disaggregate form, they are yet to achieve the practicality necessary for widespread use.

7.2.17. The modelling undertaken in chapter 5 attempted to embody a dynamic approach. Although the model may be considered aggregate in form, it mapped changes in transport systems caused by investment policies in a temporal manner. It is in relation to disaggregation that such a model would require development in order to achieve practical use.

7.2.18. What would be the result of improved forecasting procedures? Claims for accurate forecasting have in the past resulted in inflexible projects and policies:

> 'in its extreme form, this approach would represent a full circle, a return to the most simplistic elements of the first generation of travel demand models, where the future seemed pre-determined and the role of the planner is simply to discover and provide for that future.'[6]

An alternative is to 'widen the dimensions of choice'[7] which reinforces the need for broad-based assessment related to policy.

7.2.19. Aggregation of values is the key issue in evaluation procedures. Although cost-benefit analysis is now restricted to the economic evaluation of transport projects, it is still the most important factor in appraisal. Rather than setting the framework for evaluation, current policies are a factor considered along with any other. It is apparent that different solutions to transport problems reflect different policies and a more explicit role for policy is required in the evaluation process.

7.2.20. It is difficult for policies to accurately reflect all factors affecting travel behaviour in a comprehensive manner. A more explicit recognition of the partial nature of policy would make clear the role of any transport project. Matrix based evaluation methods can reflect a variety of objectives and show clearly which policies are most encouraged by individual projects. An example of such an approach is given in Table 7.1.

It is better suited to strategic-evaluation than differentiation between scheme alternatives.

7.2.21. Flexibility is a difficult factor to measure as it is dependent on many characteristics of transport projects.

Potential inflexibility of alternative policies or projects could be indicated by using achievement of objectives as a proxy. An objective to minimise capital costs would highlight those projects with minimal commitments to infrastructure. A benefit cost ratio would provide similar information, although large scale projects would be acceptable if they showed high levels of benefits. This particular measure of value for money would be an improvement to existing procedures based on net present value even if the matrix approach was not adopted.

7.2.22. Lead time could be incorporated into the matrix in a similar fashion. The advantage of the matrix based approach is that it allows inclusion of those factors important to each individual project. The difficult issue for this method relates to the aggregation of all the elements of the matrix. In its basic form it resembles the Leitch framework used in trunk road assessment[8] except that policy provides the framework for appraisal rather than another factor to be assessed alongside economics and environmental impact. However if some aspects of policy were considered to be more important than others the achievement of objectives would be weighted according to their perceived significance and a points scoring method used to achieve an overall ranking of projects.

Transport Policy and Decision-making

7.2.23. It is apparent that transport policies are no longer a rational response to technical processes. They are more explicitly partisan and orientated to achievement of objectives. However, this is not inconsistent with the transport planning process outlined above. Strong and coherent policies are desirable both for transport modelling and evaluation.

7.2.24. The development of policy sensitive transport models will only be of use where policies and objectives are clearly stated. One of the problems of the comprehensive transport planning process was that its very comprehensiveness encouraged generalised policy statements such as 'improvement of mobility'. This is very difficult to test in transport modelling, as it is dependent on so many factors. However, more explicit objectives such as levels of public transport subsidy or the distribution of airport capacity could be input to a policy sensitive model and their effects monitored.

7.2.25. The effects of such a policy are then more easily accommodated in an evaluation matrix such as that shown in Table 7.1. Hence:

> '....a 'policy sensitive' activity model would be one which incorporated the effects of those changes in transport systems which could be influenced by policy. The problem of whether the forecasts are then correct or not is a separate matter'[9]

So accurate forecasting is less important when transport planning is policy-led. Thus an accurate, objective forecast of the future is not required to formulate policy. Policies are prescriptive, based on societal preferences and modelling is used to support and advise on the best means of achieving them.

7.2.26. Hence strategic policies such as those for public transport pursued by the GLC are not inadmissable. They were successful in achieving their aims of increased patronage and reduced traffic congestion. However, they also achieved success because they avoided the constraints of infrastructure described in earlier chapters. They required little capital investment and their lead time, mostly related to organisation of ticketting, was very short. Furthermore, given the changes in the level of subsidy in London that occurred in the 1980s following a series of legal decisions, they must be considered flexible and responsive to changing constraints.

7.2.27. Difficulties in policy formulation arise when the success of policy depends on capital investment with long lead times and requires comprehensive planning. A comprehensive approach is likely to be rigid and unresponsive to changing needs and values, but strategic co-ordination need not be so inflexible. Public transport subsidies, roadbuilding and investments in airports will probably have effects on housing, industrial location and the environment and these effects will always be important to the comprehensive approach. However, although strategic co-ordination will always be required in planning activity which seeks to improve environments and therefore requires some assessment of impacts, the effects of transport schemes on other sectors will not be so important to their immediate success.[10]

7.2.28 In relation to the statutory processes of transport planning, the comprehensiveness of policies will also lead to delayed approval. The public inquiries undertaken in relation to the case studies analysed highlighted this protractedness. Both the GLDP inquiry and those for the third London airport suffered because of the comprehensiveness of the issues involved. In both cases, alternative inquiries for smaller projects proceeded much more quickly. In the case of airport development local inquiries allowed development at individual sites (Heathrow and Gatwick), becuse there was no reliance on a comprehensive policy for the national airports system. Similarly, road schemes have been completed in London since the GLDP inquiry again because their benefits were not perceived to be dependent on the completion of a comprehensive plan. However, in both cases the projects were consistent with strategic policies.

Assimilation of Change

7.2.29. Overall, the changes to transport project appraisal outlined above would require a significant re-orientation of current policies and techniques. However, change occurs gradually, partly because of the experimental nature of new techniques, but also because of the vested interest of some transport authorities in maintaining existing practice. Despite this gradual change and because of the problems that strategic planning has faced, some improvements have been realised.

7.2.30. Expansion of existing London airports proved to have a greater efficacy in increasing airport capacity than the search for a third site. However, the ultimate choice of Stansted as a Third London airport reflects a desire to minimise capital investment, capital costs and lead times. The evaluation of this project was significant in its rejection of cost-benefit analysis and its concentration on simple indicators of the extent of capital investment. Such indicators would be compatible with matrix based assessment.

7.2.31. In London, large-scale road building programmes have been rejected. Those who still propose roadbuilding solutions to traffic congestion now do so with less extravagant plans. The role of public transport investment has been shown to be important because it can be effective with minimal capital investment and short lead times. In addition greater attention is being given to other methods of traffic restraint such as road pricing which also require less commitment to infrastructure.

7.2.32. The issue of transport in London also highlighted the great importance of policy in project appraisal. Major roadbuilding was shown to be no less a policy initiative than public transport improvement. Assessment relative to policy objectives has now become more important although it has yet to be formalised in any agreed methodology. Net present value still remains the major criteria in highway appraisal.

7.2.33. Forecasting and traffic modelling procedures have been amended little. There is still a practical requirement for definitive forecasts for design purposes. However this could be accommodated beyond the assessment of strategic issues. At the strategic level it is important that the assumptions of different policies are clearly tested and policy-sensitive forecasts will be required if this is to occur. Although dynamic analyses of travel demand require further development to be of practical use, more limited improvements are possible in the short term.

7.2.34. The Leitch committee recommendation in favour of forecasts dependent on different policies has not been explored beyond assumptions regarding economic growth. It is important that such forecasting be used to predict the effects of demand of alternative strategic investments. However, traffic forecasts used by the Department of Transport are still considered matters of policy and not open to criticism. The lack of progress on this issue indicates perhaps the sensitivity of project appraisal to traffic forecasts.

7.3 SUMMARY OF FINDINGS

Scale

7.3.1 In seeking to plan and implement transport projects to meet forecast demand, the scale of developments is critical particularly in environments of great uncertainty. For transport modes where the provision of capacity has little or no generation effect on demand, a simple demand satisfaction approach will tend to increase overcapacity within the system as scale increases. (e.g. airports). Where traffic generation is present (e.g. due to road construction in urban areas), the difficulty of forecasting the level of suppressed demand increases with the size of the project creating subsequent problems for evaluation.

Lead time

7.3.2 In conventional analyses of appraisal under uncertainty it is assumed that lead time is the most important factor in the forecasting of transport system development, i.e. the more distant the planning horizon, the more difficult the forecast. This study has shown that scale is more important in this respect i.e. the greater the scale of the project the more difficult it is to match capacity with demand. However, lead time is still critical because:

1. Increasing scale is often accompanied by increasing lead time.

2. Long lead times do make forecasting more problematic although not to the extent of scale itself.

Techniques

7.3.3 Current modelling and forecasting techniques do not formally acknowledge the increased difficulty of transport planning caused by increasing scale and lead time. This is partly due to the emphasis on the cross-sectional aspects of traffic analysis and model validation. More emphasis on the temporal dimension is required at the strategic level if the time dependent effects of large scale projects such as traffic generation are to be better understood.

7.3.4 The inadequate treatment of scale and lead time in transport modelling is both reflected by, and a product of, an equal inadequacy in appraisal methods. The risk associated with large scale projects is not directly considered in economic or environmental evaluation but only through conventional measures of economic or environmental performance. It is difficult to incorporate indicators of large scale capital intensity into utilitarian appraisal methods. This may only be done when the risk of such undertakings is appreciated and its reduction perceived as a goal.

7.3.5 Matrix-based assessment methods offer the best opportunity for the incorporation of such factors in the evaluation process. Only when their importance is formally acknowledged will their impact be minimised.

It is also apparent that at the strategic level, there is no single correct solution to any planning problem. This was confirmed by analysis of case studies, where in the case of London's roads and its third airport the politics of location were a major factor, reinforcing the need for policy sensitive evaluation.

CHAPTER 7

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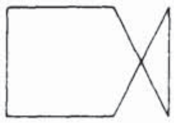
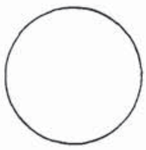
10. See McConnell (1981), ch.4

APPENDICES

APPENDIX A

DYNAMO NOTATION

	Level
	Rate
	Auxiliary
	Information
	Materials
R	Rate
L	Level
A	Auxiliary
N	Initial Value
T	Table
S	Supplementary

APPENDIX B

DEMAND PROFILE EQUATIONS

B.1 The demand profiles illustrated in Fig. 4.7 are derived from the equations defined below.

Profile 1

B.2 Profile 1 is a simple linear curve where demand increases by 200% over the length of the run.

$$D_K = ID(1 + 2tk/T)$$

where D_K = current demand

ID = initial demand

tk = current time period

T = length of run

Profile 2

B.3 Demand profile 2 is based on exponential growth which again increases by 200% over the length of the run:

$$D_K = ID(1 + 2tk^2/T^2).$$

Profile 3

B.4 Profile 3 is defined by the logistic curve:

$$D_K = \frac{ax}{x + (a-x)e^{-2vt(z-x)^1}}$$

where: x = initial demand

D_K = demand at time K

a,r = constants'

This becomes:

$$D_K = 3\ ID/(1 + 2e^{-0.2tk})^1$$

The saturation level is defined by three times the initial demand. When tk = 0, D_K = ID. As tk approches infinity, D_K approaches 3ID.

Profile 4

B.5 The equations for profile 4 are similar to those for profile 3. Demand increaes logistically to a saturation level of 2ID halfway through the run:

$$D_K = 2ID/(1 + e^{0-2tk})$$

For the second half of the run the level of demand decreases and is given by the equation.

$$D_K = \frac{1 + 0.33e^{-0.2t_K - 20}}{0.66ID}$$

REFERENCE

1. Tanner (1965), p.346

APPENDIX C

FORRESTER'S FORECASTING METHOD

C.1 Forrester's forecasting method is based on an extrapolation of smoothed demand. In DYNAMO terminology, smoothed demand is an expression of delayed demand, i.e. it relates to a previous point on the demand curve. A second smoothing of demand will identify a previous point on the smoothed demand curve. Together with the current value of smoothed demand, the slope of the curve is defined and allows an extrapolation or forecast. Figure C.1 illustrates the smoothing processes.

C.2 The smoothing equations are:

$$S.K = S.J + \frac{DT}{SDD}(D.JK - S.J)$$

$$DS.K = DS.J + \frac{DT}{DSDD}(S.J - DS.J)$$

where S = smoothed demand

D = actual demand

DS = doubly smoothed demand

DT = solution interval

SDD = smoothed demand delay

DSDD = doubly smoothed demand delay

J,K = previous and current time periods

C.3 The forecast equation is then given by

$$F.K = S.K + \frac{T}{DSDD}(S.K - DS.K)$$

where F = forecast demand

T = lead time

Thus Forresters method is based only on demand without an explicit growth rate.

REFERENCE

1. Forrester (1961), p.439

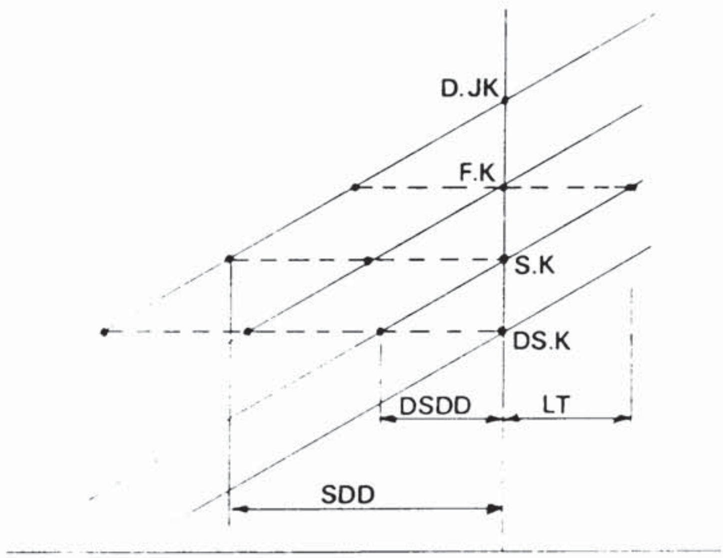


FIGURE C.1 Forrester's Forecasting Method

APPENDIX D

HOLT'S METHOD OF EXPONENTIALLY WEIGHTED REGRESSION

D.1 Exponentially Weighted Regression is amethod for extrapolating trends in time series data using local linear growth. Holt's method' is based on two variables; demand and the growth in demand. Both variables are corrected eah time period by a proportion of the error in the forecast derived for the previous time period.

D.2 The forecast error is given by:

$$E_K = D_K - DFj$$

where E_K = current forecast error

D_K = current demand

DFjd = Demand forecast at time j

Using this forecast error, smoothed demand and growth rate may be derived:

$$S_K = Sj + Gj + A(E_K)$$

$$G_K = Gj + B(E_K)$$

where S = smoothed demand

G = Growth Rate

A,B = constants

A and B may be varied depending on the weight given to past data. In the TRAIN model $A = 0.3$ and $B = 0.0268$.

D.3 The growth rate now allows a forecast of the demand variable:

$$D_{KT} = S_K + T(G_K)$$

where D_{KT} = forecast for T time periods ahead

S_K = current smoothed demand

G_K = growth rate

T = lead time

REFERENCE

1. Holt (1957). For a comparison of time-series forecasting methods see Godolphin and Harrison (1975).

APPENDIX E

MODEL OUTPUT

```
*       TRANSPORT INFRASTRUCTURE PLANNING MODEL
NOTE                       (TRAIN)
NOTE
NOTE
NOTE
NOTE    TIME COUNTER
NOTE
L       T.K=T.J+DT
N       T=0
NOTE
NOTE
NOTE
NOTE    TIME INCREMENT COUNTER
NOTE
L       TI.K=CLIP(0,TI.J+DT,TI.J+DT,1-DT)
N       TI=0
NOTE
NOTE
NOTE
NOTE    SMOOTHED DEMAND
NOTE
L       SDEM.K=SDEM.J+(DT)(DEM.JK-SDEM.J)/(SDD)
N       SDEM=IDEM
L       DSDEM.K=DSDEM.J+(DT)(SDEM.J-DSDEM.J)/(DSDD)
N       DSDEM=IDEM
NOTE
NOTE
NOTE
NOTE    FORECASTING
NOTE
A       FDEM.K=SDEM.K+(LT)(SDEM.K-DSDEM.K)/(DSDD)
N       FDEM=IFDEM
NOTE
NOTE
NOTE
NOTE
NOTE
R       DEM.KL=BDEM.K
A       BDEM.K=TABHL(DTAB,T.K,0,L,1)
T       DTAB=24.375/24.438/24.5/24.563/24.625/24.688/24.75/
X       24.823/24.875/24.938/25.000/25.031/25.125/25.281/
X       25.5/25.781/26.125/26.531/27.0/27.531/28.125/28.781/
X       29.5/30.281/31.125/32.03/33.0/34.031/35.125/36.281/37.5/
X       38.781/40.125/41.53/43.0/44.531/46.125/47.781/49.5/51.281/
X       53.125/55.031/57.0/59.031/61.125/63.281/65.50/67.781/70.125/
X       72.531/75.0
NOTE
NOTE
```

```
NOTE    ORDERING CAPACITY
NOTE
A       CADED.K=FDEM.K-SC.K-TWIP.K
A       RECAP.K=CADED.K-OTH

A       CAPR.K=SWITCH(RECAP.K/CAPU,0,TI.K)
NOTE
A       CAP0.K=CLIP(0,CAP1.K,0,CAPR.K)
A       CAP1.K=CLIP(1,CAP2.K,1,CAPR.K)
A       CAP2.K=CLIP(2,CAP3.K,2,CAPR.K)
A       CAP3.K=CLIP(3,CAP4.K,3,CAPR.K)
A       CAP4.K=CLIP(4,CAP5.K,4,CAPR.K)
A       CAP5.K=CLIP(5,CAP6.K,5,CAPR.K)
A       CAP6.K=CLIP(6,CAP7.K,6,CAPR.K)
A       CAP7.K=CLIP(7,CAP8.K,7,CAPR.K)
A       CAP8.K=CLIP(8,CAP9.K,8,CAPR.K)
A       CAP9.K=CLIP(9,CAP10,9,CAPR.K)
NOTE
R       CAP0.KL=CAP0.K
NOTE
NOTE
NOTE    WORK IN PROGRESS
NOTE
L       WIP10.K=SWITCH(CAP0.JK,WIP10.J,TI.J-DT)
N       WIP10=IWP10
A       AWP10.K=WIP10.K
L       WIP9.K=SWITCH(AWP10.J,WIP9.J,TI.J-DT)
N       WIP9=IWP9
A       AWP9.K=WIP9.K
L       WIP8.K=SWITCH(AWP9.J,WIP8.J,TI.J-DT)
N       WIP8=IWP8
A       AWP8.K=WIP8.K
L       WIP7.K=SWITCH(AWP8.J,WIP7.J,TI.J-DT)
N       WIP7=IWP7
A       AWP7.K=WIP7.K
L       WIP6.K=SWITCH(AWP7.J,WIP6.J,TI.J-DT)
N       WIP6=IWP6
A       AWP6.K=WIP6.K
L       WIP5.K=SWITCH(AWP6.J,WIP5.J,TI.J-DT)
N       WIP5=IWP5
A       AWP5.K=WIP5.K
L       WIP4.K=SWITCH(AWP5.J,WIP4.J,TI.J-DT)
N       WIP4=IWP4
A       AWP4.K=WIP4.K
L       WIP3.K=SWITCH(AWP4.J,WIP3.J,TI.J-DT)
N       WIP3=IWP3
A       AWP3.K=WIP3.K
L       WIP2.K=SWITCH(AWP3.J,WIP2.J,TI.J-DT)
N       WIP2=IWP2
A       AWP2.K=WIP2.K
L       WIP1.K=SWITCH(AWP2.J,WIP1.J,TI.J-DT)
N       WIP1=IWP1
A       AWP1.K=WIP1.K
NOTE
```

```
A       CC0. K=CLIP(AWP10. K, CC1. K, 1, LT)
A       CC1. K=CLIP(AWP9. K, CC2. K, 2, LT)
A       CC2. K=CLIP(AWP8. K, CC3. K, 3, LT)
A       CC3. K=CLIP(AWP7. K, CC4. K, 4, LT)
A       CC4. K=CLIP(AWP6. K, CC5. K, 5, LT)
A       CC5. K=CLIP(AWP5. K, CC6. K, 6, LT)
A       CC6. K=CLIP(AWP4. K, CC7. K, 7, LT)
A       CC7. K=CLIP(AWP3. K, CC8. K, 8, LT)
A       CC8. K=CLIP(AWP2. K, CC9. K, 9, LT)
A       CC9. K=CLIP(AWP1. K, AWP1. K, 10, LT)
NOTE
R       CADS. KL=CLIP(CC0. K, 0, TI. K+0. 5*DT, 1-DT)
N       CADS=0
L       TWIP. K=TWIP. J+(CAPO. JK-CADS. JK)(CAPU)
N       TWIP=0
NOTE    SYSTEM CAPACITY
NOTE
L       SC. K=SC. J+(CADS. JK)(CAPU)
N       SC=ISC
NOTE    FORECAST STORE
NOTE
L       DF10. K=SWITCH(FDEM. J, DF10. J, TI. J)
N       DF10=0
A       ADF10. K=DF10. K
N       ADF10=0
L       DF9. K=SWITCH(ADF10. J, DF9. J, TI. J)
N       DF9=0
A       ADF9. K=DF9. K
N       ADF9=0
L       DF8. K=SWITCH(ADF9. J, DF8. J, TI. J)
N       DF8=0
A       ADF8. K=DF8. K
N       ADF8=0
L       DF7. K=SWITCH(ADF8. J, DF7. J, TI. J)
N       DF7=0
A       ADF7. K=DF7. K
N       ADF7=0
L       DF6. K=SWITCH(ADF7. J, DF6. J, TI. J)
N       DF6=0
A       ADF6. K=DF6. K
N       ADF6=0
L       DF5. K=SWITCH(ADF6. J, DF5. J, TI. J)
N       DF5=0
A       ADF5. K=DF5. K
N       ADF5=0
L       DF4. K=SWITCH(ADF5. J, DF4. J, TI. J)
N       DF4=0
A       ADF4. K=DF4. K
N       ADF4=0
L       DF3. K=SWITCH(ADF4. J, DF3. J, TI. J)
N       DF3=0
A       ADF3. K=DF3. K
N       ADF3=0
L       DF2. K=SWITCH(ADF3. J, DF2. J, TI. J)
N       DF2=0
A       ADF2. K=DF2. K
N       ADF2=0
L       DF1. K=SWITCH(ADF2. J, DF1. J, TI. J)
N       DF1=0
A       ADF1. K=DF1. K
N       ADF1=0
```

```
A        PPDEM.K=CLIP(PF1.K,ADF10.K,LT,2)
A        PF1.K=CLIP(PF2.K,ADF9.K,LT,3)
A        PF2.K=CLIP(PF3.K,ADF8.K,LT,4)
A        PF3.K=CLIP(PF4.K,ADF7.K,LT,5)
A        PF4.K=CLIP(PF5.K,ADF6.K,LT,6)
A        PF5.K=CLIP(PF6.K,ADF5.K,LT,7)
A        PF6.K=CLIP(PF7.K,ADF4.K,LT,8)
A        PF7.K=CLIP(PF8.K,ADF3.K,LT,9)
A        PF8.K=CLIP(PF9.K,ADF2.K,LT,10)
A        PF9.K=CLIP(ADF1.K,ADF1.K,LT,11)

NOTE
NOTE
NOTE     FORECASTING - INITIAL CONDITIONS
NOTE
A        PFDEM.K=CLIP(INFOR.K,PPDEM.K,LT,T.K)
L        INFOR.K=TABHL(FTAB,T.J,0,10,1)
N        INFOR=24.375
T        FTAB=24.375/24.438/24.5/24.563/24.625/24.688/
X        24.75/24.823/24.875 /24.938/25
NOTE
NOTE
NOTE
NOTE
NOTE
NOTE
NOTE     CONSTANTS
NOTE
C        L=50
C        SDD=1.0
C        DSDD=1.0
C        LT=5
C        CAPU=10
C        CAP10=10
C        IDEM=24.375
C        IFDEM=24.375
C        OTH=0
C        ISC=25.0
C        IWP10=0
C        IWP9=0
C        IWP8=0
C        IWP7=0
C        IWP6=0
C        IWP5=0
C        IWP4=0
C        IWP3=0
C        IWP2=0
C        IWP1=0
NOTE
```

```
NOTE
NOTE    SUPPLEMENTARY EQUATIONS
NOTE
S       LTFE.K=DEM.JK-PFDEM.K
S       DCD.K=DEM.JK-SC.K
NOTE
NOTE
NOTE
NOTE
PRINT   DEM,SDEM,DSDEM,FDEM,PFDEM,DCD,LTFE,CADED,RECAP,CAPR,CAPO
PLOT    DEM=D,SDEM=S,PFDEM=P,SC=T
SPEC    DT=0.5/LENGTH=50/PRTPER=1/PLTPER=1
OPT     DISK
RUN     RUNSP1
EOF..
```

TIME E 00	DEM E 00	SDEM E 00	DSDEM E 00	FDEM E 00	PFDEM . E 00	DCD E 00	LTFE E 00
0.000	24.375	24.375	24.375	24.375	24.375	- 0.625	0.0000
1.000	24.438	24.391	24.383	24.430	24.438	- 0.562	0.0000
2.000	24.500	24.442	24.420	24.549	24.500	- 0.500	0.0000
3.000	24.563	24.501	24.473	24.640	24.563	- 0.437	0.0000
4.000	24.625	24.563	24.533	24.714	24.625	- 0.375	0.0000
5.000	24.688	24.625	24.594	24.780	24.688	- 0.312	0.0000
6.000	24.750	24.688	24.657	24.844	24.493	- 0.250	0.2569
7.000	24.823	24.753	24.720	24.915	24.598	- 0.177	0.2254
8.000	24.875	24.818	24.786	24.979	24.679	- 0.125	0.1960
9.000	24.938	24.877	24.847	25.027	24.747	- 0.062	0.1911
10.000	25.000	24.938	24.908	25.091	24.812	- 0.000	0.1877
11.000	25.031	24.992	24.965	25.127	24.875	0.031	0.1565
12.000	25.125	25.045	25.017	25.186	24.957	0.125	0.1681
13.000	25.281	25.144	25.097	25.377	24.998	0.281	0.2831
14.000	25.500	25.301	25.228	25.668	25.059	0.500	0.4408
15.000	25.781	25.521	25.418	26.036	25.123	0.781	0.6581
16.000	26.125	25.802	25.668	26.471	25.128	1.125	0.9975
17.000	26.531	26.146	25.981	26.971	25.256	1.531	1.2754
18.000	27.000	26.552	26.356	27.533	25.500	2.000	1.4997
19.000	27.531	27.021	26.793	28.158	25.832	2.531	1.6989
20.000	28.125	27.552	27.293	28.845	26.234	3.125	1.8910
21.000	28.781	28.146	27.856	29.595	26.702	3.781	2.0790
22.000	29.500	28.802	28.481	30.408	27.232	4.500	2.2676
23.000	30.281	29.521	29.168	31.283	27.827	5.281	2.4545
24.000	31.125	30.302	29.918	32.220	28.482	6.125	2.6427
25.000	32.030	31.145	30.731	33.220	29.201	7.030	2.8285
26.000	33.000	32.051	31.605	34.282	29.982	8.000	3.0177
27.000	34.031	33.021	32.543	35.408	30.826	- 0.969	3.2045
28.000	35.125	34.052	33.543	36.596	31.732	0.125	3.3927
29.000	36.281	35.146	34.606	37.846	32.701	1.281	3.5795
30.000	37.500	36.302	35.731	39.158	33.730	2.500	3.7696
31.000	38.781	37.521	36.918	40.533	34.827	3.781	3.9543
32.000	40.125	38.802	38.168	41.970	35.983	5.125	4.1423
33.000	41.530	40.145	39.481	43.470	37.202	6.530	4.3283
34.000	43.000	41.551	40.855	45.032	38.482	8.000	4.5176
35.000	44.531	43.021	42.293	46.658	39.827	9.531	4.7045
36.000	46.125	44.552	43.793	48.346	41.232	1.125	4.8927
37.000	47.781	46.146	45.356	50.096	42.701	2.781	5.0795
38.000	49.500	47.802	46.981	51.908	44.230	4.500	5.2696
39.000	51.281	49.521	48.668	53.783	45.827	6.281	5.4543
40.000	53.125	51.302	50.418	55.720	47.483	8.125	5.6423
41.000	55.031	53.146	52.231	57.720	49.202	10.031	5.8293
42.000	57.000	55.052	54.106	59.783	50.982	2.000	6.0176
43.000	59.031	57.021	56.043	61.908	52.827	4.031	6.2045
44.000	61.125	59.052	58.043	64.095	54.732	6.125	6.3927
45.000	63.281	61.146	60.106	66.345	56.701	8.281	6.5795
46.000	65.500	63.302	62.231	68.658	58.732	10.500	6.7677
47.000	67.781	65.521	64.418	71.033	60.826	12.781	6.9545
48.000	70.125	67.802	66.668	73.470	62.982	5.125	7.1427
49.000	72.531	70.146	68.981	75.970	65.201	7.531	7.3295
50.000	75.000	72.552	71.356	78.533	67.482	10.000	7.5177

TIME E 00	CADED E 00	RECAP E 00	CAPR E 00	CAPO E 00	TWIP E 00	CADS E 00	SC E 00
0.000	-0.6250	-5.6250	-.56250	0.0000	0.000	0.0000	25.000
1.000	-0.5699	-5.5699	-.55699	0.0000	0.000	0.0000	25.000
2.000	-0.4507	-5.4507	-.54507	0.0000	0.000	0.0000	25.000
3.000	-0.3596	-5.3596	-.53596	0.0000	0.000	0.0000	25.000
4.000	-0.2861	-5.2861	-.52861	0.0000	0.000	0.0000	25.000
5.000	-0.2202	-5.2202	-.52202	0.0000	0.000	0.0000	25.000
6.000	-0.1564	-5.1564	-.51564	0.0000	0.000	0.0000	25.000
7.000	-0.0850	-5.0850	-.50850	0.0000	0.000	0.0000	25.000
8.000	-0.0206	-5.0206	-.50206	0.0000	0.000	0.0000	25.000
9.000	0.0269	-4.9731	-.49731	0.0000	0.000	0.0000	25.000
10.000	0.0912	-4.9088	-.49088	0.0000	0.000	0.0000	25.000
11.000	0.1272	-4.8728	-.48728	0.0000	0.000	0.0000	25.000
12.000	0.1857	-4.8143	-.48143	0.0000	0.000	0.0000	25.000
13.000	0.3769	-4.6231	-.46231	0.0000	0.000	0.0000	25.000
14.000	0.6679	-4.3321	-.43321	0.0000	0.000	0.0000	25.000
15.000	1.0360	-3.9640	-.39640	0.0000	0.000	0.0000	25.000
16.000	1.4712	-3.5288	-.35288	0.0000	0.000	0.0000	25.000
17.000	1.9707	-3.0293	-.30293	0.0000	0.000	0.0000	25.000
18.000	2.5329	-2.4671	-.24671	0.0000	0.000	0.0000	25.000
19.000	3.1579	-1.8421	-.18421	0.0000	0.000	0.0000	25.000
20.000	3.8453	-1.1547	-.11547	0.0000	0.000	0.0000	25.000
21.000	4.5954	-0.4046	-.04046	0.0000	0.000	0.0000	25.000
22.000	5.4078	0.4078	.04078	1.0000	0.000	0.0000	25.000
23.000	-3.7171	-8.7171	-.87171	0.0000	10.000	0.0000	25.000
24.000	-2.7797	-7.7797	-.77797	0.0000	10.000	0.0000	25.000
25.000	-1.7805	-6.7805	-.67805	0.0000	10.000	0.0000	25.000
26.000	-0.7182	-5.7182	-.57182	0.0000	10.000	0.0000	25.000
27.000	0.4084	-4.5916	-.45916	0.0000	0.000	0.0000	35.000
28.000	1.5956	-3.4044	-.34044	0.0000	0.000	0.0000	35.000
29.000	2.8455	-2.1545	-.21545	0.0000	0.000	0.0000	35.000
30.000	4.1579	-0.8421	-.08421	0.0000	0.000	0.0000	35.000
31.000	5.5329	0.5329	.05329	1.0000	0.000	0.0000	35.000
32.000	-3.0297	-8.0297	-.80297	0.0000	10.000	0.0000	35.000
33.000	-1.5305	-6.5305	-.65305	0.0000	10.000	0.0000	35.000
34.000	0.0318	-4.9682	-.49682	0.0000	10.000	0.0000	35.000
35.000	1.6584	-3.3416	-.33416	0.0000	10.000	0.0000	35.000
36.000	3.3456	-1.6544	-.16544	0.0000	0.000	0.0000	45.000
37.000	5.0955	0.0955	.00955	1.0000	0.000	0.0000	45.000
38.000	-3.0921	-8.0921	-.80921	0.0000	10.000	0.0000	45.000
39.000	-1.2171	-6.2171	-.62171	0.0000	10.000	0.0000	45.000
40.000	0.7203	-4.2797	-.42797	0.0000	10.000	0.0000	45.000
41.000	2.7204	-2.2796	-.22796	0.0000	10.000	0.0000	45.000
42.000	4.7828	-0.2172	-.02172	0.0000	0.000	0.0000	55.000
43.000	6.9079	1.9079	.19079	1.0000	0.000	0.0000	55.000
44.000	-0.9047	-5.9047	-.59047	0.0000	10.000	0.0000	55.000
45.000	1.3454	-3.6546	-.36546	0.0000	10.000	0.0000	55.000
46.000	3 6578	-1.3422	-.13422	0.0000	10.000	0.0000	55.000
47.000	6.0329	1.0329	.10329	1.0000	10.000	0.0000	55.000
48.000	-1.5297	-6.5297	-.65297	0.0000	10.000	0.0000	65.000
49.000	0.9704	-4.0296	-.40296	0.0000	10.000	0.0000	65.000
50.000	3.5328	-1.4672	-.14672	0.0000	10.000	0.0000	65.000

1

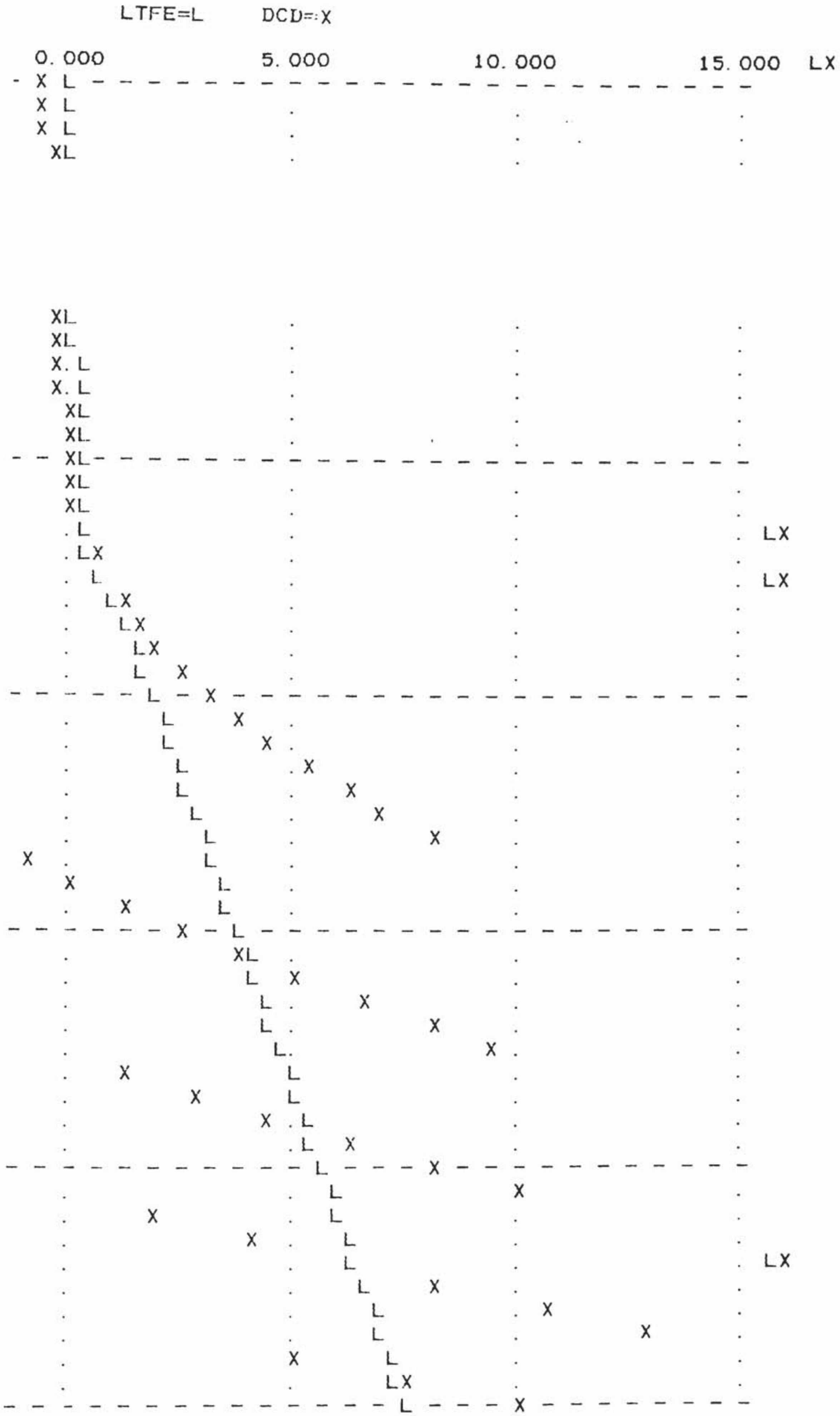
P-171 RUN-RUN34 SIMULATION OF TRANSPORT INFRASTRUCTURE PLANNING

```
         DEM=D    SDEM=S  PFDEM=P      SC=T

      20.000             40.000              60.000              80.000  DSPT
- - - - - -DT - - - - - - - - - - - - - - - - - - - - - - - - - - - - DSP
        .    D          .               .                 .  DSPT
        .    D          .               .                 .  DSPT
        .    D          .               .                 .  DSPT



        .    D          .               .                 .  DSPT
        .    D          .               .                 .  DSPT
        .    D          .               .                 .  DSPT
        .    D          .               .                 .  DSPT
        .    D          .               .                 .  DSPT
        .    D          .               .                 .  DSPT
- - - - - -  D - - - - - - - - - - - - - - - - - - - - - - - DSPT
        .    D          .               .                 .  DSPT
        .    D          .               .                 .  DSPT
        .    D          .               .                 .  DSPT
        .    D          .               .                 .  DSPT
        .    SD         .               .                 .  SPT
        .    PD         .               .                 .  PT,DS
        .    PD         .               .                 .  PT,DS
        .    PSD        .               .                 .  PT
        .    TPD        .               .                 .  DS
- - - - - -  TPD - - - - - - - - - - - - - - - - - - - - - - DS
        .    TP D       .               .                 .  DS
        .    T PSD      .               .                 .
        .    T P D      .               .                 .  DS
        .    T  PSD     .               .                 .
        .    T  P SD    .               .                 .
        .    T   P D    .               .                 .  DS
        .         PSDT  .               .                 .
        .         P SD  .               .                 .  DT
        .          P SD .               .                 .  ST
- - - - - - - - - -PTSD - - - - - - - - - - - - - - - - - -
        .            P SD.              .                 .  PT
        .            TP SD              .                 .
        .            T P SD             .                 .
        .            T  P.SD            .                 .
        .            T   P S D          .                 .
        .               .P   SD         .                 .  ST
        .               . P TSD         .                 .
        .               .  PT S D       .                 .
        .               .   TP  SD      .                 .
- - - - - - - - - - - - - - T P -SD - - - - - - - - - - - -
        .               .   T  P   SD   .                 .
        .               .        P  S D .                 .  ST
        .               .         P T SD.                 .
        .               .           P  S.D                .  PT
        .               .           TP  .S D              .
        .               .           T  P.  SD             .
        .               .           T   .P  S D           .
        .               .               . P T S D         .
        .               .               .   P    S D      .  PT
- - - - - - - - - - - - - - - - - - - - - - T P - S D - -
```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