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LAND USE-TRANSPORTATION SYSTEMS AND ENERGY CONSERVATION.

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ABSTRACT

Land-use policies are seen as one long-term means of conserving energy. An overview of recent trends in the United Kingdom's energy consumption (particularly the transportation sector's dependence on petroleum) forms the foundation for a discussion of present and future trends in urban form. As land use-transportation models, such as the Lowry-type spatial allocation model, are widely applied by planners, a review of a number of models specifically concerned with energy is undertaken. Detailed numerical experiments illustrate a number of the underlying relationships, and an extension is proposed which takes into account the existing infrastructure. Throughout the paper, broader social and political ramifications are considered.

1. INTRODUCTION.

The time when one gallon of petrol cost a pound in the United Kingdom finally came, after much speculation, in June 1979; at present, the average price is one pound and thirty pence per gallon. Figure one illustrates the changes in pump prices of petrol over time (which includes the specific effect of changes in tax rates, the Suez crisis, and so on). The general public seemingly appreciates that, the period of cheap, plentiful supplies of petroleum is over. In fact, there is extensive pessimism in some quarters about our energy future (see, for example, de Montbrial's (1979) recent report to the Club of Rome), although a number of low energy forecasts for the United Kingdom have also been recently propounded (see, for example, Chesshire and Surrey's (1978) out-line for U.K. at the turn of the century and the much-publicised, detailed report by the International Institute for Environment and Development (Leach *et.al.*, 1979)). The inherent uncertainties prevalent in forecasts of the future supply and demand for a resource means that it is extremely difficult, perhaps impossible, to give a date when physical shortages of petroleum will occur (Cook and Surrey, 1977). An international study, for instance, suggests that this period may be avoided until well into the next century, although it could well commence in the late nineteen eighties (Wilson, 1977).

The breathing space offered by the United Kingdom's offshore petroleum and gas resources must be used wisely in order to plan for the future. Whilst this will temporarily ameliorate the impact of further price increases and shortages, after the period of surplus, there will be an increasing reliance on expensive oil imports as indigenous supplies decline (presenting familiar difficulties with the country's balance of payments, specifically, and its economic activity, generally). In fact, oil is a topic of international perspective which is impossible to comprehend outside the geopolitical realities. The outcome of President Carter's ill-fated energy programme, for example, will have ramifications throughout the world, because the United States utilises a disproportionate amount of the world's total energy, and the political instability of the Middle East is of obvious concern. Thus, a cogent argument can be made for the development of a co-ordinated and comprehensive energy policy aimed at conservation.

Interesingly, it has been suggested that the 1973-4 'energy crisis' was actually a 'blessing in disguise', because it demonstrated the need for an assessment of the present situation and a formulation of future energy policies. On 16th October 1973, in Kuwait, the Persian Gulf oil-producing states decided to raise the posted price of crude oil by seventy percent, and, in Tehran, on 23rd December 1973, there was a further increase of one hundred and thirty percent; production reductions and discriminatory embargoes were also introduced. This sudden action was not caused by any physical shortages of oil, it was the result of economic and political motives of the oil-producing countries. Fundamentally, its immediate and wide-ranging impact illustrated the lack of detailed attention given to this topic and, unfortunately, after six years, insufficient effort has been made to prepare the social and economic system for a real resource limitation. It is, however, these events that generated the increasing literature on a variety of topics associated with energy.

It was only last year that a comprehensive energy policy was promulgated for the United Kingdom (H.M.S.O., 1978), but it remains primarily one of advocacy rather than action. Moreover, as large developments, which are now directly associated with the question of energy, are proposed, present financial and decision-making structures appear inadequate to accommodate these new issues. This aspect is briefly examined in conjunction with possible future alterations in land-use patterns, specifically with regard to the employment of controls to manipulate development.

1.1 Aims.

The purpose here is to discuss one aspect of the energy question: what constitutes an energy efficient urban form. Unlike many studies in the energy field, emphasis is placed upon potential social, economic and political repurcussions of land-use changes rather than many of the important technical features. No attention is given to the types and sizes of buildings, although some suggestions are made to show how the modelling framework can be extended.

At the outset, it is stressed that such issues must be attended to now in view of the long time-lags between the decision-making stage and implementation and impact. It is an extremely sensitive subject because today's planning decisions may provide fixed, long-term infrastructure which is incongruent to future needs. Any present-day, proposed land-use changes must include an examination, however tentative, of their relationships with energy consumption, because they will still have an impact on the next century. Numerous diagnoses and strategies have been proposed, many of which are analysed.

A broad definition of energy conservation is employed, because energy is only one facet of the urban environment. It should be given neither an elevated nor an isolated position of importance; in fact, great attention must be given to the wider implications of any action deemed energy efficient. Energy conservation (to reduce the rate of consumption) can, in general, result from decreased demand or technical improvements in the efficiency of utilisation. This study explores the opportunity for reducing demand for oil by altering the locational arrangement of activities in a city.

Discussion is divided into two parts. The foundation to the first part is given by an introductory overview to recent trends in the United Kingdom's energy consumption, specifically for petroleum in the transportation sector. The significant role of the motor car in the functioning of the space-economy is considered and in an examination of urban form there is an analysis of what constitutes an energy efficient urban form and the difficulties associated with its development.

This discussion forms the basis for the second part of the paper, which is concerned with urban modelling. In the review section, selected studies which have applied urban models, particularly the Lowry model, to investigate relationships between energy consumption and the land-use-transportation system are discussed.

Section six offers a detailed example for which urban models are used to consider this issue; to facilitate comparison, all the models are applied to the same urban system - Leeds. The numerical experiments include an application of the Lowry model, although attention focuses on the employment of the Coelho-Williams (1978) mathematical programming formulation which maximises locational surplus. Throughout the paper, emphasis is placed on the need to take into account existing infra-structure, and this is mirrored in the formulation of an incremental version of the Coelho-Williams model.

PART ONE

2. OIL CONSUMPTION AND PRICES.

One fairly quick impact of the 1973-1974 energy crisis was a reduction in the consumption of energy, particularly, as to be expected, in oil consumption (Figure 2 portrays that oil is now the United Kingdom's main source of primary energy). Whilst appreciating that there was room for conservation, especially as the previous development occurred at times when little attention was given to this aspect, it must be recognised that, since 1974, there has been a period of world-wide economic recession (Figure 3). Furthermore, oil supplies have also been in surplus owing to the persistence of lower levels of economic activity. Such a situation may produce a false sense of security on the ability to conserve energy in the future by its more rational and efficient consumption.

It is worthwhile re-emphasising that present trends illustrate a differential growth in oil consumption in ocntrast to other primary energy sources, and that the amount of oil consumed by the transport sector has increased disporportionately with respect to the other sectors. Interestingly, during the 1970's, the proportion of oil consumed by the tranpsport sector, specifically road transport, has steadily increased, and by 1978, road transport consumed approximately 30% of the United Kingdom's total oil consumption; this trend is expected to continue (see the I.I.E.D.'s (1979) forecast in their low energy strategy). These facts can be seen in conjunction with a 30% increase in the number of licenced motor cars in the period 1968-1978. (Figure 4 shows car ownership forecasts - it should be noted that this diagram does not represent the subtleties of the car market, particularly the likely shift to smaller, more fuel efficient cars). The almost wholly oil-specific nature of the transport sector is, therefore, a cause for anxiety, because in the future oil supplies will be dearer and more scarce. Moreover, as there appears to be no possibility for the transport sector to alter to another fuel base in the short-term, a cogent argument can be made for investigating options available to lower our level of consumption by reducing the demand for travel. The country's distribution system, and, therefore, the functioning of the economy, is dependent upon a continual oil supply.

No attempt is made to offer forecasts for the future levels of demand and supply in the transport sector. A number of detailed forecasts have been published recently (for example, Chesshire and Surrey (1977); Leach, *et.al.* (1979); Department of Energy (1977, 1978, 1979)), and it is sufficient to allude to their suggestions. It is important to note that there is a broad range in their conclusion, because of the inherent uncertainties involved; a feature exemplified by the continual up-dating of their projections by the Department of Energy (Department of Energy, 1977, 1978, 1979). All the mentioned projections applied a sectoral approach (a methodology which is described in Department of Energy (1978a)). A fundamental conclusion is that the proportion of oil consumption by the transport sector will continue to increase to the turn of the century. In the short-term, there is little optimism to suggest that technological advancements will enable electric or synthetic fuel cars to replace the present reliance on oil (Department of Energy (1978b)). (However, given the present interest in relationships between energy and urban form, Bacon's (1973) speculations on the possible impacts of electrical transport are acknowledged). In fact, the Department of Energy suggest that, by the year 2000, the transport sector could account for over half of the energy demand for oil, whilst an alternative 'low' estimate, made by Chesshire and Surrey (1977) suggests that this could be as high as three-quarters of the total energy demand for oil. In addition, it is significant that, in 1978, over three-quarters of the petroleum consumed by the transport sector was attributable to road transport, a proportion which is projected to remain high. By 1977, car traffic had become nearly 80% of the total traffic (see Figure 5).

One important facet of any energy consumption projection is the assumption concerning price. In the past, consumption patterns have been founded on cheap oil, and as substantial future price increases are expected it has been argued that market forces, via the price mechanism, will promote economy and efficiency (assuming some degree of price elasticity of demand). Figure 1 graphs the (recent) increases in the average pump prices for petrol in the United Kingdom, although it must be remembered that such increases relate to alterations in its nominal, and not its real, price; this basic distinction is of fundamental importance (Figure 6, which should be compared with Figure 1, presents the changes in the real price of petrol, having taken account of household income rises). In analysing Figure 6, it is interesting that the trends, including the immediate impact of the 1973-1974 price changes, nearly parallels the trend for aggregate private passenger road traffic, shown in Figure 7. If the real cost of motoring is declining, it is only to be anticipated that there will be an ambivalence between desires for greater consumption and greater conservation. In addition, as a large proportion of motoring is done on company expense accounts - approximately 40% of new cars are company cars (Chesshire and Surrey, 1977) - an extra cushion is provided against higher prices. It must, however, be stated that, by the turn of the century, it is estimated that the price of oil will be at least double in real terms (Department of Energy, 1977).

Thus, in the long-run, there is every indication that we must plan towards enhancing the opportunities for energy conservation. Specifically, the urban transport system is overwhelmingly and insecurely tied to the vaguaries of a continued supply of oil. In spite of an early warning of an impending ocnfrontation between transportation and energy (Goss and McGowan, 1972), few comprehensive investigations have been forthcoming on this important topic.

3. URBAN FORM: THE MOTORISED SOCIETY.

There is no requirement to dwell here on the role and the impact of the motor car in everyday life; its convenience and enhancement of household mobility cannot be doubted. The motor car has become an integral part of the functioning urban environment, particularly in relation to the spatial organisation of different activities. To a certain extent, recent urban planning has caused the motor car to become a necessity, because movement, such as the journey-to-work, is often over long distance. This man-made urban environment is not energy efficient, a vulnerable characteristic which may present future contradictions in its continued operation.

Urban spatial form is obviously a fundamental physical characteristic of the urban environment; the size, shape, density and distribution of houses, jobs, shops and other activities are spatial manifestations of a functioning dynamic system. Twenty-five years have now elapsed since Mitchell and Rapkin (1954) outlined tha notion of '*Urban Traffic: A Function of Land Use*', and it is widely appreciated that alterations in land use configurations of cities can lower the derived travel demands. It can, therefore, be suggested that one long-term answer for the so-called 'energy crises' in the urban milieu may be found in land-use planning and design. Unfortunately, as the appraisal of '*Energy Conservation in the International Energy Agency*' demonstrates, "... the real problem of residential housing patterns and general urban planning does not seem to be addressed anywhere effectively" (O.E.C.D., 1976, p.16).

Locational flexibility has increased with the private car, a feature which has facilitated the movement of households away from the city centre as their wealth increased. It can be suggested that as oil becomes scarcer and more expensive, that some force will exist to restructure the present urban form to be more energy efficient. Alternatively, the potential constraint on the availability of future oil supplies may influence the possible options of of a practicable urban form.

Urban spatial organisation, without doubt, is one of a number of features which affects energy consumption. It is propounded that analysis of the spatial distribution of various land-uses may permit the development of more energy efficient forms. For example, redistribution of activities may reduce the length of the journey to work. Such a strategy would be a planned development process, but, disappointingly, to-date, there has been insufficient examination of what an energy efficient urban form is actually composed of and how such a state can be reached given the present arrangements. Furthermore, it must be remembered that in addition to the physical constraints imposed by the present infra-structure, present social expectations would be generally antagonistic towards the notion of returning to the situation where the locations of work and home are in close proximity.

Interestingly, case studies for Dortmund, Los Angeles, New York, Sappero, Toyoko and Zürich considered energy use in the household/commercial sector, and suggested that it is in transport where the largest energy savings could accrue (O.E.C.D., 1978). In foreign cities such as Stockholm, for example, planning has explicitly attempted to reduce the benefits and needs of travelling by car (Thomson, 1978), although in the United Kingdom, even the proposal for new, energy-efficient miniature 'city cars', as suggested in the Marples' Report (1967) 'Cars for Cities', seems unattractive.

The basic tenet of the paper is that energy could be conserved by exploring urban design, especially facility accessibility (Owen, 1976); if it were possible to re-structure the various land uses, a reduction in the number of vehicle kilometres (assuming that, to a certain extent, travel is a derived demand) and enhancement of the opportunity for multi-purpose trips are feasible.

4. URBAN FORM: PRESENT AND FUTURE TRENDS.

Post-war urban development, during a period of increasing population, growing affluence, and plentiful supplies of cheap petrol, has consisted of increasing decentralisation of population (and of some types of employment) from city centres to their suburban peripheries. (This trend is well documented in the literature; see, for example, Coursey (1977), Drewett *et.al.* (1976) and Hall *et.al.* (1973)). The way of life associated with this form of development is dependent upon a number of factors, one of which is the continued availability of petrol supplies to maintain the necessary levels of household mobility. One implication of future petrol price increases or physical shortages is the possible accentuation of present trends to replace a single-centre urban form by a structure including a number of sub-centres where industrial, residential and service activities are in close proximity. Such a configuration will reduce the need for travel, and, therefore, the energy consumption; for instance, Van Til (1979) examined four models of urban form, and concluded that the only viable structure, when there is an energy shortage, is a 'diversified-integrated' city. More generally, it can be proposed as a possible real answer to the problems of urban sprawl in large cities - "The energy shortage ... may be the salvation of the bedevilled big city" (*New York Times*, 1974, p.40).

Sub-centres could be foci for development, around which urban development could be organised. Their significant feature would be physical and functional unity, which is more than the sum of its parts. (This has important implications in the phasing of co-ordinated development, which must be more than a series of separate single-purpose projects). Moreover, the increased opportunities for multi-purpose trips may reduce travel demand, and, therefore, energy consumption. Such developments will have an enormous impact on the land use patterns of a city (particularly in relation to the density of development and its multi-functional characteristics), a feature exemplified in Witherspoon *et.al.*'s (1976) detailed, case-study descriptions of recent 'mixed use developments' in the United States. The location of such sub-centres would, obviously, be largely dependent on specific characteristics of particular cities, although, in general, the foundation would be the present-day land use pattern and road network. For example, sub-centres could be associated with the current, strongly radial road system, or, alternatively, could be planned as developments based on shopping centre, light industrial estates, and so on.

In the change from a single-centre, to a multi-centre, urban structure, any notion of a consequent decline of the existing urban centre would be incorrect. It would not only be wasteful with regard to its infrastructure, which has developed over the last few centuries, but it would also undermine the whole concept of integrated, co-ordinated urban development. The need to link future land-use plans for energy efficiency to the existing pattern is clear - the future commences now. Today's urban form is the outgrowth of a historical evolution, an amalgamation of the manifestations of economic, social and political forces over many centuries. It is this configuration of housing, work-places, shops, offices, public facilities ... which is probably the most important factor determining the potential and the specific strategy required for a more energy efficient urban form in the future. The city centre and the various sub-centres should be thought of as a functionally inter-related hierarchical system. Certain functions, such as, legal, government and financial, are, by their nature, 'central city' functions, which must serve the whole city if standards and efficiency are to be maintained. In contrast, other activities, such as shopping, recreation, residential, and so on, could be located in close proximity to each other in a number of sub-centres. A range of goods and services will be offered, because of the higher density of development. Such a process would occur naturally, to a degree, as urban growth increases the market potential of some local nodes above the required threshold for development. It is important to emphasise the interrelatedness of such developments, distinguishing them from, say, today's large housing estates which possess a few local shops and a factory.

It would be wrong to have the impression, from the above sketched outline of a possible multi-centre urban structure, that a kind of restricted uniformity and localism will prevail; its essence is the functioning of interrelated activities throughout the whole urban space-economy. Variations of this strategy include directing the growth of population and employment along planned, high-density, transport corridors which radiate outwards from the city centre. Such a scheme has undergone a detailed analysis in relation to future energy consumption for Melbourne, Australia (Sharpe, 1977, 1978a, 1980) and is also included in the master plan for the Nassau-Suffolk area of New York (Owen Carroll *et.al.*, 1975) - both these examples are described in the modelling sub-section.

Any alterations to the urban land use pattern on the scale suggested will, obviously, have significant implications outside the field of energy conservation; in fact, the functional variety and scale of such developments mean that their impact is large. (For example, Dean's (1975) redesigning of the entire city of Vinona, Minnesota required a radical reorganisation of lifestyles). It has already been briefly suggested that such developments may assist in limiting the difficulties often associated with large cities. With regard to the urban financial crisis, sub-centre development may present an opportunity for reducing costs of infrastructure and service provision and maintenance. These centres should be able to benefit from scale economies, but should not be large enough to suffer from diseconomies of scale. (The significance of city size must be pointed out. Energy consumption associated with land-use-transportation patterns is, obviously, related to city size. Moreover, the possibility of scale economies accruing for a multicentre development and scale diseconomies accruing for a single centre development are also dependent on city size, see Richardson (1973)). Any savings in public expenditure that can be attained without affecting the quality of service provision is particular attractive. An additional advantage will be the increased (and equalisation of) accessibility to a variety of facilities, an aspect which is especially salient to the poor and the old whose mobility is usually relatively low. It could also be propounded that sub-centre development will assist in bringing back an identifiable 'community spirit' with its associated social and psychological rewards (although if many social problems are really the result of inconsistencies in societal organisation, as is often argued, explicit spatial policies may only ameliorate the symptoms and not attack the real problems). Moreover, it is of fundamental importance that limitations on policies, arising from locational attributes, and policy implications for urban spatial structure are adequately addressed.

Unfortunately, the opportunity to start again is rarely available (a feature often neglected when attempting to model this question), and, in fact, a particular, existing urban form may severely restrict the opportunities to save energy. Furthermore, cities adapt very slowly, and, therefore, it is only in the long-term that energy inefficiencies of the existing urban form will be ameliorated. It is this long-term nature which requires the analysis of the relationship between (transport) energy conservation and land use planning to be undertaken now. This will permit the formulation of suitable strategies which incorporate the aspect of energy conservation, specifically the concept of an energy-efficient urban form. Additional limitations on planners' ability to increase the rate of urban spatial reorganisation include the forecasted economic recession and population stabilisation. It should also be noted that any proposed plan must include an assessment of the energy consumption arising from the actual development.

Whilst the actual scope for building a New Town, designed to be energy efficient, has already been questioned, it is interesting to explore this issue briefly by mentioning a few examples. Jamieson *et.al.* (1967) gave an early demonstration that a deliberate incorporation of energy aspects within an urban design process, perhaps facilitated by employing apposite models, should be relatively straightforward. The 1970 master plan for the University town of Louvain-la-Neuve in Belgium, for instance, was influenced by a number of English garden cities, such as Letchworth and Welwyn Garden City (Laconte, 1977). Significantly, although the need for a motor car was reduced, no explicit concern was given to the generation of an energy efficient design, illustrating that energy conservation is complementary to other objectives in land-use planning. In contrast, the new satellite town of Stockholm, Jarvafaltet, has been designed primarily to be energy efficient (Owen, 1976). A linear configuration was developed in which various activities were found in close proximity in order to reduce the demand for travel.

It is becoming apparent at the official level, that there is a need to minimise travel (and, in so doing, the energy consumption) by land-use planning, For instance, this subject was noted under the heading of 'new policy topics' in the Structure Plan for South Yorkshire (Mallett and Thompson, 1978, p.90), and the conclusion of the Greater London Council's report on '*Energy Policy and London*' emphasised that "all plans should clearly specify the energy consumption implications" (quoted in *Town and Country Planning* (1979, p.238)). Similarly, a joint study by the Chartered Institute of Transport and the Institute of Road Transport Engineers states that all planning proposals involving transport should incorporate an obligatory statement of their 'energy impact' (Baily, 1980). Planners are advised to examine the new implications of the arguments for formulating future land-use plans with regard to energy conservation; undoubtedly, the incorporation of this aspect will raise a number of new issues (both difficulties and opportunities) for land use planners. While sub-centre development may be more energy efficient, it would be wrong to suggest that energy conservation will inevitably affect urban form. There is a real need for planning in this direction, recognising the alternatives available. Throughout this paper, it is stressed that energy conservation via land use policy is a long-term strategy. This does not mean that the topic is not of immediate concern; far from it, in fact, the consequences of any present-day action (or lack of action) will have their impact in the future, at a time when oil supplies are more restricted. Whilst such long lead times do not have the inherent attraction of short-term measures, an important practical fact is the essentially short-term, planning perspective adopted in government. There is, therefore, the danger that an energy policy (like other policies) will become unnecessarily incoherent and uncoordinated because of its short-term view-point, a political decision which is myopic to the requirements of future generations for a strategy towards a way of life based on a more efficient use of energy.

In addition it is important to stress that institutional structures, particularly their bureaucratic fragmentation, can determine the success of an implementation of such land use policies. The problem of coordination is particularly salient to the question of energy, a topic which is frequently considered independently at a variety of levels and in a number of departments. The envisaged land use strategies will inevitably extend across usual demarcations because of its multi-functional characteristics. Whilst not proposing the need for a complete restructuring of administration and authority, and recognising that a continuation of existing areas of responsibility would perhaps accelerate effectuation, it is important to appreciate that the complexities will necessitate greater intebration of decision-amking. For instance, the 1975 Community Land Act does not explicitly state which authorities should do what - county council, district council, and so on. This is one illustration that, to a certain extent, energy conservation is fundamentally a political, rather than a technical dilemma.

The multi-functional characteristics of the new developments will present planners with a new problem with regard to the phasing of their development; the strategy must avoid a piecemeal collection of single-purpose projects, because this would undermine the inherent advantages of such a venture. The pragmatic difficulties must be overcome, otherwise in the long-run, partial solutions may actually accentuate the problems. The scheme must be sufficiently flaxible to enable each phase to have a degree of self-sufficiency, whilst, simultaneously permitting both a favourable marriage to later phases and an ability to adjust to a changing environment.

The scale of such comprehensive programmes means that large tracts of land are an essential requisite (remembering that the existing structure will determine the scope of the original proposal). This has significant implications for land ownership, land values and land use zoning, which will only be given a cursory discussion here. Local authorities possess the legal power of compulsory purchase by which it is possible to obtain large blocks of land for development; one objective of the 1975 Community Land Act is to enable the community to control the development of land in accordance with its needs and priorities. Although private developers probably do not have the opportunities to undertake large-scale development because of difficulties of acquiring large expanses of land, their financial backing will obviously be of great assistance, if not essential. A difficulty will result from the inevitable increase in land values. Public ownership would enable any growth to accrue to the community at large, noting that, at present, the 1975 Community Land Act ensures that 30% of the development value of land goes to the Local Authority. No doubt problems of speculation will exist, and it may be necessary to devise some (transfer payments) procedure to compensate households, businesses and so on which have to relocate. Related to land values is the common regulatory land-use policy of delimitating zone type, as undertaken, for example, in Structure Plans. The existing pattern is likely to require some redefining to accommodate multi-use zones (in contrast to single-use zones), the decisive feature of the suggestions.

Finally, in re-emphasising the need for coordination between urban planning and energy conservation, it is apposite to indicate that, although the organisational structure necessary for urban and regional planning is well established, no similar framework is presently available to examine energy, which is primarily considered at the national level.

There has, therefore, been sufficient discussion to demonstrate that there is a need to conserve energy and that there is a possibility of achieving this end through land use policies. In the next part of the paper, there will be an attempt to formalise some of these suggestions by reviewing some of the available mathematical models of the land-use-transportation systems.

PART TWO

5. LAND USE-TRANSPORTATION MODELS AND ENERGY: A REVIEW.

The basic tenet underlying the previous part of the paper is that land use policies have potentially a significant role to play in attempts to conserve energy. Recently, land use planners have employed mathematical models to assist them in the process of policy promulgation and assessment. With this in mind, in this part of the paper a review of a number of models which have been specifically concerned with energy is undertaken, and then alternative models will be examined in detail. Throughout the discussion, attention will focus on policy ramifications (remembering the issues which have already been raised) rather than on techniques *per se*. The literature pertaining to analyses of the optimum land use pattern with respect to energy utilisation essentially amounts to a number of isolated, individual investigations (Dendrinos, 1978). This does not aid the reviewer to develop central notions to knit the studies together, and, therefore, a primarily descriptive account is presented.

A detailed report by Flachsbart (1977) suggests that the long-run aim to enhance the efficient utilisiation of energy calls for the attention of land use policies; any developments, such as clustered and mixed land use patterns, must also take into account the range of amenities that the consumers require. Whilst this examination of the Los Angeles area echoes the findings of many of the other papers discussed, it does not set out to model the urban system. It is, however, a very interesting and detailed survey, which provides a useful introduction to this review section. To a certain extent, the examination is unique in that it considers the impacts of the O.P.E.C. oil embargo on urban travel behaviour, petrol consumption and attitudes towards access to urban opportunities (for six trip purposes: work, school, shopping, cultural, entertainment and recreation) in a case-control design framework.

Flachsbart was fortunate in being able to employ data collected prior to the embargo and compare it with the post-embargo situation. Whilst the reader is given sufficient details of the research design and data collection procedures, the fact that the initial survey was actually undertaken to re-evaluate residential planning and design standards and did not explicitly focus on energy issues does present certain problems. Insufficient information was gathered from the first survey to produce large samples of well-matched population categories. More fundamentally, although bias was avoided because the subjects were unaware of the attention on energy, one has to question such comparative studies on the grounds of whether it is valid to ascribe the differences in observation to the O.P.E.C. oil embargo. Furthermore, it is important to remember that evidence has been given to suggest that any impact on behaviour was both immediate and short-lived, and that there was a fairly quick return to a general attitude of complacency towards energy conservation. Given the problems of survey standardisation, the results offer directional, if not always statistically significant, tendencies, and form the basis for an interesting descriptive and explanatory account of the immediate impacts of the O.P.E.C. oil embargo on the U.S.; it also indicated avenues for future research, some of which can be considered by the application of urban models.

5.1 *Lowry-Type Models.*

As a number of individuals have employed a Lowry-type model as the foundation of their inquiries, it seems appropriate to consider these together.

In general, land-use modelling, particularly in Britain (Batty, 1972) has evolved around Lowry's (1964) model for the Pittsburgh city region and its subsequent extensions (for example, see Batty, 1976, and Wilson, 1974). The aim of Lowry's *"A Model of Metropolis"* was to develop

> "an analytical model capable of assigning urban activities to sub-areas of a bounded region in accordance with those principles of locational interdependence that could be reduced to quantitative form".

Basically, the model explicitly treats the linkages between the main sub-systems of the city system; concern is centred on the organisation of the population (basic (primary and manufacturing) employment, and service employment) activities and their matching (residential, industrial and service) land-uses in the urban space-economy. The economic base method generates the activity levels, and the location of the activities is determined by either potential models or, more recently, by gravity models. Iteration produces a stable pattern of activities, (Figure 8).

Two features of the model deserve noting as they turn up throughout the discussion on land-use and energy consumption. The model is a static equilibrium model - 'an instant metropolis' - although dynamic versions have been proposed by Batty (1972a), Crecine (1969) and Wilson (1974). Second, it is not in aggregate, an optimising model; that is, it does not necessarily convey the optimum land-use configuration. In spite of criticism, Lowry-type models have been widely operationalised; employment being attracted by their apparent simplicity and limited data needs. It is, therefore, not surprising that the Lowry-type models, which have proved to be a fertile avenue for urban and regional model building, have been applied as the basis for investigation into energy/land-use-transportation relationships.

Edwards and Schofer (1976) offer a compromise to applying either a normative/optimising approach (as employed in Dantzig and Saaty's (1973) '*Compact City*' which is mentioned by Edwards (1977)) or an empirical approach by simulating travel behaviour in a series of hypothetical cities using both the Lowry model and data from an existing city, Sioux Falls, South Dakota. Their analysis

> "(a) chooses a representative city in which aggregate travel behaviour has been observed and documented; (b) resettles the residents of that city into different patterns and analyses the travel and accessibility characteristics and the transportation energy requirements arising from changing the spatial variables (shape, form, density patterns); and (c) identifies those factors that most strongly affect transport energy requirements and activity accessibility" (Edwards and Schofer, 1976, p.53).

It is important to note here that although the energy efficiencies of different urban spatial structures were compared, other facets of travel behaviour must also be included into the analysis, especially if the orientation is towards acceptable long-term policy development.

In total, thirty seven different experiments were undertaken; their sequential framework of investigation permitted information generated from one experiment to assist in the choice of subsequent experiments. To facilitate comparison, activity variables (such as employment by category, population, labour force participation, interzonal impedance (friction) factors by trip type, and trip rates per capita by trip type) were fixed to a constant size, although they did vary spatially. The interaction variables (such as density patterns and shape, highway speeds and transit routes, modal split, and transport technologies) did exhibit variety between designs.

Their land-use designs, arranged via a Lowry-type model, were founded on three basic urban shapes: concentric, linear and poly-nucleated. (Two experiments combined features of the linear and poly-nucleated shapes by analysing a pure cruciform design, which enables a spatial dissociation of residential areas from industrial and commercial areas). Urban shape was identified as one of four contributing factors accounting for the differential energy needs and accessibility patterns; (the model to be outlined later has the advantage that it is not restricted to specific geometrical shapes). The other three explanatory factors considered by Edwards and Schofer, were: the geographical extent of the city; the degree of concentration of the population about the city's centroid; and the degree of concentration of employment about the city's centroid.

In their resume, Edwards and Schofer (1976, p.52 and p.54) were able to say that

> "Preliminary findings suggest that structural changes in transportation and land-use patterns can produce significant reductions in energy consumption for urban passenger travel".

Specifically,

> "Cities with compact land-use patterns occupy energy efficient locations in the space of feasible structures".

A Lowry-type model and three different land-use patterns (a mono-centric city, a polycentric city and a one-sided (Chicago-type) city) were also applied by Peskin and Schofer (1976) in their study to assess the promise for energy conservation via land-use-transportation policies. Like Jamieson, *et.al.* (1967), Rice (1975) and Romanos (1978), they conclude that a poly-nucleated city, as highlighted in the first part of this paper, offers the most energy efficient urban form. In fact, Slayton (1976) suggests that *'Tomorrow's city will look like a collection of small towns'*, and that this will partly result from deficiencies in future energy supplies.

It should be noted in parentheses, that a wider range of abstract urban configurations were employed by Rice (1975) in his detailed analysis of the travel needs of six different urban forms: central, homogeneous, multi-centred, radial corridor, linear and satellite. Data from a number of cities, rather than a mathematical model, was the foundation for each land-use pattern. A two-mode transportation system was superimposed (as efficiently as possible) onto each urban form; standard travel demand and assignment models gave the travel needs of each urban form. The multi-centred form required the shortest average *work*-trip length (a 22% improvement on the next best pattern) and the lowest number of person-hours of *work*-trip travel (a 29% improvement on the next best pattern). (The central pattern was the next best).

Two specific features of the Peskin and Schofer (1976) analysis which merit comment are their attempt to consider supply-demand inter-action and their simulation of the future form of the city. In its usual representation of the urban system, the Lowry-type model focuses attention on demand, examining the relationship between land-use and travel demand. The incorporation of transportation supply notions (network structure and service level) is achieved by explicit reflection of the impact of both congestion and energy travel costs on accessibility, and thus on the residential and service land-use pattern. Model runs simulate the current urban configuration, and, employing an exogenously-given incremental 'layer' of growth, a second model run, called 'a standard incremental run', generates the land-use pattern which is applied as a control to compare the effects of different policies (Figure 9). Simmulated policies included: altering travel behaviour, changing transportation facilities, increasing travel costs and modifying the spatial orientation of urban growth.

Owen Carroll, *et.al.* (1975) conducted an examination of *'Land use and energy utilisation'* employing a Lowry-type model, and 'testing' was undertaken in the Nassau-Suffolk area of New York City. Specific interest focused on the analysis of energy consumption in all sectors, including the transport sector, as a function of land-use. Emphasis was placed on planning applicability for the development of future land-use patterns until the end of the century. Analysis was founded on two land-use scenarios, each having the same projected values for future population, industrial employment, commercial floorspace, desired number of housing units, and so on. A continuation of existing tendencies was described by the base scenario - 'urban sprawl'. The 1985 master plan proposed by the Nassau-Suffolk Regional Planning Commision, which envisages new expansion to take the form of main transportation corridors (confined to the central exis of Long Island in order to protect the natural beauty of the coastal areas), clusters of residential neighbourhoods, and a number of service/employment centres, was applied as the second scenario. The use of rather over-confident assumptions with respect to the potential for energy conservation in the residential and industrial sectors results in the spatial configuration of 'corridors, clusters and centres' offering an apparently large energy saving in comparison to present development patterns. It is, however, the possible energy conservation in connection with transportation, amounting to approximately 50%, which is of prime interest here, particularly in view of this sector's near total reliance on petroleum.

It must be realised that all the previous studies are essentially land-use modelling exercises with travel mdoels either built into the Lowry-type model or post-determined by gravity models (for example, for the social and non-home-based trips considered by Edwards and Stopher (1976)). The resulting trip tables enable the total energy requirements under different conditions for different needs. In no way, however, do the Lowry-type models intend to employ transportation energy efficiency as a criterion for determining an optimum urban configuration. The minimisation of energy consumption through travel, however, seems one attractive avenue to pursue; yet it can be suggested that such a formulation is by no means a panacea, because any land-use policy should not be based on energy consumption *per se*.

5.2 *Optimisation Models.*

There is, obviously, a wide range of mathemtical programming procedures which can be employed in optimum plan design. (A growing literature has, in fact, developed since Schlager's (1965) portrayal of *'A Land-use Plan Design Model'* as maximising a mixed welfare function containing 'cost' and 'value' terms). There methods compute the optimum value of an objective function subject to a number of itemised constraints by searching a defined feasible solution,

Hemmens (1967) was explicitly motivated by the objective of minimising urban passenger travel demand. The reciprocity between urban form and travel demand was addressed through testing various urban configurations for a hypothetical city split up into zones. A linear programming formulation determined the inter-zonal pattern of shopping and work trips which depicted the minimum total travel cost for each urban structure. Whilst recognising that assignment of shoppers and workers to their nearest shops and work-places, respectively, did not mirror observed behaviour, Hemmens (1967) suggested that minimum travel requirements for each urban form could act as operational benchmarks to enable comparison of different land-use patterns. But the use of norms as aids to comparison and explanation must be questioned on the grounds of structural equifinality. Consequently, policy makers need to be aware of the different possible causal relationships underlying the patterns.

Given these comments it would, however, seem relatively simple to extend the analysis by employing a compatible model which relaxes the nearest centre hypothesis through the incorporation of a spatial interaction model. Moreover, as aggregate travel cost can be considered as an inappropriate criterion of user benefit when consumer choice is included, perhaps an alternative welfare function, consistent with the behavioural model, should be applied. (These notions are included in the Coelho-Williams (1978) model, which is studied below).

In fact, minimisation of energy consumption *per se* should be avoided as it may generate new problems. With foresighted planning it should be possible to ensure that

> "Energy conservation is an area where energy policies and wider social and economic policies can be advanced simultaneously" (H.M.S.O., 1978, p.23).

The existence of interaction between many aspects of an energy policy and other dimensions of Government policy is essential and inevitable.

Hemmen's (1967) paper did however, stimulate further research. One of his conclusions, which has been widely discussed, was that the optimum urban form was independent of the transportation network, and consequently that the close relationship, at the aggregate scale, between urban land-use planning and transportation planning is a myth. However, this result has been deemed inconclusive as insufficient land-use patterns were analysed (Schneider and Beck, 1973). Interestingly, the particular transportation system can be demonstrated to be of significance by a comparison of the different experiments undertaken by Edwards and Stopher (1976); urban forms were portrayed as energy efficient when public transportation became predominant, but they were energy inefficient when travel was restricted to the motor car. Another conclusion, this time supported by a number of separate studies (such as by Edwards and Stopher (1976), Levinson and Roberts (1965) and by Schneider and Beck (1973)), is that total travel is directly related, *ceteris paribus*, to the degree of centralisation of (employment and retailing) activities in a city centre; this feature is one of the major factors behind the suggestion that an integrated multi-centre urban form is appropriate for a future of energy shortages.

More recently, Dendrinos (1978a) has presented a linear programming formulation, to assist local governments to plan for energy conservation, which simultaneously derives the optimum land-use-transportation interactions and the optimum energy allocations. His objective function is designed to minimise total social costs, by optimally allocating the economic activities over an urban area split up into zones. For each zone, land constraints are given exogenously for the residential, industrial and commercial activities; the level of aggregate urban population and the total urban employment, disaggregated by type, are also inputs into the model. The consideration of energy can either be incorporated into the objective function, acting as a penalty function, or as an explicit resource constraint, rationing over space.

As Dendrinos (1978a, p.2) states,

> "The model employs specific energy utilisation coefficients per density type for the different economic activities. The dual formulation of the linear programming problem (can be) derived, together with an economic interpretation of the compulsory slackness conditions and the dual variables as possible instruments for energy conservation and land-use policy".

It would be interesting to try to interpret the marginal influence of the energy resource constraint on total social costs, and, although Dendrinos (1978a) did allude to this possibility, unfortunately, the analysis was not forthcoming in his paper. For instance, given the constraints applied in the original simulation, it would be possible to consider the opportunity costs of particular residential and industrail land constraints and even of the total energy consumption.

One particular area which offers rich potential is the interpretations assigned to the dual variables. The dual solutions to the primal formulation present notification of the importance of the constraints by ascertaining the so-called 'shadow price' for each constraint. It is then possible to check the degree to which a marginal strengthening or weakening of a specific constraint (or specific constraints) will affect the aggregate value of the objective function; that is, in economic terminology, it is a gauge, in the units of the objective function, of the particular constraint's marginal opportunity cost. This is especially significant as many of the constraints are directly imposed by the policy-makers, and, therefore, a method which can examine the sensitivity of the constraints is extremely attractive (Ben-Shahar, *et.al.*, 1969).

The assets of linear programming's relatively easy computation procedure are especially attractive, but one must question the realism in the conceptualisation as a linear objective function with linear constraints. Specifically, realistic spatial interaction models are not included in these linearly-constricted formulations and also no representation of internal scale economies and agglomeration economies is feasible.

The restrictive assumptions of linearity were relaxed by Sharpe (1978), who was interested in the possibility of increasing energy utilisiation efficacy in Australian cities, specifically Melbourne (a subject consdiered in other papers by Sharpe, 1977, 1978a and 1980). This involved a consideration of a number of viable future alternatives and an illustration of related life-styles. A brief portrayal of the present situation offered the foundation to analyse three scenarios: 'Business as usual scenario year 2000'; 'Energy Crisis (2000)'; and 'Medium density alternatives (2000)'. Assessment of the minimum cost development options, imaginable for Melbourne, was undertaken by applying the TOPAZ (Technique for the Optimum Placement of Activities into Zones) model to Melbourne for the various scenarios. Essentially, land-use planning is evaluated by means of spatial cost-benefit analysis; that is,

> "incremental growth of activities may be allocated on the basis of minimising total city establishment and transport costs less benefits, subject to constraints on zonal capacity" (Sharpe, 1978, p.7).

Conceptually, a beneficial feature of the TOPAZ model is its explicit, combined partrayal of present and future land uses. Future development is, therefore, realistically mirrored as a part of an on-going process building onto the present urban stock; a feature which was stressed as important in the preceding part of this paper. This formulation represents spatial interaction through a doubly-constrained gravity model, and is solved by iterative linear programming. In expressing the requirement for further research, Sharpe (1978) was aware of the inconclusive character of his own investigation. However, by grasping the requisite that policy-makers must clearly state and confront their basic premises, he demonstrated the relevance of the role the modeller can play in future actions.

The final paper to be described in this review section is in agreement with many of the ideas already expressed; for instance, Romanos (1978, pp.93-94) indicates that planners

> "could greatly benefit from information about present energy-consumption patterns, and about the relationship of these patterns to the existing urban spatial structure, to the transportation system, *and most of all to the dynamics of urban growth and change*". (Emphasis not in the original paper).

Concern in the paper centres on attempts to save energy in the urban environment within the context of the on-going process of employment relocation. The theoretical basis is at the micro-scale, and involves utility maximisation with the consumer trading-off the cheaper cost of houses located away from employment in the city centre and the costs of travelling between home and work.

Utility analysis of households' residential location decision is conducted to act as a foundation for assessing the impact that energy price alterations may have on the land-use trends. (This approach to residential location is well documented in the literature; for example, it was explicitly adopted by Alonso (1964) and implicitly by Wingo (1961). More recently, Muth (1969) has described the application of various utility functions to examine the housing market, and Mills (1972) has employed this conceptualisation to consider urban models in general). Formally, utility is maximised subject to the budget constraint by which household expenditure must equal income, and is at the point where increases in travelling costs arising from moving residence away from the employment location equal savings in housing expenditure. Romanos concludes that the resulting urban structure will be a multinucleated system of centres.

The fundamental feature of the analysis is the exposition on how this development will be influenced by increases in the real price of energy. The impact of energy on the configuration of the urban environment is sensibly placed in perspective at the outset:

> "Although energy alone may not be a powerful enough factor to make dramatic land-use changes possible, it is of interest to observe the *trends* that these effects are likely to indicate". (Romanos, 1978, p.100).

Interestingly, Romanos finds that the energy impact will augment existing processes (Figure 10); a fact which may assist in the successful implementation of an energy policy. (Note the earlier comments on the new town development of Louvain-la-Neuve in Belgium). He asserts that:

"As far as the intraurban location of economic activities is concerned energy effects should be expected to *reinforce* the steady trends of business and industry relocation from the central city to the suburbs simply because this move is likely to produce transportation energy savings for the suburban labour pool. On individual hosueholds, however, the energy effects are likely to be more apparent. Medium- and lower-income households in particular are likely to respond to the energy price/quantity changes faster because the effects of these changes on their real income will be felt sooner". (Romanos, 1978, p.100; italics added).

This latter comment portrays one future issue, equity, which should be considered by decision-makers, as the impact of the energy crisis will not impinge on individuals uniformly. This demonstrates that exclusive conceptualisation of the energy question as a problem of inefficiency in the utilisation of a scarce resource is misplaced, and although this is a significant aspect, other issues, such as equity of resource allocation, are important. Optimising models of the urban environment, in fact, are increasingly looking at the normative facets of both efficiency and equity. Clearly, yet unfortunately, social welfare possesses no one, unified definition; yet despite no consensus, practical analysis is both possible and essential. Welfare involves both equity and efficiency, and this fact must be recognised in the present context, because the impacts of a future 'energy crisis' are unlikely to fall uniformly across society. In fact, evidence suggests that the denouement will be highly inequitable in distribution, augmenting existing inequalities.

6. LAND USE-TRANSPORTATION MODELS AND ENERGY: AN EXAMPLE.

In this section two urban models will be applied to the city of Leeds, which is divided into twenty-eight zones on the basis of wards, (see Wilson *et.al.* (1977) for more details on the application of urban models in Leeds). In contrast to many previous studies, Figure 11 illustrates that no restrictive assumptions on urban shape are present. Analysis will commence with an application of a Lowry-model for a given distribution of basic employment. Parameter and transport cost alterations enable a representation of different energy situations, and the various patterns are compared. In addition, using the same data base, which facilitates comparison, the land use design model, formulated by Coelho and Williams (1978), is employed. This model has the additional feature that optimisation includes the determination of the optimal configuration of the basic employment; this is especially apposite because, as the models are dependent on an economic base mechanism, the initial pattern of basic employment is a major influence behind the generation of the final urban form. Finally, it is indicated that the Coelho-Williams model renders itself to an incremental framework in which optimisation takes place subject to the original distribution of activities.

6.1 *Lowry Model.*

The structure of a Lowry model has already been described (see Figure 8); basically, it involves the interplay between two spatial interaction sub-models: one representing workplace-residence relationships and the other one representing residence-services relationships. These are equilibrium, singly-constrained models, which can be described by the following equations,

$$T_{ij} = B_j E_j H_i^{\gamma} e^{-\beta^W c_{ij}} \tag{1}$$

where

$$B_j = \left(\sum_i H_i^{\gamma} e^{-\beta^W c_{ij}}\right)^{-1} \tag{2}$$

is a balancing factor which ensures that

$$\sum_i T_{ij} = E_j \tag{3}$$

and,

$$S_{ij} = A_i e_i P_i W_j^{\alpha} e^{-\beta^S c_{ij}} \tag{4}$$

where

$$A_i = \left(\sum_j W_j^{\alpha} e^{-\beta^S c_{ij}}\right)^{-1} \tag{5}$$

is another balancing factor which ensures that

$$\sum_j S_{ij} = e_i P_i . \tag{6}$$

T_{ij} is the number of jobs in zone j allocated to people residing in zone i, and S_{ij} is the number service jobs in zone j generated by the population in zone i. E_j is the employment in zone j, which, because of the incorporation of an economic base mechanism, can be thought of as the sum of the employment in zone j from basic (E_j^B) and non-basic/service (E_j^S) activities. H_i is the attractiveness weight (or size) of residential activity in zone i, β^W is the travel dispersion parameter for work trips; c_{ij} is the interaction cost component from zone i to zone j; e_j is the per capita expenditure on services by residents of zone i; and P_i is the population of zone i which is determined from the number of workers in zone i by the following equation

$$P_i = \rho \sum_j T_{ij} \tag{7}$$

where ρ is an inverse activity rate. W_j is the attractiveness weight (or size) of service activity in zone j; β^s is the travel dispersion parameter for service trips; and α and γ are parameters representing scale economies or diseconomies.

The relationships between these equations are described in Figure 12, which also shows how the employment variables, T_{ij} and S_{ij}, can be simply transformed into trip variables, $\hat{T}_{ij}$ and $\hat{S}_{ij}$, respectively

$$\hat{T}_{ij} = \varepsilon T_{ij} \tag{8}$$

$$\hat{S}_{ij} = \varepsilon S_{ij} \tag{9}$$

ε and η represent the number of trips associated with each unit of employment. This enables an examination of the total travel (T.T.) in the system,

$$T.T. = \sum_i \sum_j (\hat{T}_{ij} + \hat{S}_{ij})\ c_{ij} \tag{10}$$

which, assuming a direct relationship between travel distance and energy consumption, gives some indication of the aggregate consumption of energy through travel.

Given the data base for Leeds, application of the Lowry model involved an alteration of the transport costs (c_{ij}) and of the travel dispersion parameters (β^W and β^s). Specific interest concentrated on the resulting patterns of activities, remembering that the distribution of basic employment remained fixed throughout.

As was to be expected, uniformly scaling the interaction costs, c_{ij}, for fixed values of β^W and β^s (β^W and β^s equal 0.001), had no effect on the pattern of activities, which is illustrated in Figure 13a for comparison with later results. The resulting configuration was, as to be expected, not altered by proportional increases in transport costs, although, obviously, the total travel cost increased.

The previous analysis can be thought of as an attempt to portray various increases in the cost of travsportation per unit of distance; alternatively, it petrol prices increase, the degree of travel dispersion may decrease. This behavioural feature can be portrayed by increasing the values of β^W and β^S. The two diagrams given in Figure 13 demonstrate the effect of increasing their values. In both these extreme cases, the distribution of basic employment is the same. For β^W and β^S equal to 0.001, service employment is relatively concentrated in the city centre, zone one. Services are still found in the suburbs, but there is very little provision between these two areas. In addition, the population, essentially located in the suburbs, is shown to be away from the zones of basic and service employment. This spatial pattern is to be expected when transports costs are deemed to be relatively unimportant in trip behaviour. This situation, however, is likely to alter as the real price of petrol increases (or if there are supply shortages). Figure 13b depicts a relatively close association between the different activities; it is noted that the total amount of travel is reduced. The actual configuration is, obviously, highly dependent on the original pattern of basic employment.

6.2 *Coelho-Williams Design Model.*

The preceding analysis has many similarities to previous applications of the Lowry model to examine relationships between energy and urban form. It is re-emphasised that no optimisation strategy is incorporated, and the resulting spatial configuration of activities is highly dependent upon the original distribution of basic employment and its sequantial decision-making structure.

Given these comments, it was decided to employ Coehlo and William's (1978) mathemtical programming version of the Lowry model, which optimises the value of a well-defined objective function given a set of well-defined constraints. The model extends the Lowry model, as previously described; the usual iterative procedure (see Figures 8 and 12) can be recognised as a causal sequence in which residential location is dependent on the residential zones' and the transport costs associated with work-trips and service facility location is dependent on their attractiveness and the transport costs associated with shopping trips. The selection of service facilities is, therefore, founded on residential location, yet residential location is independent of accessibility to the service facilities. The Coehlo-Williams model overcomes this restrictive assumption by representing, at the individual level, the joint decision process of residential and service location. Their model, embedding realistic spatial interaction and activity location models, maximises a locational surplus function, which, in the notation of the previous models, is

$$\begin{aligned}\max_{\{\underline{T},\underline{S},\underline{H},\underline{E}^B,\underline{E}^s\}} LS = & -\frac{1}{\beta^W}\sum_{ij} T_{ij}\left(\log\frac{T_{ij}}{H_i}-1\right) - \sum_{ij} T_{ij}\,c_{ij} \\ & -\frac{1}{\beta^s}\sum_{ij} S_{ij}\left(\log\frac{S_{ij}}{W_j}-1\right) - \sum_{ij} S_{ij}\,c_{ij} \qquad (11) \\ & -\sum_i m_i^H H_i - \sum_j m_j^s E_j^s - \sum_j m_j^B E_j^B\end{aligned}$$

subject to the consistency condition,

$$\sum_j T_{ij} - a^{(1)} \sum_j S_{ij} = 0 \qquad (12)$$

the economic base relation,

$$\sum_i T_{ij} - a^{(2)} \sum_i S_{ij} - b^{(2)} E_j^B = 0 \tag{13}$$

the 'market clearing' conditions,

$$\sum_j T_{ij} - a^{(3)} H_i = 0 \tag{14}$$

and

$$\sum_i S_{ij} - a^{(4)} E_j^S = 0 \tag{15}$$

the supply constraint on total basic employment,

$$\sum_{ij} T_{ij} - a^{(2)} \sum_{ij} S_{ij} = b^{(2)} E^B \tag{16}$$

a land-use capacity constraint (L_i) (where δ^H, δ^S and δ^B are density coefficients),

$$\delta^H H_i + \delta^S E_i^S + \delta^B E_i^B < L_i \tag{17}$$

and the non-negativity constraints on the planning and interaction variables (which are now defined in terms of trips),

$$\underline{H} > 0;\ \underline{E}^S > 0;\ \underline{E}^B > 0;\ \underline{T} > 0;\ \underline{S} > 0. \tag{18}$$

"The first four terms in the objective function account for the interaction benefit arising from mutual accessibility of the activities, while the latter three identify disbenefit terms depending on local coordinates. Thus m_i^H represents the marginal cost of establishing housing in zone i". (Coehlo and Williams, 1978, p.80).

Constraint (12) describes the necessary accounting consistency between the residential population predicted through the work trip matrix, T_{ij}, and the service trip matrix, S_{ij}, scaled by the parameter $a^{(1)}$. The economic base foundation of the model, with the basic employment generating the total employment, is portrayed by constraint (13). Constraints (14) and (15) ensure that demand and supply for residential and service facilities are equated; no excess supply or demand is permitted. A supply constraint on basic employment, which, in this model, is optimised and not an exogenous input, is given by equation (16). Constraint (17) ensures land availability for particular activities in zone i is satisfied, and the non-negativity constraints, equation (18), are given in standard vector notation.

This equilibrium, design model seems apposite to examine the issue of an energy efficient urban form. The configuration of basic employment, the fundamental generator of a Lowry model, is, itself, optimally distributed in this model, which optimally locates and allocates the interrelated activities. Moreover, within the objective of maximising locational surplus are encompassed the aims of the urban system's various spatial actors:

<u>Households</u> - maximise access to home-based activities (work and services),

<u>Services.</u> - maximise access to purchase power and minimise site costs,

<u>Sabic Industry</u> - maximise access to the labour force, maximise access to external markets, and minimise set up costs.

Thus, whilst not explicitly concerned with the energy efficiency through the minimisation of transportation costs, this model, maximising a locational surplus welfare function, seems consistent with many of the notions expressed in the first part of the paper; it is interesting to note, however, that when the trip dispersion parameters, β^W and β^s, are infinite, a linear objective function, which minimises total transport costs and establishment costs, is formed. (Note, one possible extension is to assume establishment costs are associated with energy consumption of different buildings and so on).

A series of numerical experiments, using the associated dual formulation because of its dimensional advantages for computation, were undertaken, by varying the values of the dispersion parameter, β^W and β^s (see Figure 14). The β parameters depict a trade-off between transport costs and qualitative spatial choice attributes related to different supply location and goods; transports costs are not a contributor to consumer choice when β equals zero, but as β increases, choices, tastes and other non-transportation factors in consumer behaviour decrease in significance (something which may occur as real petrol prices increase). For β^W and β^s equal to 0.500, service activities are highly concentrated in the city centre, zone one, and, therefore, relatively long trips from the suburbs are required. Some basic employment is found in nearly every zone, although it is significant that none is found in the city center. For comparison, Figure 14b illustrates the configuration for the (linear programming) limit, when β^W and β^s are extremely large (that is, when transport costs are deemed to be very important in travel behaviour). All activities are concentrated along a north-west/south-east corridor, which

> "is a product solely of the spatial characteristics of the transport network. It emphasises the 'all-or-nothing' features of the linear programming approach (see the earlier comments on the other studies), which is expressed even more dramatically in the zero entries of the work and service trip matrices". (Coehlo and Williams, 1977, p.32).

These simple analyses have demonstrated the need for future studies of the relationships between energy consumption and urban form; the results, whilst interesting in themselves, must be seen as introductory and suggestive, rather than as definitive statements.

One recurrent theme of the first part of the paper is the need, when planning for energy conservation, to take account of the present urban infrastructure. However, the models' analyses have primarily excluded this feature. To conclude this section, the formulation of a model which incorporates this fundamental characteristic is stated.

The problem can be thought of as one of ascertaining the spatial configuration of the required increments (positive or negative) in industrial, residential and service facilities, ΔE^B, ΔH and ΔE^S, respectively, which maximises locational surplus subject to a set of adapted constraints. The mathematical programme is

$$\underset{\{\underline{\Delta H},\ \underline{\Delta E}^B,\ \underline{\Delta E}^S,\ \underline{T},\underline{S}\}}{\mathrm{Max}} \quad LS = -\frac{1}{\beta^W}\sum_{ij} T_{ij}\left(\log\frac{T_{ij}}{H_i} - 1\right) - \sum_{ij} T_{ij}c_{ij} - \frac{1}{\beta^S}\sum_{ij} S_{ij}\left(\log\frac{S_{ij}}{W_j} - 1\right) - \sum_{ij} S_{ij}c_{ij} - \sum_i m_i^H \Delta H_i - \sum_j m_j^S \Delta E_j^S - \sum_j m_j^B \Delta E_j^B \tag{19}$$

subject to the consistency condition,

$$\sum_j T_{ij} - a^{(1)}\sum_j S_{ij} = 0 \tag{20}$$

the economic base relation,

$$\sum_i T_{ij} - a^{(2)}\sum_i S_{ij} - b^{(2)}({}^oE_j^B + \Delta E_j^B) = 0 \tag{21}$$

(where ${}^oE_j^B$ is the original distribution of basic employment)

the 'market clearing' conditions,

$$\sum_j T_{ij} - a^{(3)}(\Delta H_i + {}^oH_i) = 0 \tag{22}$$

and

$$\sum_i S_{ij} - a^{(4)}(\Delta E_j^S + {}^oE_j^S) = 0 \qquad (23)$$

(where ${}^oH_i$ and ${}^oE_j^S$ are the original distributions of residences and service employment respectively)

the stock constraints on residences and housing

$$\sum_i \Delta H_i = \Delta H \qquad (24)$$

and

$$\sum_j \Delta E_j^S = \Delta E^S \qquad (25)$$

the supply constraint on total basic employment,

$$\sum_{ij} T_{ij} - a^{(2)} \sum_{ij} S_{ij} = b^2({}^oE_j^B + \Delta E_j^B) \qquad (26)$$

a land use capacity constraint,

$$\delta^H({}^oH_i + \Delta H_i) + \delta^S({}^oE_i^S + \Delta E_i^S) + \delta^B({}^oE_i^B + \Delta E_i^B) < L_i \qquad (27)$$

and the non-negativity conditions on the planning and interaction variables

$$\underline{\Delta H} + {}^o\underline{H} > 0;\ {}^o\underline{E}^S + \underline{\Delta E}^S > 0;\ {}^o\underline{E}^B + \underline{\Delta E}^B > 0;\ \underline{T} > 0;\ \underline{S} > 0. \qquad (28)$$

It is possible to formulate the associated dual program to assist computation (and to attempt to interpret the dual variables), and the results of numerical analyses will be reported in the future (Beaumont, forthcoming).

PART THREE

7. SOME CONCLUDING THOUGHTS.

New developments have necessitated an appreciation of influences which, a decade ago, were rarely addressed by urban planners. The potential shortages of energy in the future means that to disregard the possible serious implications of our lavish utilisation of energy would be unwise. To realise any advance along these lines, direct effort by analysts is required. In many ways, therefore, this paper deliberately set out to raise a number of the issues involved, rather than actually answer them; preliminary and tentative solutions to the problem of designing more energy efficient urban forms are considered. For that reason, description of the various studies demonstrates where the specific approaches succeed, rather than what they fail to achieve, and what particular facets of the problem they incorporate, rather than what they exclude. They all presented some well-founded insights, and their special strengths, plus the informative contrasts rendered, provide a suitable preliminary basis for further examination.

Simply, there has been much indication of an apparent need to manage urban growth, perhaps into a polynucleated configuration. It is one thing to display the possibility of saving energy by proposing structural alterations to urban land-use patterns, it has been shown that it is another thing to consider its practicability. Gilbert and Dajani (1974) asked this fundamental question of how such configurations could be discharged into the future long-term development and redevelopment of urban areas. Whilst such a policy may not have the immediate impact of some measures, such as real petrol price increases, car-pooling, traffic engineering, modal switch, and so on, it has been demonstrated that it is essential to address this long-term problem soundly and comprehensively, and not rush into short-term schemes which only really address the symptons. The shortcomings of inadequate land-use management will increasingly manifest themselves; urban growth, in periods of cheap and abundant energy, quite naturally was not concerned with energy efficiency.

One recurrent notion is that a desire for an energy efficient urban form will strenthen present decentralisation tendencies. The multi-centred spatial pattern, comprising of a hierarchy of different sized centres, has a number of advantages and disadvantages. Suggested advantages include compatibility with market trends, and general notions of functional self-sufficiency and urbanity. Specifically assuming that alterations in residential and work locations result in their closer proximity, aggregate travel requirements, and therefore energy consumption, will fall. With respect to equity, residential relocation may present the opportunity to dissolve the inner-city concentration of low-income households. The generation of value from the development of the outer centres could subsidise this household dispersion. Whilst such propensities may help ameliorate inner city problems, planners must also be aware that they may offer a danger to a continued functioning of the city centre (Weiss and Burby, 1976). Perhaps more fundamental is the planning operability of such a venture; the large spatially-contagious areas required for such developments are not a natural outgrowth of a large number of owners of small pieces of land. In fact,

> "The general lack of an organised, effective and vocal constituency for the polycentric concept has been largely responsible for its relative lack of priority and study", (Schneider, 1978, p.43).

The main issue with regard to urban spatial and functional form relates to the incompatibility of an environment which has grown up during a period of cheap and plentiful energy supplies. How can an energy efficient urban form be approached given the existing infrastructure?

Some redirection is essential. Whilst all the studies are concerned with the aversion of a possible lasting crisis, analysis is not expressed in such terms, being seen as only a slight modification of the present. At the outset, the employment of well-tried techniques, such as linear programming, is perhaps natural, yet, disappointingly, there is little indication of a desire to cnsider new representations, which could offer important and original insights. Such a conceptualisation cannot accommodate technological innovation, for example; the fallibility of picturing a new means, such as telecommunication, to execute an old task has already been demonstrated in a previous paper (Beaumont, 1979). It is of paramount importance to break-away from the outlook unrealistically portraying the inertia of the present. It will be tempting fate to plan to permit present tendencies. Diminishing returns on energy exerted on further refinements are likely, and it appears that a re-orientation of approach is due. It is rather ironic that the relative significance of transport costs in location theory could actually increase again, and, more fundamentally, it is necessary to extend the view, incorporating concepts such as equity and justice, to enable the explicit consideration of ideology. Such re-orientation stems from a general humanistic anxiety over the future 'quality of like' for individuals, a feature accentuated by our reliance on energy.

If the necessary planning is not forthcoming, existing choices will gradually disappear until urban form, specifically, and the functioning of space-economy, generally, have to alter through necessity; individual attempts to conserve energy, without comprehensive and coordinated planning, will not, by themselves, result in a more energy efficient urban form.

Interestingly, in the foreword of the book, 'A World of Scarcities: Critical Issues in Public Policy', Novick (1976) argues that,

> "The shortage is really in man's ideas and planning rather than the physical limits of non-renewable resources of our globe".

To some extent, at least at present, the problem of energy resources is political, economic and social, rather than physical.

Given the speculations on what constitutes an energy efficient urban form, it still remains to ask whether the suggested alterations to the existing land-use planning framework are both politically and publically acceptable - ultimately, it is a political decision. It seems inevitable that the role and responsibility of the government, both central and local, should be emphasised. Land-use planning is an example of state intervention, the need for which can be interpreted as a reflection of the inherent contradictions in the capitalist mode of production. Land-use planning, therefore, can be thought of as an ameliorating meduim which irons out conflicts as they arise (Scott and Roweis, 1977), although it does not reduce the embedded, antithetic tendency that,

> "... the contradition with 'nature' ... inevitably arises out of the relation between the dynamics of accumulation and the 'natural' resource base as it is defined in capitalist terms" (Harvey, 1978, p.103).

One feature, which becomes increasingly apparent with more detailed analysis, is that different (and sounder) viewpoints accrue with regard to policy formulation. It shines through the reviewed studies that efficiency in energy utilisation is not inexorably concordant with other socio-economic objectives. Such disharmony may hinder the pursuance of energy conservation, *per se*, but with foresighted planning it should be possible to ensure that

> "Energy conservation is an area where energy policies and wider social and economic policies can be advanced simultaneously" (H.M.S.O., 1978, p.23).

Thus, it is not sufficient to solely address energy; analysts must broaden the perspective of their models.

Therefore, this paper's isolated discussion of relationships between energy consumption and land-use-transportation systems is, of course, an over-simplification; the development of urban form is also one feature of a much wider topic, the future urban environment. In fact, by itself, any desire to conserve energy is unlikely to offer a reason for alterations in land-use policies. Energy conservation is important and this must be explicitly recognised by planners, but compromises will probably have to be made. Indeed, whilst energy conservation through land-use policies should not be discouraged, particularly as it is also likely to reduce congestion, ameliorate environmental impacts of transport, and improve accessibility, it is only one approach. Moreover, because of the complexities involved, there is the need for forther research to examine the direct and indirect consequences. Actually, there is a general need for energy research to examine social ramifications as well as technological aspects. For instance, any analysis of the possible land use changes resulting from a telecommunications-transportation trade-off must include its broader social, economic and political facets (Beaumont, 1979a). The discussion has illustrated the significance of both the notions - efficiency and equity. Inequality is viewed as more than variations in income level; the opportunities for consumption must also be included.

Finally, although concerned with long-term effects, it would be unwise to be complacent today. Whilst specific details of the future situation are, obviously, highly uncertain, there seems no doubt that increases in the real price of energy (and perhaps rationing) will arrive, and, therefore, we would be advised to examine the issues further to enable improved preparedness.

Given the long time-lags associated with land-use planning, purposeful action, explicitly considering energy consumption, must commence now. It is a sobering thought that it seems likely that no strong commitment will be forthcoming, and that the urban environment will be largely left open to the vagaries of the market mechanism and geopolitics.

The present paper has only touched the surface of the problem, and it is unclear, without more extensive research, what the impending impacts really are. There is an obvious need to attain efficient energy use in the context of various urban forms, and a greater comprehension of the relationship between energy and urban form would be of enormous assistance in the planning of the structure of future cities.

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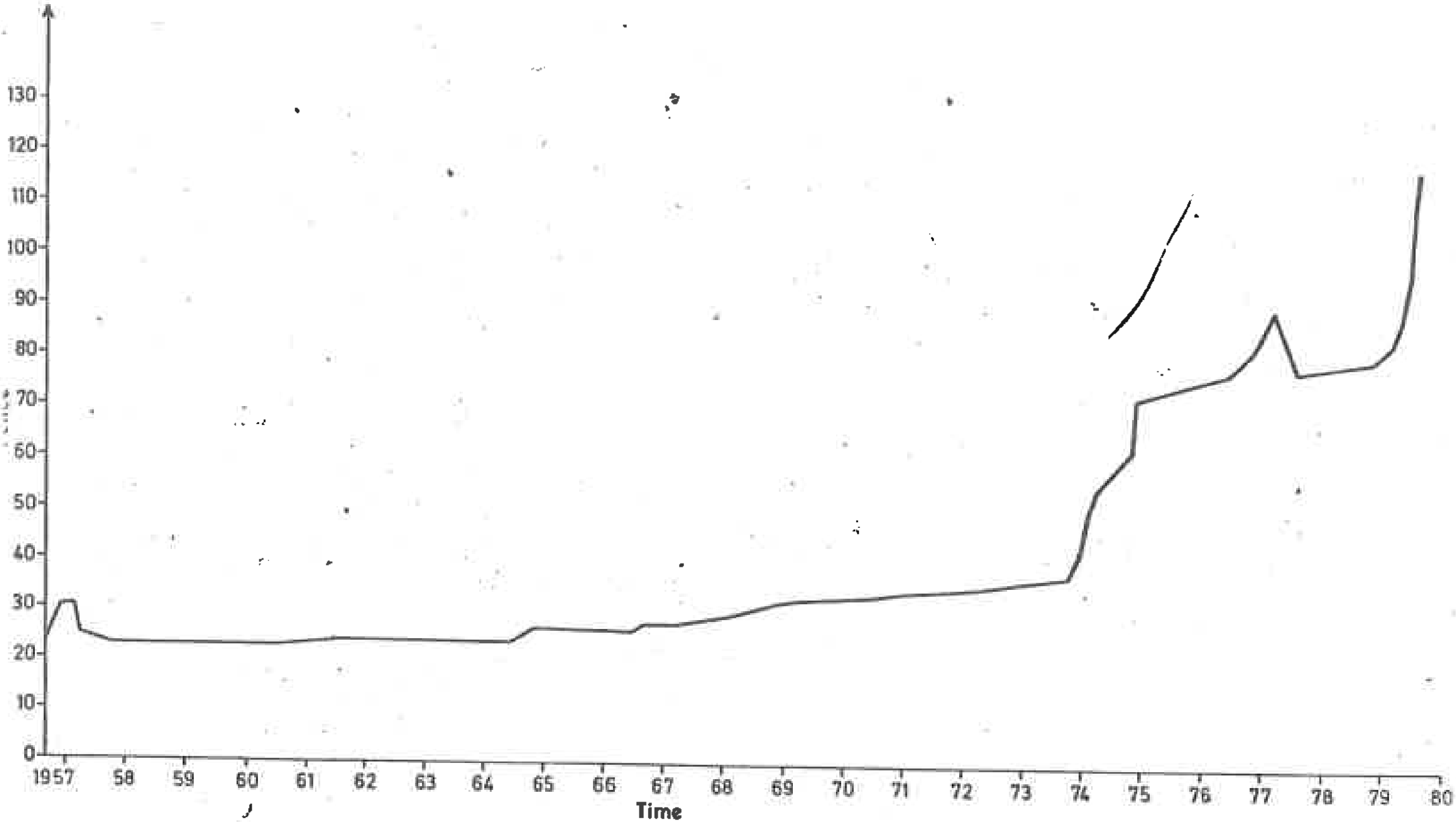
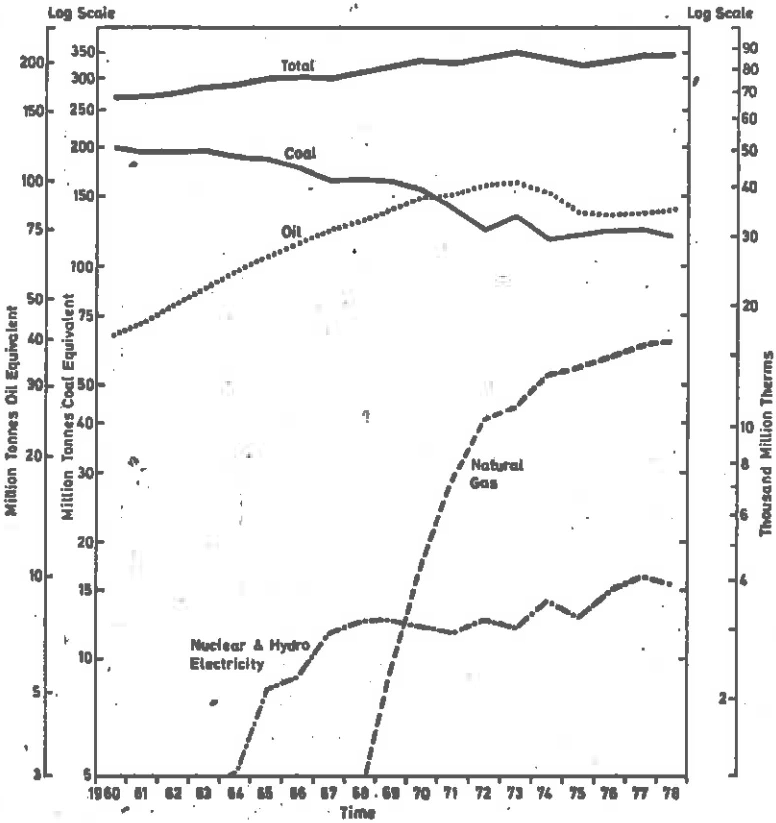
Figure 1: Petrol Pump Prices



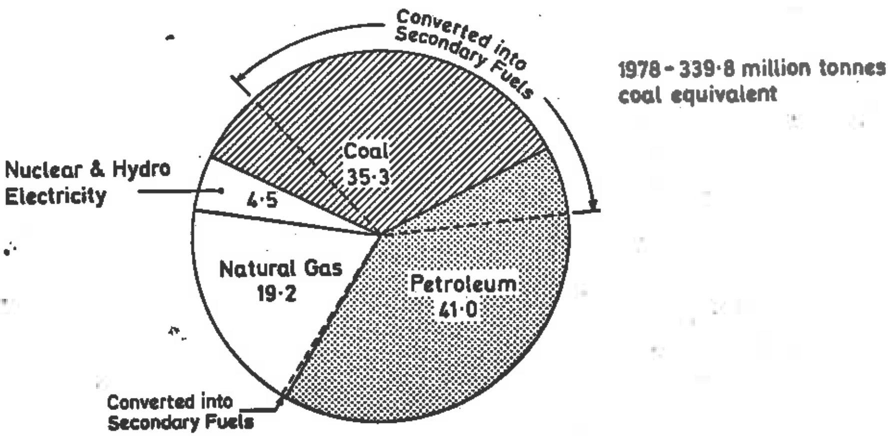
(Source : Institute of Petroleum)

Figure 2a : Energy Consumption in the United Kingdom - 1968-1978



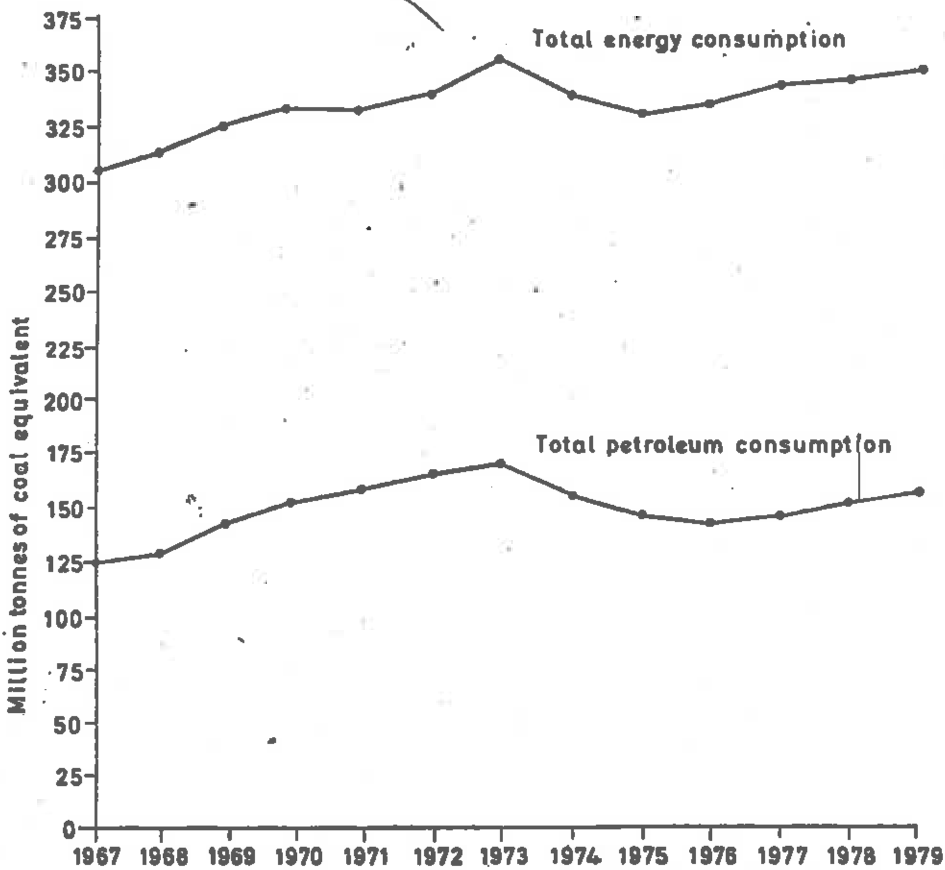
(Source : U.K. Digest of Energy Statistics 1979)

Figure 2b : Total Consumption of Primary Fuels in the United Kingdom - 1978



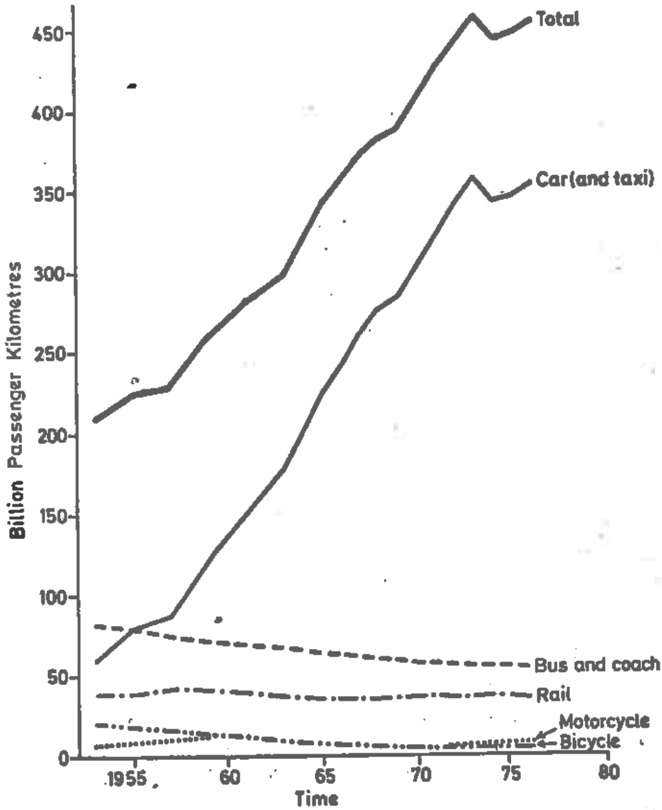
(Source : U.K. Digest of Energy Statistics 1979)

Fig.3. Annual total energy and petroleum consumption in the United Kingdom, 1967 – 1979



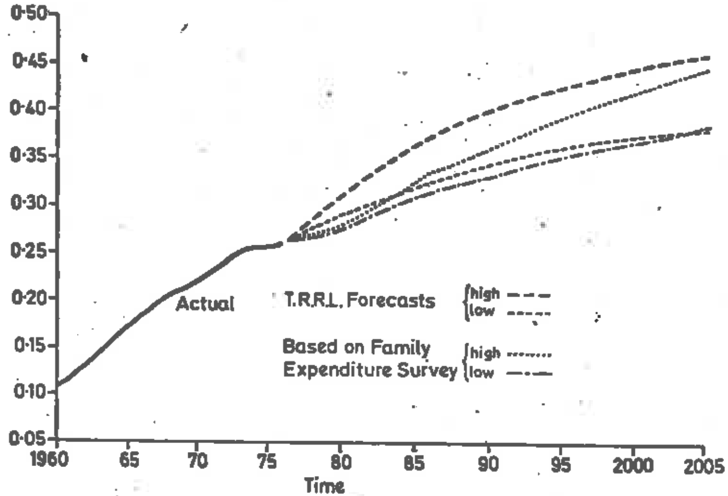
Source: U.K. Digest of Energy Statistics 1979

Figure 4: Passenger traffic in Great Britain -1953 -1976



(Source: Leach, et al., 1979)

Figure 5 : Cars per person, U.K. 1960-2005



(Source : Giles & Worsley, 1979)

Fig. 6: A comparison between personal disposable income and petrol price indexes – 1964–1979

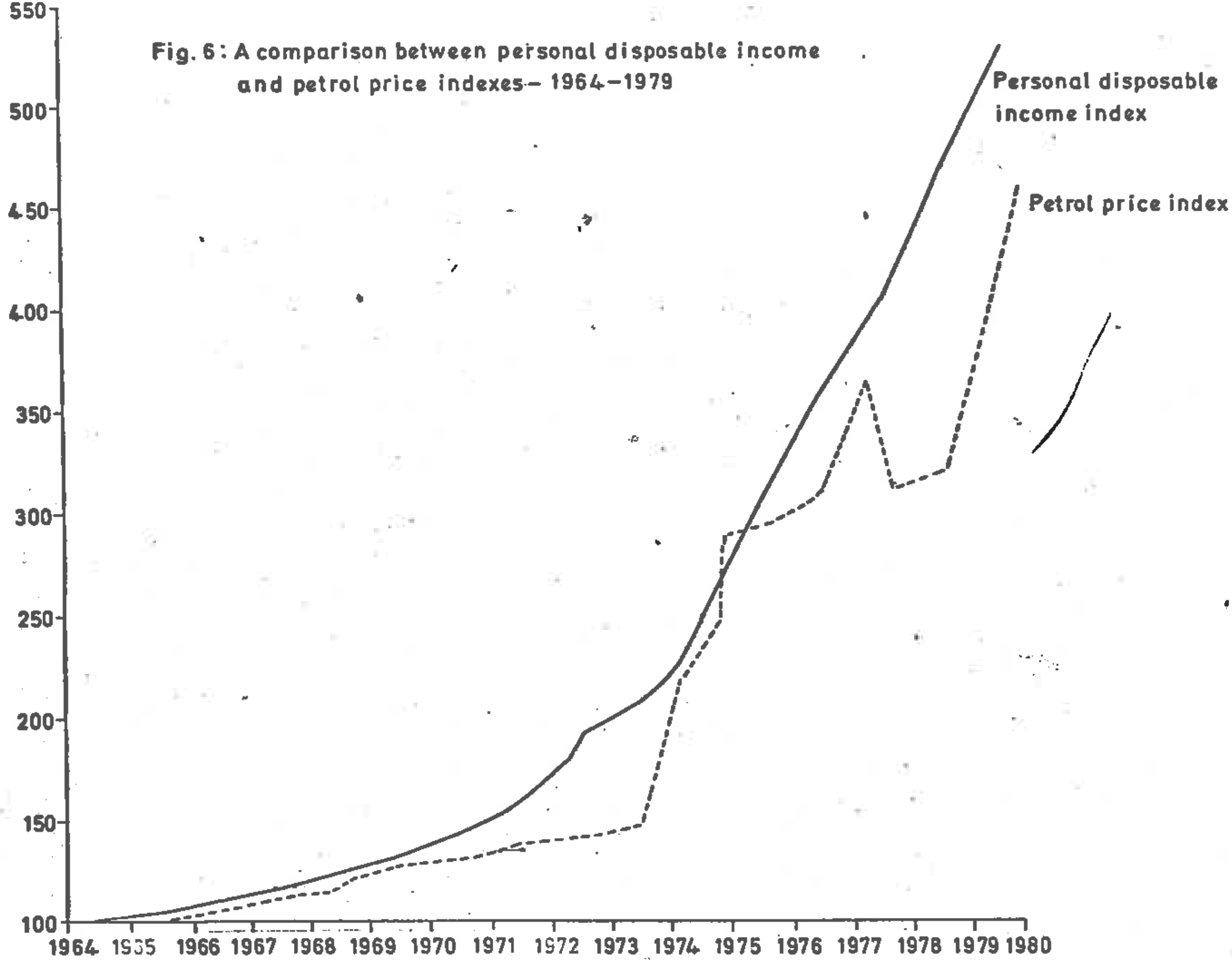


Fig. 7: Private road passenger transport–1967–1977

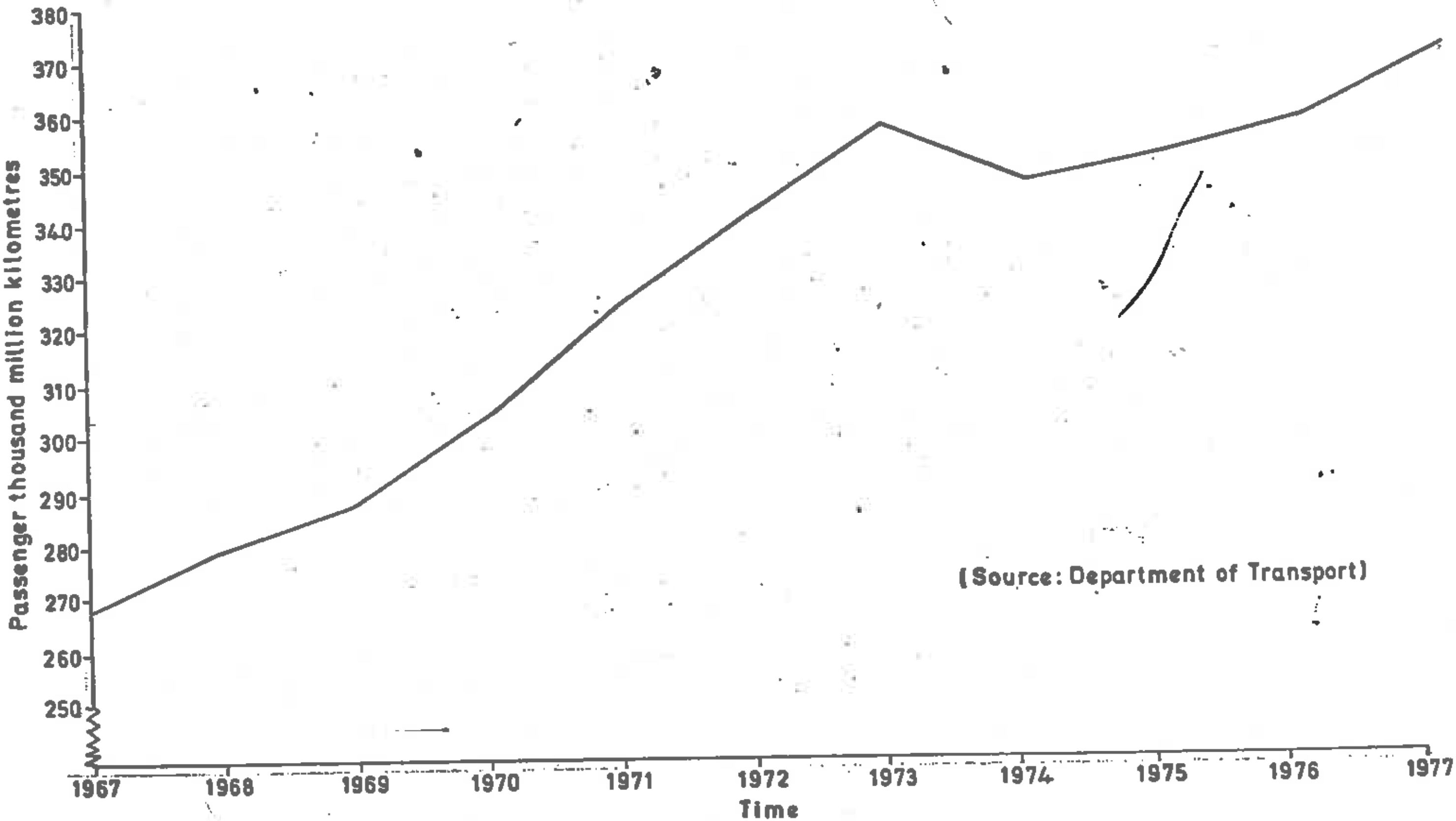


Figure 8: Functional Structure of The Lowry Model

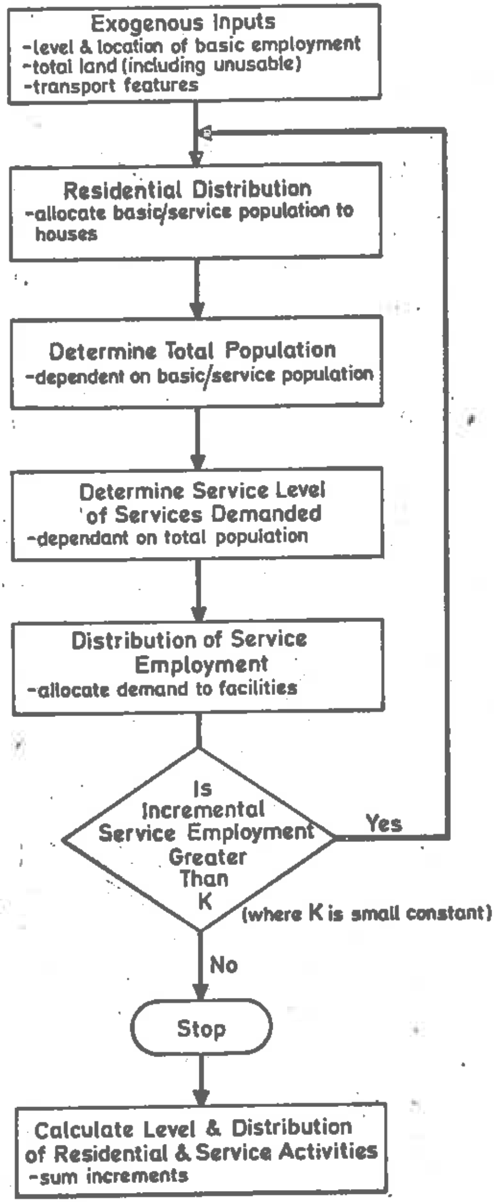
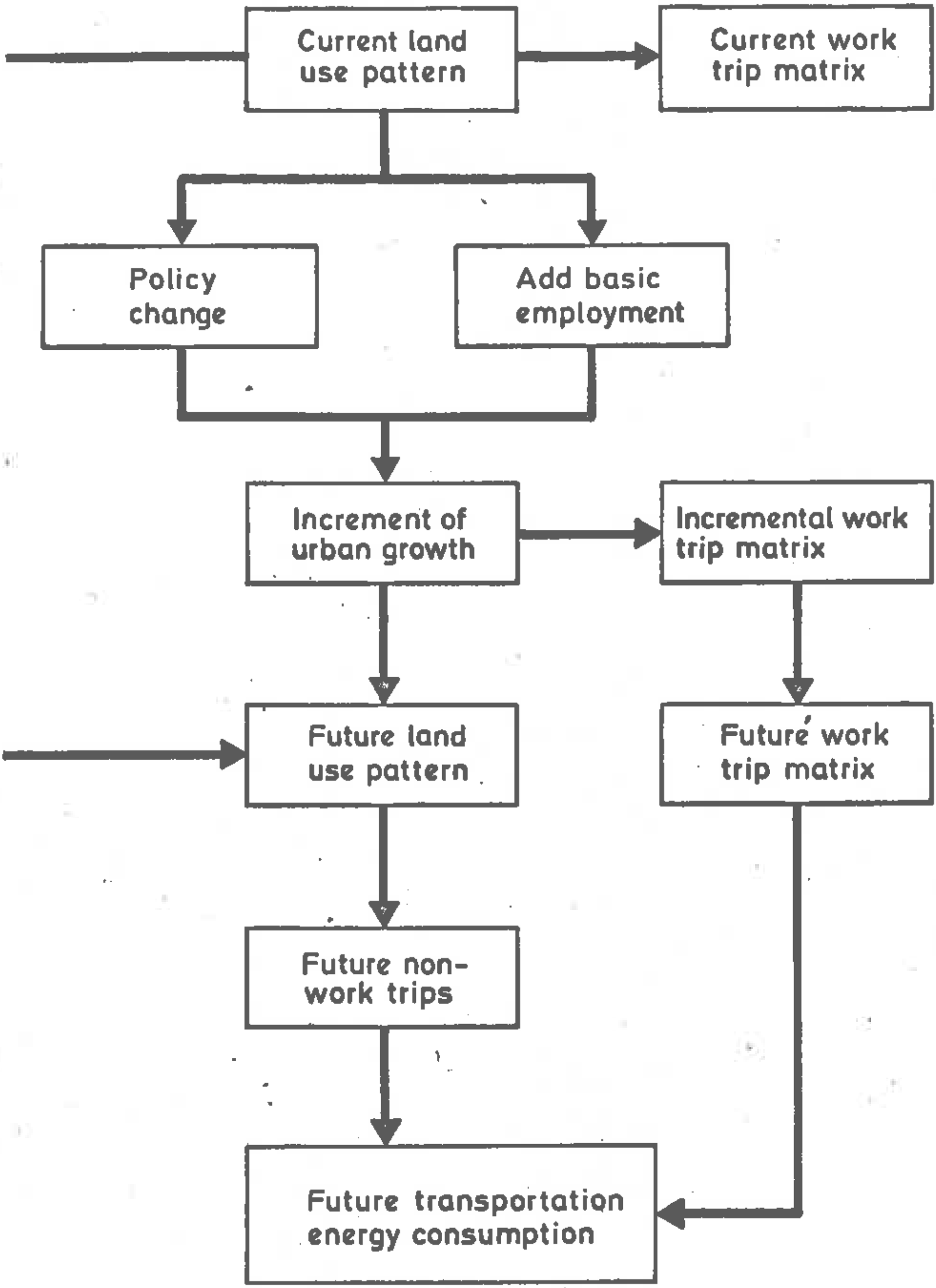
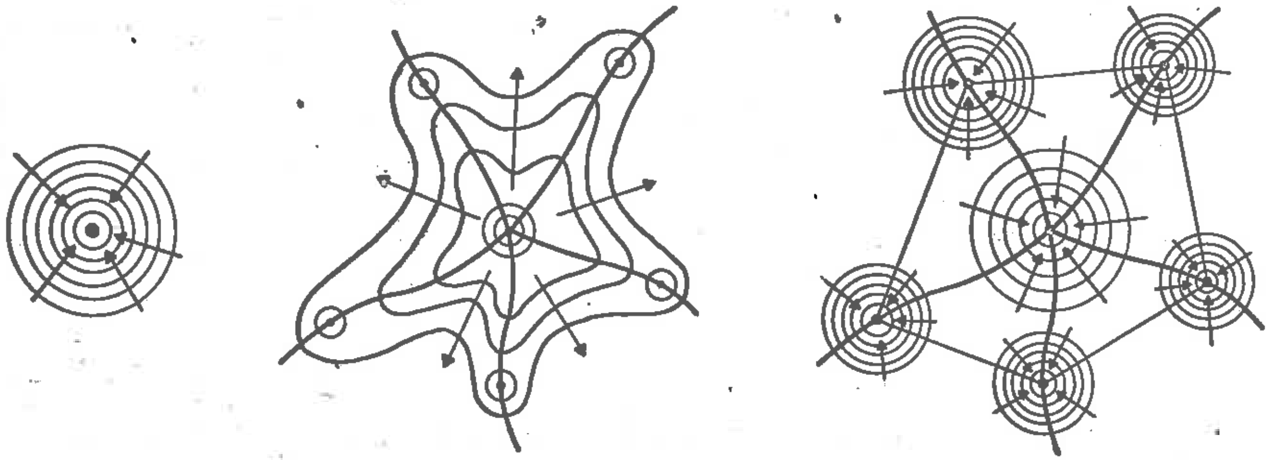


Figure 9: A Dynamic Incremental Simulation Model



Source: (Peskin and Schofer, 1976)

Fig. 10: Stages in the development of the city



(Source : Romanos 1978)

Figure 11: Zonal System for Leeds

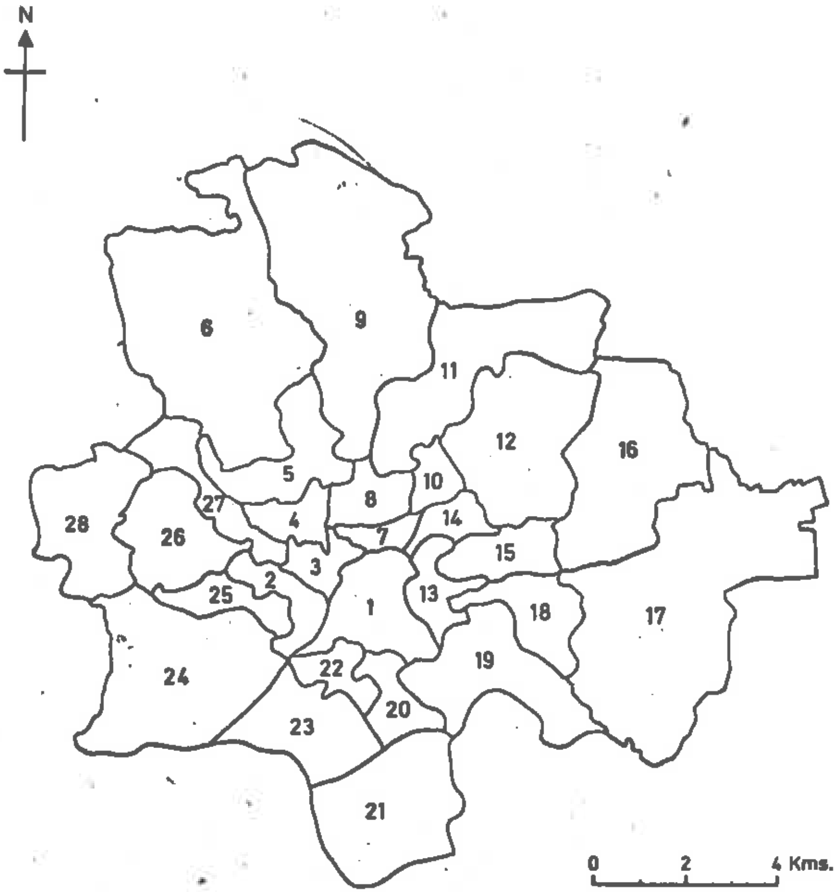


Figure 12: The Lowry Model - Relationships between the Equations

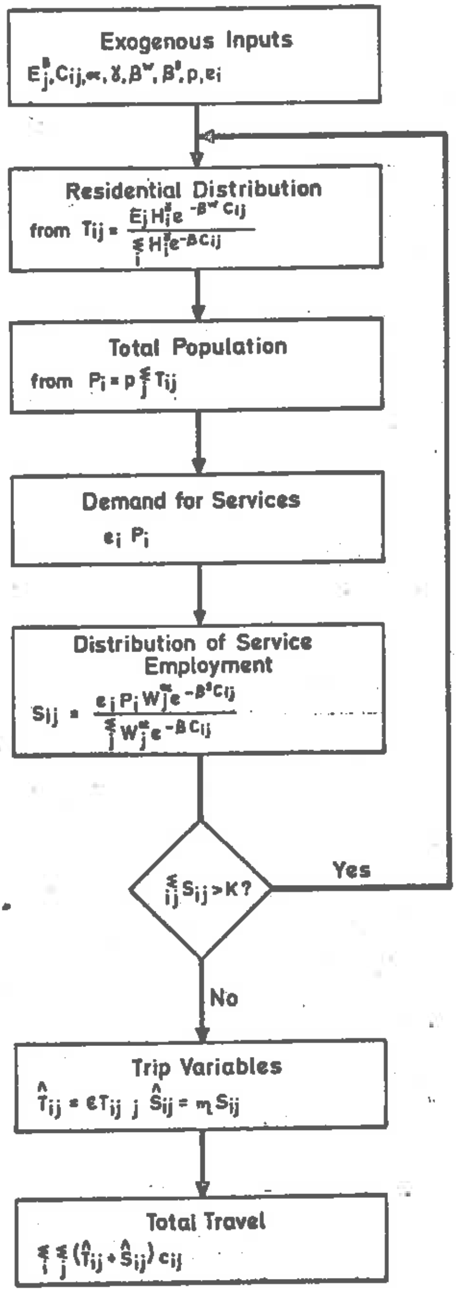
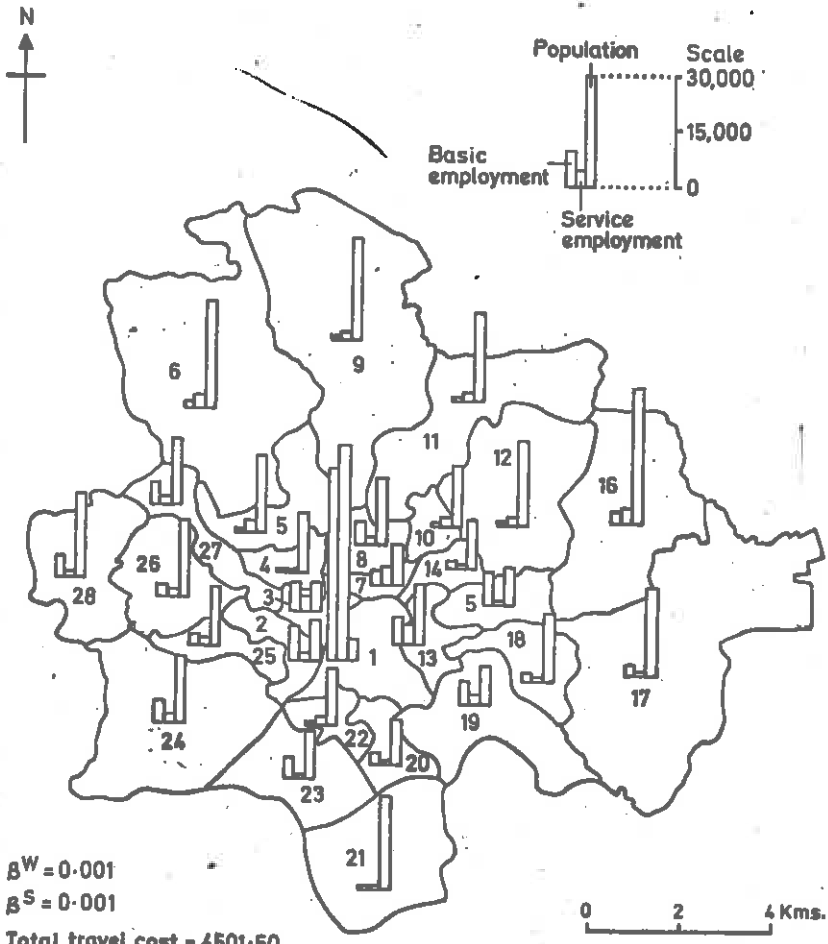


Figure 13a : Leeds-Lowry Model

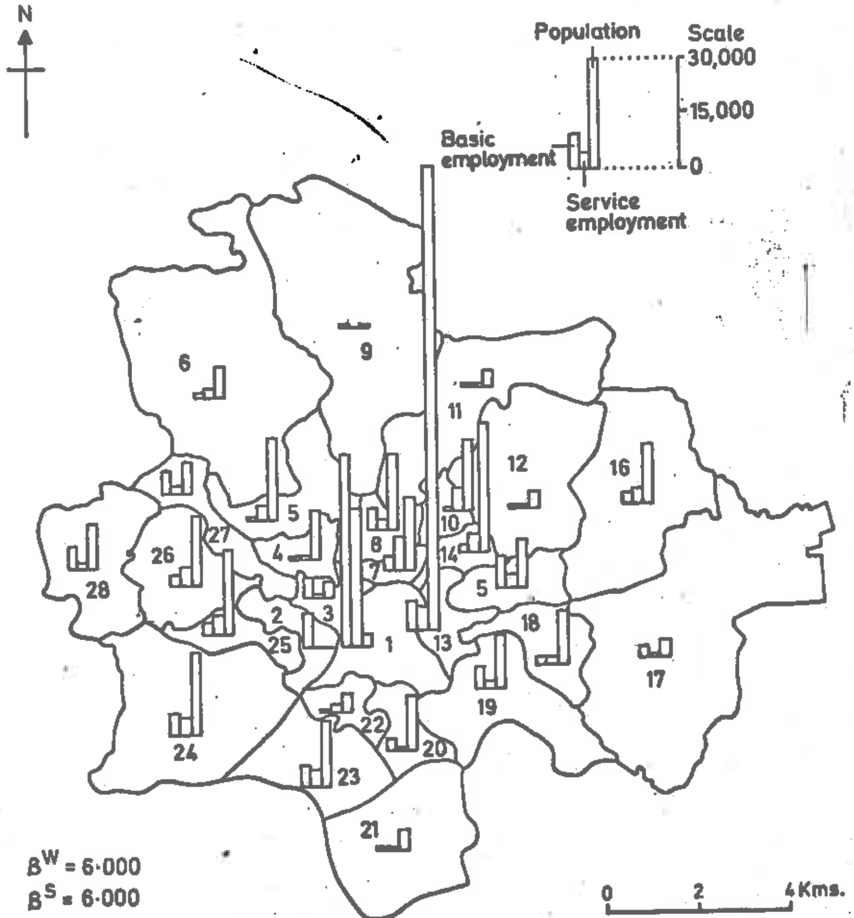


$\beta^W = 0{\cdot}001$

$\beta^S = 0{\cdot}001$

Total travel cost = 4501·50

Figure 13b : Leeds - Lowry Model

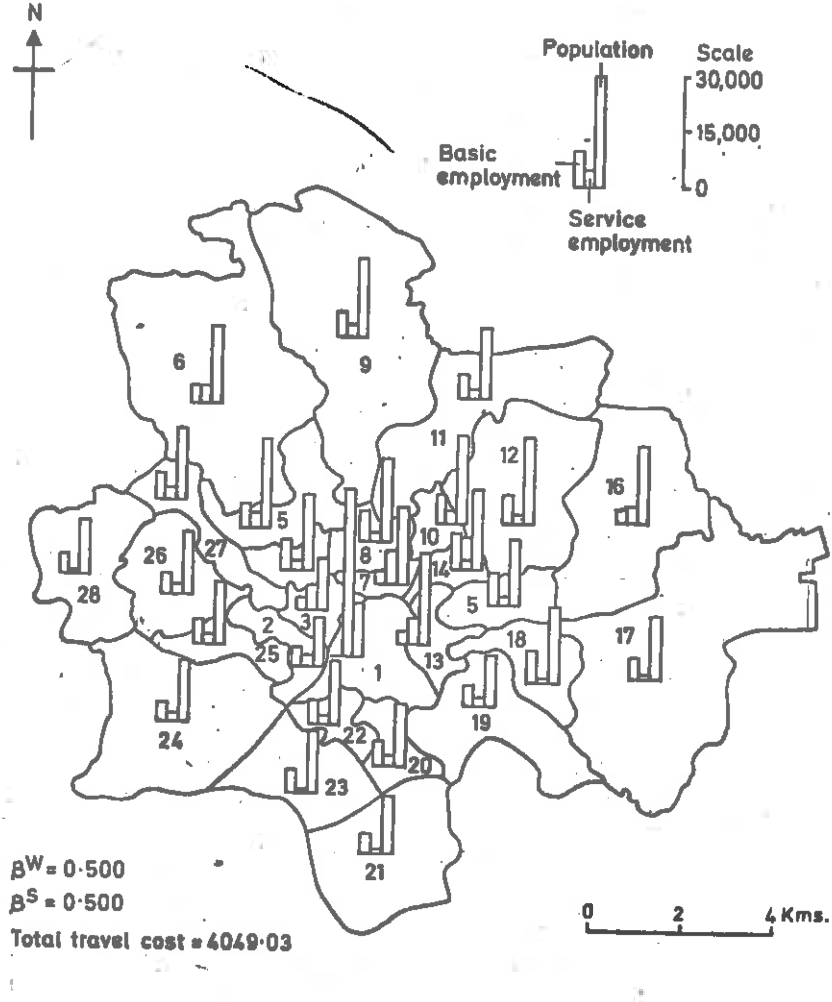


$\beta^W = 6{\cdot}000$

$\beta^S = 6{\cdot}000$

Total travel cost = 2772·27

Figure 14a : Leeds - Design Model

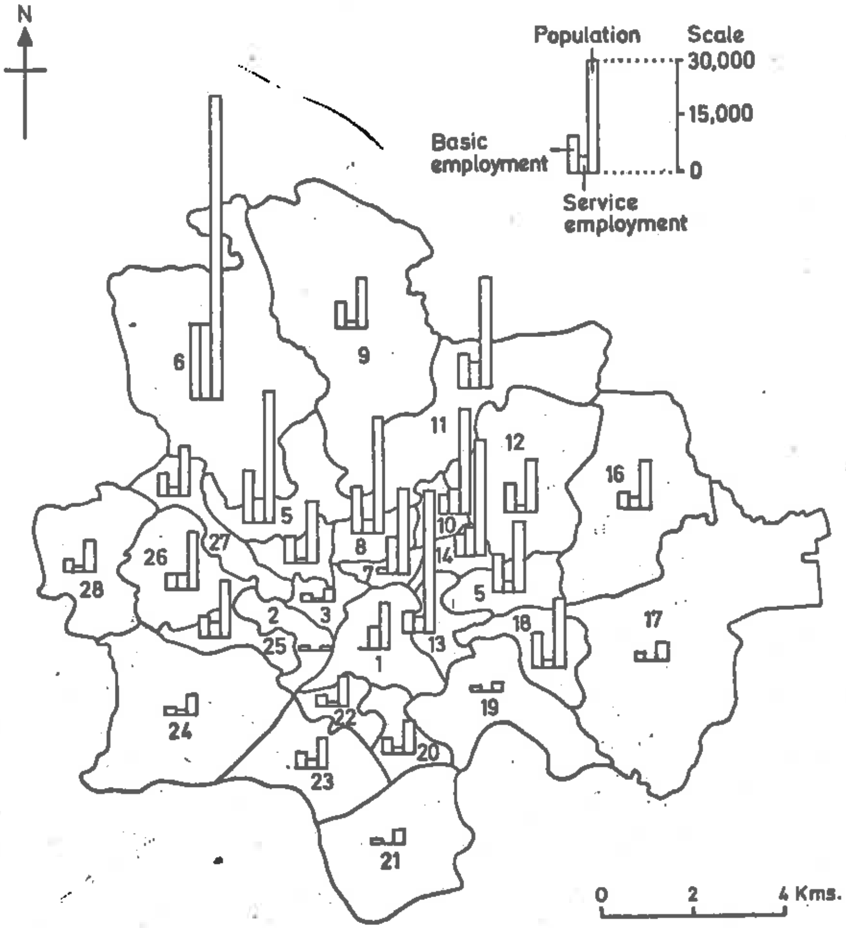


$\beta^W = 0{\cdot}500$

$\beta^S = 0{\cdot}500$

Total travel cost = 4049·03

Figure 14b : Leeds - Design Model



(Source : Coehlo & Williams, 1977)