models in planning: a case study of the region of Athens

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introduction

The main object of this study is to present the result of a run that the Land Use Built Form Studies model produced for the region of Athens. The model has been tested for several years in the centre for LUBFS in Cambridge and has been proved to be a useful tool for the simulation of cause and effect relationships of urban areas. It was felt that its application to the metropolitan area of Athens could provide a useful planning aid for politicians and planners in the decision making process.

The paper is divided into four main parts:
Part One contains a review of the existing literature under the headings of scientific planning, systems theory, and mathematical models.
Part two gives a comprehensive account of the Land Use Built Form Studies Model.
Part three reproduces the application of the model to the metropolitan area of Athens using 1971 data. In the same section, as well as the brief description of the area, there is a full account of the various data sources necessary for the run.
Part four consists of the outputs of the model given in the form of computer print-out.

I. review of the current literature

a. *Planning*

Planning is an extremely ambiguous and difficult word to define. Professional planners are involved with diverse topics in different fields.

Definitions of the word «planning» provide one clue to the confusion. The Concise Oxford Dictionary and the American Webster define the noun «plan» as either «the way of showing or representing something», for instance, «a drawing», «a diagram», «a detailed map of a town or district» or «a method of doing something». To define the verb «to plan», the same dictionaries suggest either «to arrange the parts of», «to have in mind», or «to design». These definitions can include many different human activities, if not all of them. In short, the concept of planning seems to be «all things to all men».

We are concerned with urban and regional planning, or as it is alternatively called, town and country planning. Referring to urban or town and country planning is a tautology. They both deal with the arrangement of human activities on the land available. Many authors refer to them with the common name of physical or spatial planning.

In England, although this activity existed from the earlier years, its actual name first formally appears with the «1909 Housing and Town Planning Act». John Burns, the president of the Local Government Board, summarized the act: «The object of the Bill is to provide a domestic condition for the people in which their physical health, their morals, their character and their whole social condition can be improved by what we hope to secure in this Bill. The Bill aims in broad outline at, and hopes to secure, the home healthy, the house beautiful, the town pleasant, the city dignified and the suburb salubrious» (Parliamentary debates 1908).

Even though this act is similar to the nineteenth century Public Health legislation, it contains the first attempt to control the use of land.

In the following years and until after World War II, physical planning went through different stages. However, it had a consistent output of very precise large-scale maps, which showed the exact disposition of all land uses activities and proposed developments.

The classic sequence taught to all planning students was based on a survey-analysis-plan process. First, the planner surveyed the study area collecting all the information. He then analysed the information available and tried to project it as far as possible in order to foresee the future changes and developments. Finally he planned, utilizing his surveys and analysis which sought to harness and control the trends of development.

After World War II and with the introduction in planning of sociology, economics and management, there was a tendency to abstract the urban problems. No more detailed maps were necessary. Planning had to be concentrated more on «board principles» than on details.

Sociologists are inverstigating the needs of people at a marco and micro level. They analyse the changing social structure of the population, the work mobility of different groups, the family structure in relation to income, age or educational background, all of which are related to the changes that affect the spatial structure of cities or regions.

Economists are generally concerned with the progress of the economic structure of a region. They analyse the effects that changes in occupations, ways of production of goods and services and problems of exchange, have on space.

The management approach to planning is mainly concerned with the decision-making process borrowing concepts from philosophy, politics, economics or sociology.

After 1960 and with the introduction of large scale computers into management and planning there was a rising interest in sophisticated control systems. The new emphasis on fields of rational decision making and control in planning appeared with the introduction of disciplines such as cybernetics, operation research, systems analysis or statistics.

b. *Operation Research*

Chadwick defines O.R. as «the application of scientific knowledge to business and industrial organisation, involving cybernetics and systems analysis (Chadwick 1971).

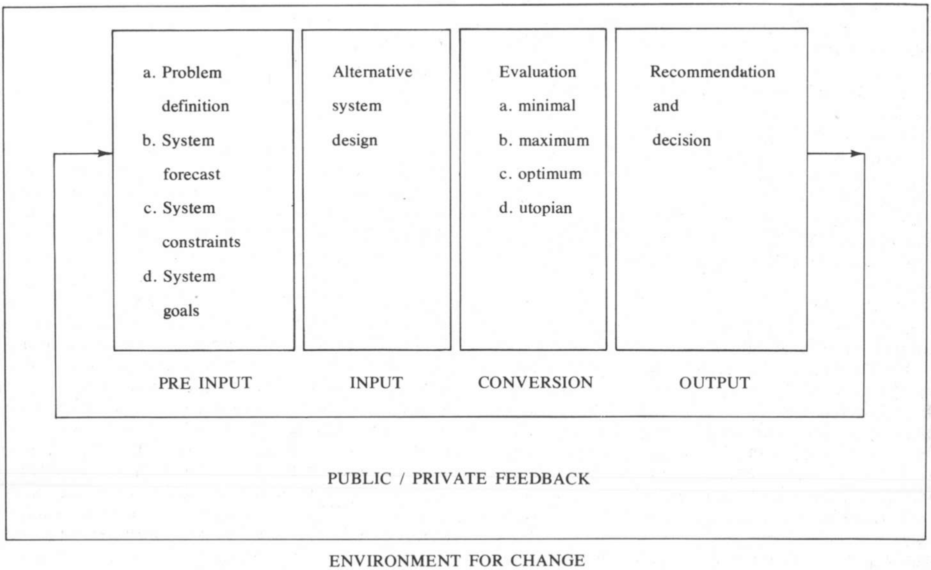
Similarly Beer (1966) suggests that: «O.R. is the attack of modern science on complex problems arising in the direction and management of large systems of men, machines, materials and money in industry business, government and defence. Its distinctive approach is to develop a scientific model of system, incorporating measures of factors such as, change and risk, with which to predict and compare the outcome of alternative decisions, strategies and controls».

Basically, as Page (1960) points out, «O.R. by its very nature is the application of all forms of human knowledge to the solution of a 'whole' problem». Everything goes in an O.R. study as soon as its purpose is «the optimization of the performance of a system».

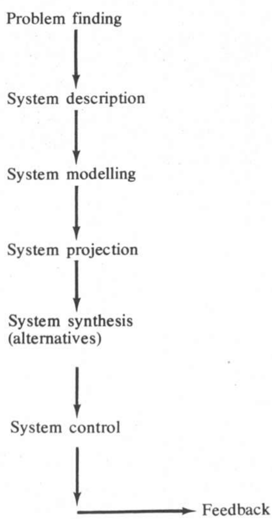
c. *Systems*

The modern systems theory originated around 1920 with the concept of «mechanistic reductionism» in biology. According to this theory, life can be understood only when it is reduced to chemistry or physics. Ludwig von Bertalanffy describes general system theory as «a logico-mathematical discipline, the subject matter of which is the formulation and derivation of those principles which hold for systems in general. A «system» can be defined as complex of elements standing in interaction. These are general principles holding for systems, irrespective of the nature of the component elements and of the relations of forces between them» (L. von Bertalanffy 1968).

In human sciences the idea of the system has been centrally located for forty years now. Morris Cohen (1969) writes that, «ordinary, pre-scientific, or common-sense knowledge is disconnected fragmentary, and chaotic or illogical. Science is devoted to the ideal of system in which these defects are to be overcome. Indeed, instead of saying that system is a characteristic of science like certainty, evidence, and proof definiteness and accuracy, or abstract universality and necessity, *The Systemic Planning Process*



This procedure is fairly similar to the one proposed by Chadwick (1971) summarized as follow:



we may well maintain that the one essential trait of developed science is system and that all these other traits are incidental to it». He then points out that there are three main traits for scientific systems: interconnectedness of parts, completeness, and logical order. The concept of systems was introduced in planning in recent years. Chadwick (1971) defines systems as «complex whole», or «a set of connected things or parts, a department of knowledge or belief considered as an organized whole».

Every system has a structural configuration (arrangement of its components parts) and performs certain functions. It can include different subsystems the number of which depend on the relationships between certain parts.

There are different ways of classifying systems according to the factors taken into consideration.

Taking into consideration their relationships with the environment we can classify them into «open», the ones not isolated from their environment, and «close» having only a few relationships with their environment.

According to the way that their components are expressed, there is a distinction between «real», including material entities and existing in real space, and conceptuals having concepts as components.

The degree and kind of human involvement provide another classification into «mechanistic», where the human element is confined to the choice of system composition, and «adaptive» or «variable utilization», in which humans are making the modification in the operation of the system in a non-mechanistic way.

Whether systems are real or conceptual Chadwick suggests that one can regard them as: «having a structure or morphologie (i.e. being), undergoing internal (endogenous), changes in time (behaving), undergoing irreversible external (exogenous) changes in time (becoming)».

Catanese and Steiss (1968) analyse the systemic planning process, and suggest that it can be structured in seven phases visualized in the diagram of page 143.

d. *Urban System*

So far, we made an attempt to describe the basic characteristics of systems giving different definitions and possible disaggregation between them. The necessity of this brief overview lies on the existing relationship between systems and the urban structure.

In the after war period there is a growing feeling between planners that the only way to better understand and resolve the very complicated problems of our cities is by mathematical models. In doing so the urban structure has to be considered as a system of interrelated factors. Any change occurring in one of the variables of the system affects all the others. As Perraton (1972) points out, «The new systems aprroach to planning makes difficult demands upon planners requiring them to rethink many traditional policies and procedures. It also demands that they should have a greater understanding of how the urban system works and a better technology to aid them in simulating that system and in forecasting the probable results of different courses of action, so that they may decide which is the most likely to promote chosen objectives».

The following diagram shows the levels of resolution of the urban system suggested by LUBFS planning group in Cambridge.

At the first level of the pyramid there is the urban system.

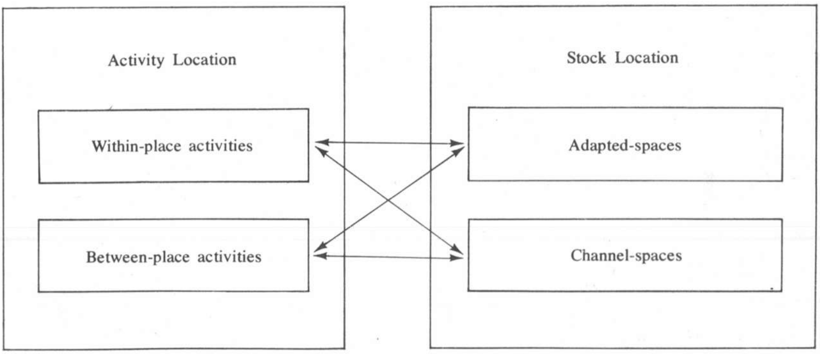
At the second level, the urban system is disaggregated into activities and stocks. Activities are all human tasks, such as, working, travelling,

Urban System

Activities		Stocks	
Within Place	Between Place	Adapted Spaces	Channel Spaces
Basic employment	Journeys to work	Land	Transportation
Service employment	Journeys to services	Floorspace	Network
Residential population			

residing, etc. Stocks are all the infrastructure which contains these activities, such as, houses, roads, shops, offices. There is a basic supply-demand relationship between stocks and activities. Man's activities demand stocks of physical infrastructure to accommodate them, which once built restrict the location of activities. The reason being that while activities can easily change in time, it is very difficult for stocks to change. For example, it is easy to change an apartment into an office (residing into working activity) but when a road network is built its life span is going to be shorter or longer depending on the economic conditions of the country we refer to.

At the third level, activities are disaggregated into within-place and between-place; stocks are divided into adapted-spaces and channel-spaces. The following diagram shows the relations existing at this level:



The theoretical basis of this diagram are to be found in the work of Chapin (1965), Foley (1964) and Webber (1964).

Chapin introduces the concept that man is always involved in either within-place or between-place activities. The first relates to localised activities, such as, industrial, residential or commercial while the second represents the flows occurring between them of information, money, goods and people.

Man's activities demand stocks of physical infrastructure to accommodate them. Foley and Webber suggest that there are two kinds of stocks: adapted-spaces, representing buildings or land that accommodates within-place activities and communication network that include the between-place activities.

The next level of resolution involves eight elements of the spatial system. The within-place activities are subdivided into basic and service employment and residential population. Garner (1962) defines basic employment as «the proportion of the total labour in any town which is directly concerned with the production of goods for export. These are called basic or city forming workers because their efforts bring money into the town thereby enabling the purchase of raw materials, food and manufacturing goods which the town can not produce for itself. The remaining workers can be considered as non basic or city serving since their primary role is to service the basic sector».

The between-place activities are subdivided into journeys to work and journeys to services, which represent the relationship between the within-place activities.

At the same level, adapted-spaces are distinguished into land and floorspace.

The channel-spaces are interpreted with the transportation network. Further disaggregation is possible introducing for instance different types of basic employment or distinguishing the means of transport.

e. *Models*

At this point we would like to introduce the concept of a model: «it can be considered as a theory or a law or a hypothesis or a structural idea. It can be a role, a relation or an equation». Skilling (1964).

Conventionally the term «model» is employed to indicate: «as a noun, implying a representation, as an adjective, implying a degree of perfection, or as a verb, implying to demonstrate or show what something is like». Ackoff, Cupta and Minas (1962).

A model is a representation of reality as perceived by the model builder according to certain purposes.

«It is usually a simplified and generalized statement of what seem to be the most important characteristics of a real world situation; it is an abstraction from reality which is used to gain conceptual clarity, to reduce the variety and complexity of the real world to a level we can understand and clearly specify. The value of a model is that it can be used to improve our understanding of the ways in which a system behaves in circumstances where it is not possible (for technical, economic, political, or moral reasons) to construct or experiment with the real world situation.» Lee (1973).

Models have been use in all branches of research going from history and economics to biology and physics, to mathematics and social sciences, to geography and planning.

Because of this vast and extensive use, it is very difficult to classify models without a degree of ambiguity.

Haggett and Clorley (1967) suggest that one classification can lie between «descriptive» expressing a «stylistic description of reality» and «normative being the expected reaction of a system under certain stated conditions». Descriptive models can be static, concentrating on equilibrium structural features, or dynamic, concentrating on processes and functions through time. The same authors suggest another classification according «to the stuff they are made of», into, firstly, «hardware, physikal or experimental constructions» and secondly, into «theoretical, symbolic, conceptual or mental».

Ackoff, Cupta and Minas classified the first of them into «iconic wherein the relevant properties of the real world are represented in the same way with only a change in the scale or analogue having real world properties represented in different properties».

Rosenblueth and Weiner (1945) distinguish the second into «verbal or mathematical». The latter of them can be further subdivided into «deterministic and stochastic».

When discussing models, Chadwick proposed that the main concerns fundamental to the model builder are:

1. The level of aggregation of the phenomena taken as the basis for the model meaning that the model-builder has to make an initial choice about the dimension of the «systemic behaviour»; whether he will focus on a «large systemic behaviour», macro-analysis, or a rather «individualistic one», micro-analysis.

The macro-analytic or social-physics approach is well known in fields like geography, economics, and planning. It looks at the urban phenomena «in aggregate» and focuses on mass behaviour. Relevant examples of this approach started with Carey's «general gravitational theory» (1958), Ravenstein's first «migration model» (1885) revised by Carrother (1956) and Olsson (1965); Reilly's first «retail location model» (1931) which was followed by the introduction of «multicentrity» by Huff (1962) and Hansen's «market potential model» (1965). In the same classification we can include the most recent work starting with Clark's «law of density» (1959) and Lowry's «model of metropolis» (1964) which was extended by Batty (1969) and the Cambridge LUBFS group.

The micro-scale or behaviouristic approach uses classical economic theory to explain the urban structure. According to this approach the world can be understood «through the mechanism of an economic market composed of producers and consumers in perfect competition». Echenique (1972). This approach was initiated by von Thunen's «agricultural location model» (1826). Webber later used it for the creation of his «industrial location model» (1909), and Losch for the «service location model» (1954) based mainly on Christaler's «central place theory» (1933) and Alonso's «residential location model» (1964).

2. The way in which the model treats the time factor. Chadwick (1971) distinguishes between static which is mainly concerned with structural features in equilibrium, and dynamic concentrating on changes in the systems through time. The first of them can be used in order to describe situations in equilibrium, while the second can be considered «as predictive of future situations».

3. The purpose of the model. Echenique (1972) distinguishes the following kinds of models:

a. *Descriptive models,* generally concerned with a stylistic description of reality. The intention of these models is purely explanatory. They analyse particular phenomena and their relationships with urban systems. Descriptive models ignore the time factor, appearing static without specifying how this static or equilibrium situation is generated.

b. *Predictive models,* their main purpose is to forecast the future. Echenique (1968) classifies them into: «extrapolative», dealing with the continuation of present trends and «conditional», based on the mechanism of cause and effect

which controls the determination of the variables.
c. *Explorative models,* «their main intention is to discover, by systematic speculation, other realities that may be logically possible, starting from the systematic variation of the basic parameters used in the descriptive models». Echenique (1968).
d. *Planning or normative models.* Lowry (1965) defines them as follows: «a measure of optimisation is introduced in terms of chosen criteria in order to determine means of achieving stated planning goals». The way in which these models are trying to achieve planning goals is by putting forward certain indices or criteria which do not represent future projections of natural forces but express in their outputs the desires of the planner.
4. At the end, the «means of representing reality» constitute the last classification. Echenique (1968) distinguishes two different types of models: «physical» and «conceptual».
a. *Physical models* are those representing reality by the «same or analogous material characteristics». According to that he subdivides them into «iconic» models representing reality as it is but in a different scale (maps, architectural models, photographs), or «analogue models» having «real world properties represented by different properties» (maps, graphs, plans). Haggett (1967).
b. *Conceptual models,* where the representation of their relevant characteristics is made by «logical concepts». Echenique (1968) classifies them into «verbal», where reality is represented by verbal or written logical terms and «mathematical», describing reality through mathematical symbolism and operations. A further division into the latter category disaggregates them into «deterministic» and «stochastic» (including the degree of probability involved).

f. *Gravity models*

As previously stated, a classification of models can be based on the aforementioned four aspects. We are now going to consider models that have been classified as macro-analytic, static, descriptive and conceptual (mathematical). They examine the urban phenomena «in aggregate», assume a state of equilibrium in space, describe the urban reality according to certain parameters and finally express urban activities and their relationships in mathematical symbols and operations respectively.
The Newtonian concept of gravity has been used in models in order to express the interactions between human activities in cities.
Newton's law of «universal gravitation» states that «two bodies in the universe attract each other in proportion to the product of their masses and inversely to the square of their distance appart». This law can be expressed as follows:

$$F=\frac{GM_1M_2}{d^2}$$

where:

F = the force which each body exerts to the other,

M_1= the mass of the first body,

M_2= the mass of the second body,

d = the distance between them,

G = constant (pull or force of gravity)

Carrey (1858) formulated a gravity model, stating that «gravitation is here in human society as every where else in the material world, in the direct mass of the cities and inverse ratio of the distance between them». Carrey in his concept of the material world made no distinction between minerals, animals, or human beings. Under his universal law which «governs matter» everything is the same. A simple version of a gravity model can be expressed as follows:

$$I_{ij}=G\frac{P_1P_2}{d_{ij}^b}$$

where:

I_{ij}= the interaction between areas i and j,

P_1P_2= the size of areas i and j,

d_{ij}= the distance between areas i and j,

b = exponent applied to the distance between the areas,

G = constant (pull or force of gravity).

This formula expresses the probability of interaction between zone i and zone j of size P_i and P_j respectively and distance d between them. The use of the exponential is necessary in order to provide to the large distances a greater proportional deterrence than small ones.

Gravity models have been used in transportation studies expressing the flows of traffic between different areas of the city. The following formula is a generalised version of the distribution equation between two zones of the city:

$$T_{ij} = O_i A_i D_j d_{ij}^{-b}$$

where:

$T_{ij} =$ trips between zones i and j,

$O_i =$ trips originated in zone i,

$D_j =$ measure of the attraction factor in zone j.

Gravity models have been also used to the problem of allocation of urban activities. A simple population distribution problem can be expressed as follows:

$$P_j = T_{1j} + T_{2j} + T_{3j} + \ldots + T_{nj} = \sum_{i=1}^{n} T_{ij}$$

where:

$P_j =$ number of workers living in zone j,

$\sum_{i=1}^{n} T_{ij}$ = the sum of flows of workers from their place of residence to their place of work.

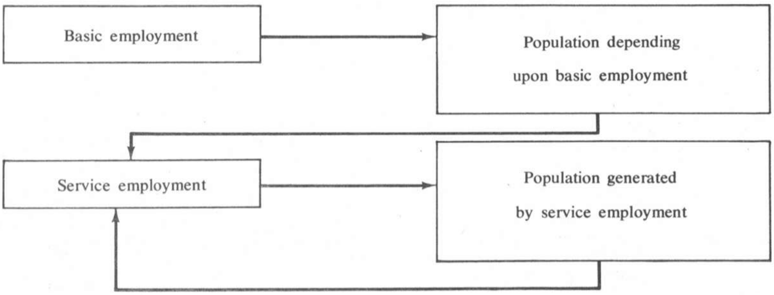
In the above cases, gravity models have been used in order to find the interactions between the different activities or to allocate them in the urban structure. The first successful attempt to include both the description and the allocation of the urban reality in the context of the same model, have been realized in the Lowery model of a metropolis.

g. *The Lowry model*

It was developed in 1962-63 and published by the Rand Corporation in 1964. Its main purpose has been «to generate alternatives and aid decision-making in the Pittsburgh Comprehensive Renewal Program». Describing his model, Lowry (1964) says that it consists of a series of distributional algorithms one for each activity.

Chadwick (1971) describing Lowry's model says: «through an iterative sequence, the model carries a running account of land uses in each zone, beginning with fixed amount assigned to exogenously located basic employment and fixed amounts of unusable land. Each class of retail trade absorbs land at a fixed rate per employee so long as additional space is available, thereafter, retail densities automatically rise to accomodate the assigned number of employees. For most zones, however, the assigned complement of retail trade absorbs only a small fraction of the available land. The remainder is then classified as residential».

This process can be visualised within the following diagram:



The system of equations of the Lowry model can be expressed as follows:

a. Land use accountance

$$L_j = L_j^u + L_j^b + L_j^r$$

where:

L_j = total land in zone j,

L_j^b = land for the location of basic employment,

L_j^u = usable land in zone j,

L_j^s = land for the location of services,

L_j^r = land for the location of the residential population.

b. Service location

$$S_j^{1z} = \Sigma_i (a^z R_i f^z (d_{ij})) + b^z E_j$$

where:

S_j^{1z} = the number of people using service z in zone j,

R_i = residential population in zone i,

$f^z (d_{ij}) = \frac{ds}{dx} (c - dx + ex^z)^{-1}$ distance function used for services z.

where:

x = radial distance d_{ij}

$c, d, e,$ = parameters,

E_j = employment in zone j,

a^z, b^z = parameters.

So the service employment is expressed as:

$$S^z = \frac{S_j^{1z} V^z}{k S_k^{1z}}$$

where:

S_j^z = service employment type z to population ratio subject to the minimum size constraint

$S_j^z > S_{min}^z$ otherwise $S_j^z = 0$

$$L_j^{sz} = S_j^z W^{sz}$$

where:

S_{min}^z = minimum size constraint type z,

L_j^{sz} = land used for service type z,

W^{sz} = land used per employee type z.

c. Residential location

$$R_j = k\, u\, \Sigma_i E_i d_{ij}^{-\beta}$$

where:

R_i = residential population living in zone i,

k = constant,

u = labour participation rate,

E_i = employment in zone i,

d_{ij} = distance between zones i and j,

β = parameter.

Lowry's model has been largely applied in the field of urban research. His descendants used the model in his original form or after making additions to the model's theoretical framework.

The earliest revision was the Time Oriented Metropolitan Model formulated by the Research Corporation for the Pittsburgh Urban Renewal Program by Steger in 1964 and Crecine in 1968. Their major contribution to the model was the way in which relocations of basic activities in the city are determined on the basis of conditions within the simulation by the Industrial Allocation Model, and the method of distributing activities incrementally rather than in one shot.

Garin and Rogers with the Bay Area Simulation Study (BASS) in 1966, replaced the iterative process of population-service employment generation, used by Lowry, with a simple dynamic matrix formulation.

Wilson (1968) introducing the «entropy maximization concept» enlarged the framework of the allocation functions.

Other contributions to the model have been made by Cripps and Food (1969) with their «subregional model» for the Bedford County, Batty (1969) with the Nottingham-Derby study and Echenique and the urban-studies group of LUBFS, with the model of Cambridge. Their main contribution to the Lowry model is the addition of a stock location model so that the spatial structure of the urban system is explained more completely, adding adapted spaces to activities.

The simple static model has been successfully applied to the town of Reading, to the new towns of Stevenage, Milton Keynes and Hook, and to the metropolitan areas of Santiago, Caracas and Sao Paolo. In all these applications the simple static model has been adapted to the situations presented in each case and to the purposes of the studies with sufficiently encouraging results.

II. a description of the LUBFS model

Since 1967 the group of urban studies in the centre for LUBFS of Cambridge University has been working on mathematical urban models. The main concerns of these models are summarised in the following three points:

a. Simulation of land use allocation; the model is able to describe the land uses existing in an area such as employment or residential population.

b. Spatial interaction between the different land uses; it reproduces the amount of trips generated between them.

c. Evaluates alternative planning strategies of urban growth or development.

A city is regarded as a system of interrelated elements; in that way its complex structure is disaggregated into single elements easier to analyse. For complexity reasons mainly, the elements taken into consideration are the most significant for the city's functioning. The choice that has to be made is based on the principle reason for which the model is built for. Having defined the most significant elements of the urban system and described the structural relationships between them, it is possible to build a model which will simulate the cause and effects processes which occur in reality. In a mathematical model this is done by representing the elements in a form of symbols or variables and the relationships between them by mathematical equations. With the help of a large computer the problem will be resolved with maximum accuracy and speed, using large quantities of data.

It was felt necessary at this point to give a descriptive account of what the LUBFS model does.

In applying the model, the first step is the definition of the study area; it can be a city or a region with more than one urban centre. It must be included into a very boundary and divided in zones.

The second step of the model's performance is the allocation of the fundamental elements taken into account. Recalling back the resolution of the urban structure (diagram p. 7), these elements are:

a. *Basic employments,* defined as that employment which sells its goods and services to clients outside the study area and can be considered as city forming. In our case basic employment includes agriculture, industry and central government offices.

b. *Service employment* can be considered practically all the rest. Its location in a certain area depends on the relative population and basic employment location. In our case it includes whole sale and retail sale trade, transportation, administration and health, leisure and public works and finally professional and technical jobs.

c. *Residential population,* considered to be only the residing population of a zone.

d. *Built-up land,* it includes all land which at the time of the study was occupied by «localised activities». It does not take into account agricultural land, mountains, parks, rivers or lakes, land used for transportation infrastructure, playing fields, etc.

e. *Floorspace* is considered to be all flooring which gives shelter to human activities (houses, shops, schools, etc.).

f. *Journeys from work to home and from home to services;* they constitute the liaison between the elements taken into account. For our case they have been considered only the ones done by public transportation means.

g. Finally the transportation network which is considered to be all primary and secondary infrastructure that connects the different parts of the city.

The inputs required for the performance of the model are: the distribution of basic employment, the distribution of built-up land and the transportation infrastructure in each of the zones that the study area was divided.

A range of ratios are also required as additional inputs to the model:

a. *Labour participation rate* (u) expresses the total population of the area divided by the total employment: $\Sigma P/H\Sigma E$

b. *Service employment rate* (v) expresses the total service employment divided by the total residential population of the study area: $\Sigma S/H\Sigma P$

c. *Total floorspace per employee* (w) expresses the overall ratio of total floorspace for all residents and services within the study area to total employment.

d. *The average space standard per basic employee* (p).

e. *The average space standard per service employee* (q).

f. *Space friction parameters for stock, residential and service submodels.* $(\beta^f, \beta^r, \beta^s)$

Besides all the previous data the model requires an accessibility matrix and an attractiveness factor.

The accessibility matrix expresses the shortest route by road between each zone and all the other zones of the study area. It can be calculated by running a minimum path program for the transportation routes of the study area. This can be done by inputing into the machine a digitised map of the existing transportation network and the coordinates and linkages of each junction.

The concept of attractiveness being used in previous model formulations has been revised in order to include the «capacity» that a site has to accommodate activities. It is measured by the amount of floorspace available for occupation in each zone of the study area. In this way it is possible to take into account the stock constrainity effects on the allocation of activities.

a. *Iterative structure of the model*

The model consists of three interrelated submodels:

1) a floorspace submodel which allocates the floorspace for residential and service activities in each zone of the study area according to its relative accessibility to employment and to the availability of land for development it contains.

2) a residential submodel which allocates residents to each zone of the study area according to its accessibility to their workplaces and to the amount of land available for residential development.

3) a service employment submodel which distributes services to each zone of the study area according to its accessibility to residential population, to the amount of floorspace and to all other service employees within the zone.

The use and the probable location of activities and stocks are given by a series of iterative runs of the model.

In the first iteration the floorspace submodel distributes florspace for the location of basic employees to all zones of the study area. This distribution is done according to the capacity (land available) and the accessibility of each zone in relation to the competing capacity and accessibility of all other zones.

The residential submodel distributes all basic employees to homes (journeys to work) taking into account the capacity (floorspace available) and the accessibility of each zone in relation to the competing capacity and accessibility of all other zones of the study area.

Finally, the service employment submodel distributes all the service employees produced by the residential population, to their work-places (journeys from home to services). This distribution considers the capacity (floorspace available including the one used by the previous residential location), the accessibility and the number of service employees that the area already contains, all in relation to the rest of the competing zones of the study area.

At the second iteration the service employment just located is added to the basic employment and gives a new figure for total employment in each zone. But since basic and service employees were added they constitute a major number of residents to be located in each zone from the previous residential distribution. So the residential location submodel does a new distribution using as floorspace the new figure derived from the second iteration. Consequently a new service distribution follows done by the service employment submodel and replaces the old one.

At the third iteration the model produces a new figure for total employment, which is distributed to a new floorspace available for residences and services.

In each iteration the figure expressing the floorspace, residential population and service employees distributed increases, although the actual value difference between two consecutive iterations decreases.

The same process is repeated until the quantities of floorspace, residential population and service employees distributed are relatively close to the known totals. At that stage it can be said that the model reached the state of equilibrium.

Generally speaking this state of equilibrium is reached after six or seven successive iterations.

The outputs produced by the model are:
The total floorspace in each zone.
The residential population in each zone.
The service employees in each zone.
The journey to work matrix.
The journey to services matrix.
The mean trip to work and to services.

The iterative structure of the model as well as the inputs required and the outputs produced are shown in the diagram of the next column.

c. *Mathematical formulation of the model*

The mathematical formulation of the floorspace location submodel takes the form:

$$F_j = \Sigma_i A_i E_i w L_j e^{-\beta^f} d_{ij} \qquad (1)$$

where:

F_j = floorspace available distributed to zone j,

E_i = employment in zone i (basic and service),

w = demand for floorspace per employee,

L_j = built-up land in zone j (residential and services)

d_{ij} = distance between zone i and j,

β^f = space friction parameters for stock submodel,

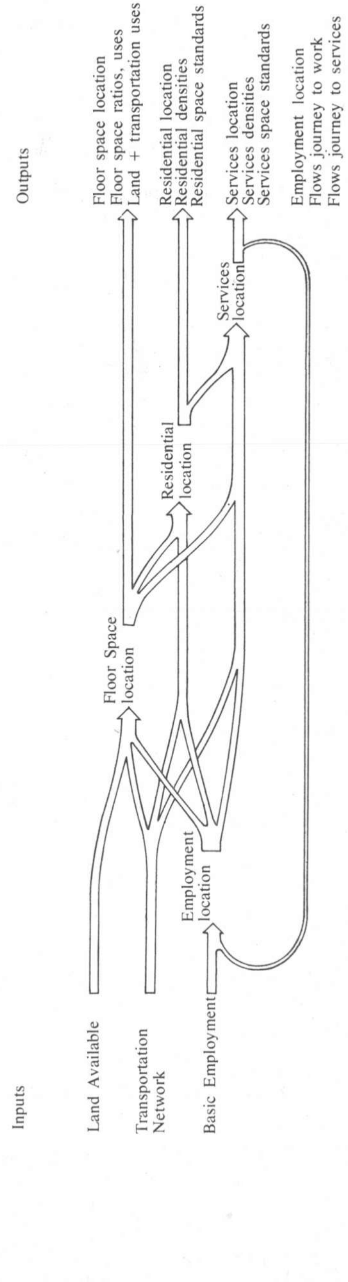
$A_i = 1/\Sigma_j L e^{-\beta^f} d_{ij}$ normalisation parameter.

If we substitute the value of A to the first equation (1) then we will have:

$$F_j = \Sigma_i \frac{E_i w L_j e^{-\beta^f} d_{ij}}{\Sigma_j L_j e^{-\beta^f} d_{ij}}$$

In words, this formulation states that the amount of floorspace produced by employment in zone i and distributed in zone j, is relative to the capacity and the accessibility of zone j.

The residential location submodel takes the form:



$$R_j = \Sigma_i A_i E_i u F_j^r e^{-\beta^r} d_{ij} \qquad (2)$$

where:

$R_j =$ residential population distributed to zone j,

$E_i =$ employees in zone i,

$u =$ labour participation rate $(\Sigma_j R_j / \Sigma_i E_i)$

$F_j^r =$ floorspace available for residents in zone j

$$(F_j^r = F_j - (E_j^b p + E_j^s q)$$

$d_{ij} =$ distance between zone i and j,

$\beta^r =$ space friction parameter for residential submodel,

$A_i = 1/\Sigma_j F_j e^{-\beta^r} d_{ij}$ normalisation parameter.

If we substitute the value of A to the second (2) equation then we will have:

$$R_j = \frac{\Sigma E_i F_j^r e^{-\beta^r} d_{ij}}{\Sigma_j F_j^r e^{-\beta^r} d_{ij}}$$

In words, this formulation states that the amount of employees working in zone i and being attracted to reside in zone j, is relative to the capacity and accessibility of zone j, in comparison with the attractiveness of all the other zones of the study area.

The service location submodel takes the form:

$$S_j = \Sigma_i A_i R_i v W_j^s e^{-\beta^s} d_{ij} \qquad (3)$$

where:

$S_j =$ service employees distributed in zone j,

$R_i =$ residential population of zone i,

$v =$ service employment to population ratio $(\Sigma_j S_j / \Sigma_i R_i)$

$W_j^s =$ attractiveness of zone j for service location,

$\beta^s =$ distance friction parameter for service submodel,

$d_{ij} =$ distance between zones i and j,

$A_i = 1/\Sigma_j W_j e^{-\beta^s} d_{ij}$ normalisation parameter.

If we substitute the value of A to the third (3) equation then we will have:

$$S_j = \frac{\Sigma_i R_i v W_j^s e^{-\beta^s} d_{ij}}{\Sigma_j W_j e^{-\beta^s} d_{ij}}$$

In words, this formulation states that the amount of service employees produced by the residential population of zone i and located in zone j, is relative to the attractiveness and the accessibility of zone j, in comparison with the attractiveness and accessibilities of all the other competing zones of the study area.

III. run of the simple static model for the region of Athens

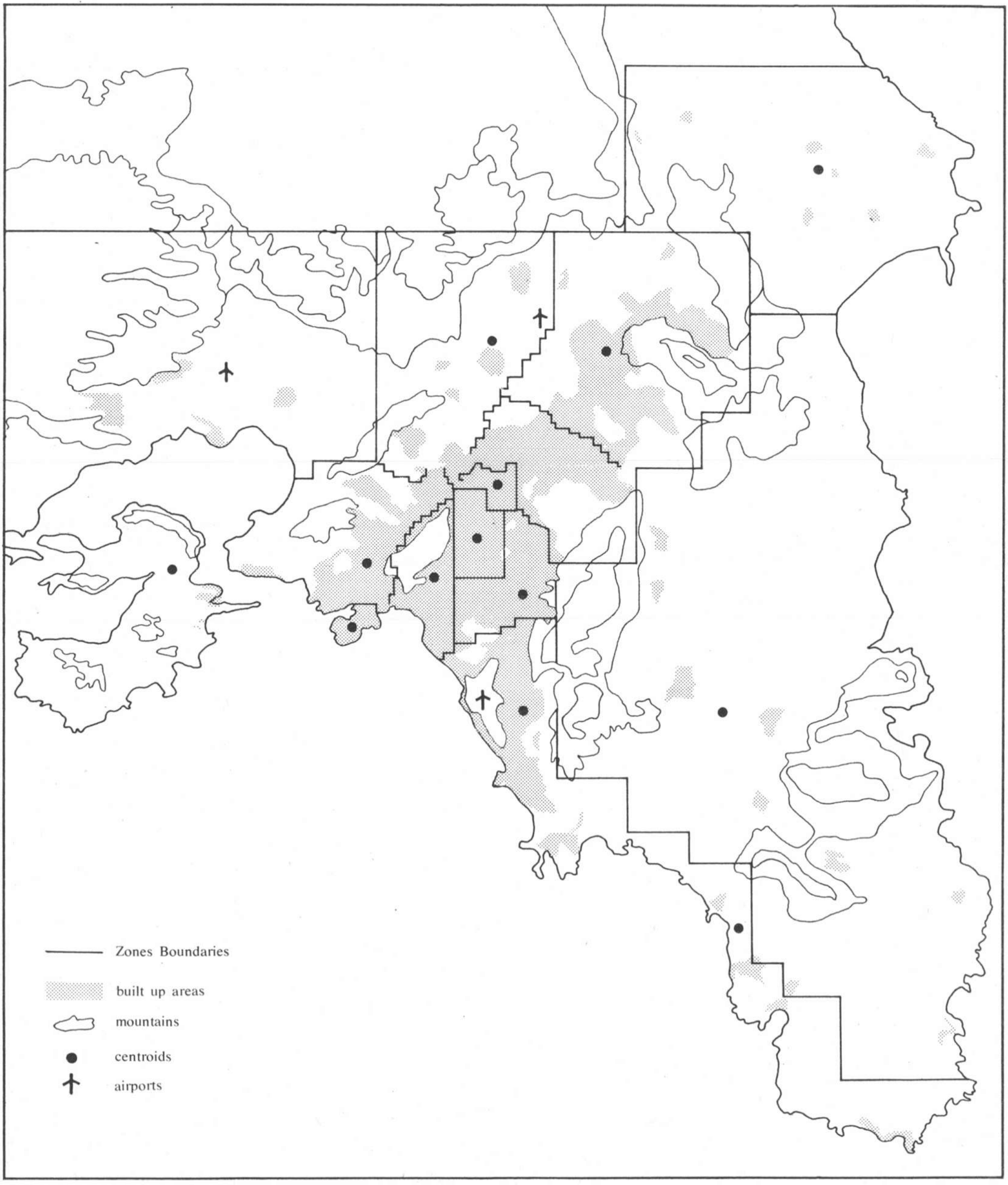
So far we described the theoretical background of the model, its iterative structure and its mathematical formulation. In the following part of the paper we are going to describe a run of the model for the region of Athens using 1971 data.

a. *The site*

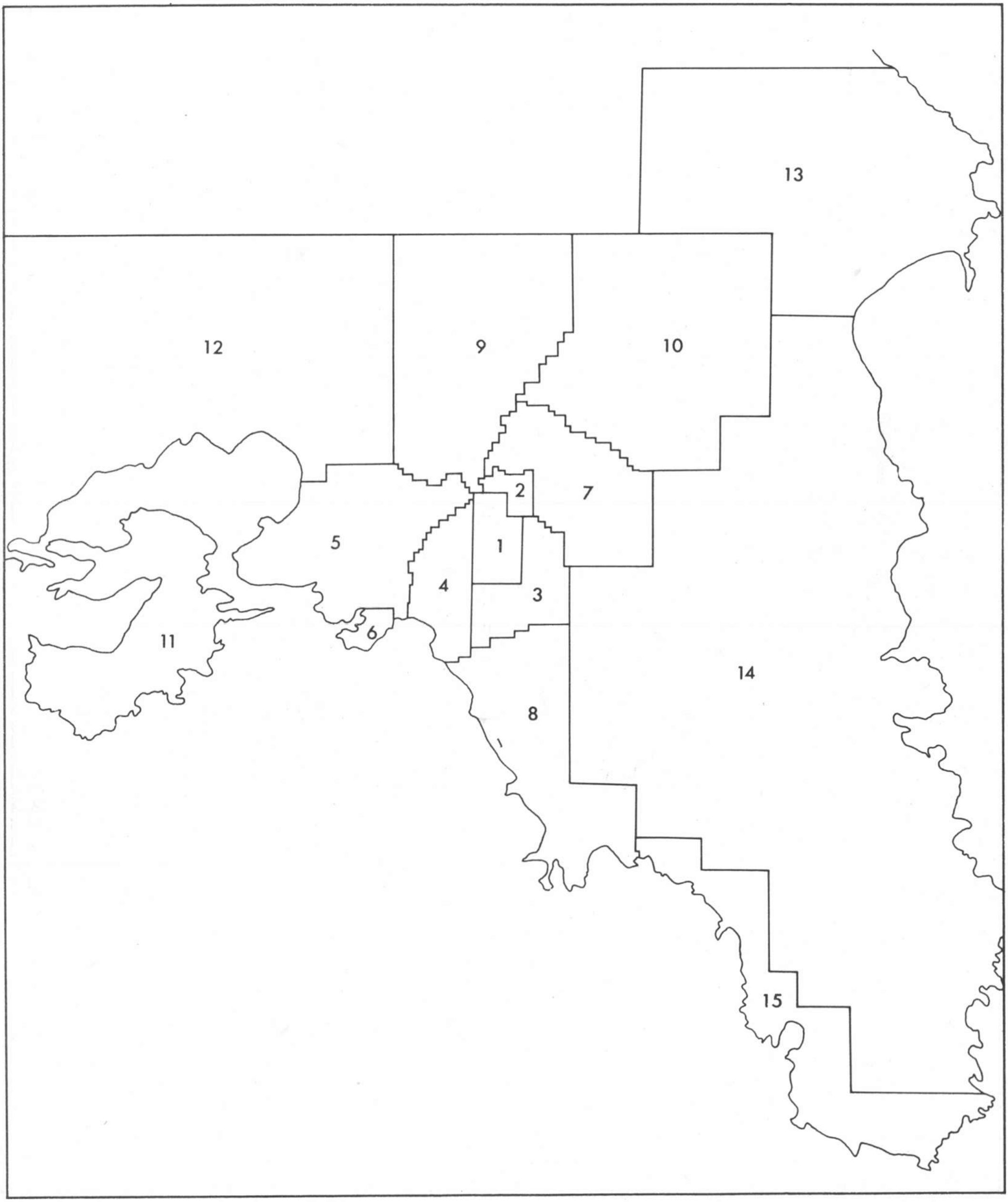
The area we intend to study occupies almost the totality of Attica region. On the NW, Parnes mountain and the SE the coastal line of Saronikos gulf, constitute its natural boundaries.

The main urban development of the region is located in the basin of Athens, which is surrounded by the mountains of Parnes Imittos, Egaleo and Pendelikon. The basin is open to the sea on the south. It contains a usable land of 350 km² and it is divided by a chain of low hills running from N to S, Philopapou, Acropolis, Lycabettos, and Tourkovounia (map. 1). There are four main openings through the larger mountains. To the north a wide pass between Parnes and Pendelikon, gives possibilities for further urban expansion and provides the main rail and road connections with northern Greece. To the west and north-west, Iera Odos passage and a wider opening between Parnes and Egaleo, are

Map 1. ATHENS METROPOLITAN AREA



Map 2. ATHENS REGION - 14 STUDY SECTORS



Map 3. GREECE-STUDY AREA-EXTERNAL SECTORS

Athens Metropolitan Area
DATA TABLE 1. *Within Place Activities: Employment*

	A.	L.I.	H.I	N.L.G.	R.	WS.	TR.	AD.H.	L.P.S.	P.W.	P.T.W.
1	0	33051	19945	38079	31088	33125	22718	71	25678	4407	9190
2	0	2640	1953	1245	2712	513	111	2	2171	196	24
3	0	12512	9157	5222	6421	875	879	1285	6210	1490	152
4	0	22271	26576	6026	6276	3378	3378	260	3848	386	625
5	0	10704	20186	3435	11294	4473	683	242	5560	1356	78
5A	0	13489	14771	10991	7078	4931	29980	595	3914	822	1546
6	0	14560	5956	4442	8391	952	351	219	2517	421	117
7	0	1809	2521	932	1157	421	3204	121	2761	5	51
8	65	2987	3274	882	7065	487	420	79	2510	51	25
9	56	8687	3503	1233	2029	299	109	176	1885	126	65
10	1320	169	274	49	475	59	151	5	342	19	9
11	1250	1103	5537	369	1000	433	330	34	553	199	29
12	1645	41	25	17	126	13	15	13	108	15	12
13	4226	1381	1004	342	1219	472	364	52	1670	159	23
14	762	28	14	49	163	34	121	44	315	27	10

Not specified employment total: 32.702

A. Agriculture
L.I. Light industry
H.I. Heavy industry
N.L.G. National and local government
R. Retail trade
WS. Wholesale trade
TR. Transportation
AD.H. Administration and health
L.P.S. Leisure and personal services
P.W. Public works
P.T.W. Professional and technical works

Athens Metropolitan Area
DATA TABLE 2. *Within Place Activities*

	P.	B.E.	S.E.
1	434501	91075	126277
2	115779	5838	5729
3	396473	26891	17312
4	297221	54873	18151
5	417620	34325	23686
5A	235369	39251	48866
6	241871	24958	12968
7	108625	65262	7720
8	176603	7175	10637
9	82422	12908	64689
10	18240	1812	1060
11	57080	8259	2578
12	11425	1728	302
13	56953	6953	3959
14	2823	853	714
Total	2653005	322161	284648

P= Population
B.E= Basic employment
S.E= Service employment

connecting the region with the industrial sites of Eleusina and Megara and south-east regions of the country. To the east, a passage between Pendelikon and Imittos, leads to Messoghia Plain and to the east coast of the region.

For study purposes, the region is divided into 15 zones of irregular size and shape. This subdivision corresponds to the one given by the Athens-Attica traffic and transportation study of Smith Association in order to make use of its transportation data (maps 2, 3).

b. *Data*

As mentioned before, the data required for the run of the model are: the location of basic employment, the land available, the transportation network, an accessibility matrix, and the values of parameters, such as, labour participation rate, service employment ratio, floorspace demand and space friction parameters. The sources providing these data are briefly summarised in the following two points.

c. *Adapted spaces and within-place activities*

Employment data is given in table 1 for eleven different categories including agriculture and livestock, light and heavy industry, national government, transportation, administration and health, leisure and personal services, public works and professional and technical employment. The first four of them constitute basic employment and the remaining constitute service employment (table 2). All the previous data refers to 1969 and is taken from the Master Plan Office of Athens.

Athens Metropolitan Area
DATA TABLE 3. *Within Place Activities*

	P.	H.	I.	P.C.	C/H.	P/C.
1	434501	167302	9332	56005	0,335	7.75
2	115779	39546	7956	13032	0,330	8.88
3	396473	134735	7670	37378	0,277	10.60
4	297221	100471	8168	27431	0,273	10.83
5	417620	124926	6666	32910	0,263	12.68
5A	235369	76345		17408	0,228	13.52
6	241871	74993	8094	28754	0,383	8.41
7	108625	34228	7662	15510	0,453	7.00
8	176603	49905	6200	14364	0,288	12.29
9	82422	25301	8393	12821	0,507	6.42
10	18240	5630	6377	1945	0,345	9.37
11	57080	16117	6195	5967	0,345	9.56
12	11425	3512	6148	1392	0,396	8.20
13	56953	16287	7045	7507	0,461	7.58
14	2823	873	9749	716	0,820	3.94
Total	2653005	878171	7749	272740	0,313	9.13

P. Population census 1971 extended to 1972
H. Households census 1971 extended to 1972
I. Monthly income of the household in Drachmas
P.C. Private cars including motorcycles data 1972
C/H. Number of cars per household, 1972
P/C. Number of persons per car; 1972

Athens Metropolitan Area
DATA TABLE 4. *Within Place Activities Trip Ends*

	V.	P.T.P.	T.	%T.	Tx.	%Tx.	T.Pr.
1	813910	1271147	97894	15,6	331415	44,0	589278
2	86492	131884	13607	2,2	26437	3,5	142920
3	303446	421989	59303	9,5	88495	11,7	455750
4	344824	408326	97709	15,6	83642	11,1	351053
5	272200	356321	74859	12,0	56195	7,5	579571
5A	252320	385755	62226	9,9	52681	7,0	
6	237252	268131	63468	10,1	43853	5,8	254633
7	138757	133092	25851	4,1	25335	3,4	124665
8	70222	118218	22238	3,6	8380	1,1	128389
9	123550	88905	33061	5,3	26812	3,6	84811
10	8718	16723	901	0,1	0	0,0	11465
11	51861	44388	16726	2,7	2864	0,4	35133
12	17924	9335	7933	1,3	808	0,1	6296
13	95681	31351	47830	7,6	6346	0,8	41630
14	5435	1190	2348	0,4	87	0,0	2070
Total	2882592	3686755		100,0		100,0	2807664

V. Total number of vehicles 1972
P.T.P. Public transportation (passengers) 1972
T. Total number of trucks 1972
Tx. Total number of taxis 1972
T. Pr. Trip production 1972

Data for residential population is taken from the Athens-Attica traffic and transportation study and refers to 1971. The same source provided data for the number of households in each zone, as well as the income of each household, car availability and trip ends by different transportation means (tables, 3, 4, 5).

d. *Channel spaces and between-place activities*

The basic transportation network has been considered to be the basis for the calculation of accessibility between the zones of the study area. The centroids of each zone had been defined and

Athens Metropolitan Area
DATA TABLE 5. *Within Place Activities Trip Ends (external zones)*

External zones	Private cars	Trucks	Total external trip ends*
901	1319	697	2016
902	3620	3266	6886
903	312	205	517
904	1712	1449	3161
905	711	481	1192
906	2506	1862	4368
907	396	223	619
908	36	41	77
909	1314	1142	2456
9101380	1380	1485	2856
911	0	4	4
Total	13306	10855	24161

* Without public transportation

a run of minimum path program determined the accessibility matrix (maps 4, 5, and table 6).

The Athens-Attica traffic and transportation study provided all the data necessary for the traffic flows between two zones of the region. Unfortunately the origin-destination survey included in the study provided only the means and not the purposes of the trips. However, totals and percentages were given for trip purposes (tables 7, 8, 9).

The parameters necessary for the calibration of the model are given in the following table:

Parameters:		
ALPR	=	4.50724411
SERP	=	0.10797113
FSS	=	0.00960400
ALO	=	0.18599999
AL1	=	0.00100000
AL2	=	0.00300000
P	=	1.50000000
BSS	=	0.00140000
SSS	=	0.00180000
IUL	=	7

where:

ALPR = Labour participation rate, (u)
SERP = service employment rate, (v)
FSS = total floorspace standard per employee, (w)
ALO = space friction parameter for stock submodel, (b^f)
AL1 = space friction parameter for residential submodels, (b^r)
AL2 = space friction parameter for service submodels, (b^s)
P = economy of scale parameter, (assumed)
BSS = space standard per basic employee, (p)
SSS = space standard per service employee, (q)
IUL = number of iterations

TABLE 6. *Accessibility Matrix*

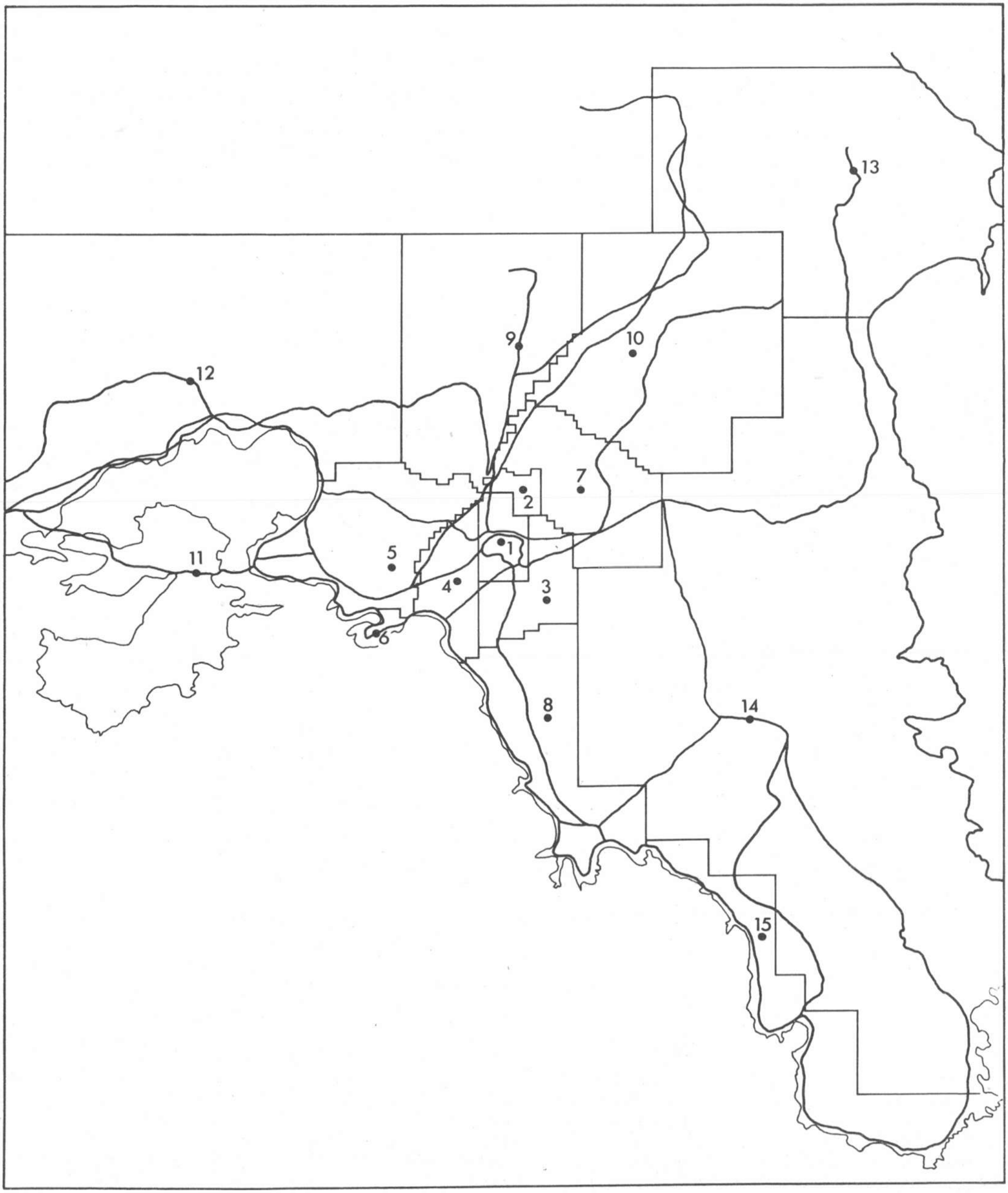
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
1	8	15	19	27	32	36	25	28	30	45	69	52	68	38	58	550
2	17	5	26	38	35	49	12	33	16	22	89	65	53	48	72	580
3	21	28	7	36	41	24	48	22	41	55	88	78	73	48	27	637
4	25	35	36	11	13	12	45	30	60	78	45	82	98	68	43	681
5	30	33	48	11	8	10	48	36	62	79	25	40	107	61	55	653
6	36	49	21	10	11	7	58	22	76	72	30	32	87	60	36	607
7	26	15	48	43	48	50	9	43	48	19	92	77	30	39	82	669
8	26	33	28	32	35	26	44	12	58	73	94	65	96	48	14	684
9	29	18	48	64	69	72	45	58	13	15	101	80	25	85	78	800
10	45	20	58	72	76	78	18	74	16	14	115	113	16	80	88	883
11	71	85	80	48	28	35	98	94	101	115	15	48	138	105	71	1132
12	47	60	78	82	46	38	78	64	85	118	45	15	110	88	98	1052
13	65	55	73	95	102	88	34	95	25	16	132	115	12	36	115	1058
14	34	48	48	68	68	65	38	48	86	83	108	85	36	14	16	845
15	55	75	29	47	58	34	82	16	74	83	73	94	119	18	11	868
	535	574	647	684	676	624	682	675	791	887	1121	1041	1068	836	864	

IV. results of the model

There are two principal objectives to this part of the paper: Firstly, the presentation and analysis of the results from the model followed by a brief critique of the main limitations and inaccuracies that we observed during the short term experience of the run. Secondly, proposals for future work.

The output of the model consists of three submodels, namely, stock, residential and services and the trips distribution: i.e. journeys to work, journeys to services and total trips distribution. We will try to analyse the results comparing them with the real data so as to determine the degree of accuracy of the model. This will be followed by a short interpretation of the results.

Map 4. PUBLIC TRANSPORTATION



Map 5. PRIVATE TRANSPORTATION

Athens Metropolitan Area
DATA TABLE 7. *Traffic Demand between Sectors (Origin destination survey 1972)*

	1	2	3	4	5	5A	6	7	8	9	10	11	12	13	14
1	190500														
2	34913	8555													
3	105577	4194	42895												
4	90699	6443	34925	51759											
5	36864	3288	5937	32074	57145										
5A	27525	1852	8981	30775	47010	55593									
6	55777	9562	20991	12460	5490	5061	46377								
7	32640	1771	20695	14171	5451	9013	4488	21895							
8	14073	2841	2223	7340	8504	2187	4677	1407	11135						
9	20025	3094	7490	4935	4369	3180	15923	2047	2058	28979					
10	440	0	140	224	1213	676	128	0	0	0	2796				
11	3287	487	400	3040	6121	2688	874	530	1426	391	20	16228			
12	1808	262	1103	1090	382	300	1256	162	638	1186	0	81	3830		
13	8290	675	4766	2597	1081	1645	7365	2878	578	894	285	60	1996	30693	
14	991	0	234	533	120	240	440	314	0	0	0	0	0	1785	38

It does not include public transportation but it includes trucks and taxis.

Athens Metropolitan Area
DATA TABLE 8. *Public Transportation Demand (Origin Destination survey 1972)*

1	214654													
2	75628	3498												
3	215690	8839	31669											
4	161861	10416	38081	30792										
5	86402	3136	15112	33728	50433									
5A	57341	7444	12654	39439	79537	77537								
6	111052	8385	23205	19276	6577	10605	31862							
7	39894	2403	24547	15542	5093	7339	4158	13954						
8	50330	4080	4548	14431	10873	4745	3614	3524	8881					
9	27632	2936	6316	7663	4146	4956	11186	1344	1721	9813				
10	1469	0	142	603	2161	1447	503	0	126	0	5136			
11	5305	404	2689	1755	5684	3711	580	138	626	52	0	11328		
12	1625	82	1009	511	216	162	1022	0	251	923	0	788	918	
13	5109	624	4393	3168	478	430	3903	1242	670	300	0	0	411	519
14	104	0	395	159	250	0	45	0	0	0	0	0	0	0

Athens Metropolitan Area
DATA TABLE 9. *Average Trip Length by Purpose, 1972*

Trip purpose	Private Cars	Public vehicles
Home based work	15,5	35,7
Home based social recr.	22,2	39,2
Home based school	0	27,5
Other home based*	17,4	32,5
Non home based	16,6	30,3
All purposes	17,5	34,2

* Includes shopping, personal business, employee's business

a. *Stock submodel*

As stated on page 27 the formulation of stock submodel takes the form:

$$F_j = \Sigma_i A_i E_i w L_j e^{-f} d_{ij}$$

The data used for E,w,. dij, were taken from the 1972 Athens-Attica region Traffic and Transportation Study (A-ARTTS).

Unfortunately there were no data available for built up land, but we obtain an overall approximation by studying a very accurate map of the area; needless to say, a certain degree of error is unavoidable (table 10).

Athens Metropolitan Area
DATA TABLE 10. *Within place Activities*

	T.L.	B.A.	C.A.	L.A.	B.F.S.
1	14	10	4	0	1378
2	6	5	1	0	136
3	27	22	4	1	607
4	25	19	4	2	547
5	64	23	26	15	749
5A	11	9	2	0	369
6	63	34	10	19	554
7	82	36	34	12	521
8	137	18	31	88	316
9	164	66	30	68	280
10	93	5	57	31	16
11	564	18	234	146	64
12	224	4	36	184	23
13	621	27	147	447	72
14	94	4	31	59	21
Total	1735	398	651	1072	5653

T.L. Total land
B.A. Build up land
C.A. Land under planning or geographical constraints
L.A. Land available
All numbers are expressed in Km^2 and they are round figures.
B.F.S. Total amount of built floor space in hectares

The value for the parameter was taken from the tun of the Automatic Calibrated Urban Model (ACUM), a description of which is given in table 1. Diagram 1 gives a graphic representation of the table. In studying table 1 and diagram 1 together, one can get a fairly good idea of the simulation. The model reproduces perfectly well the stock in the two centres of Athens and Piraeus zones 1 and 6, as well as the external zones: 10, 11, 12, 13, 14, 15. It overestimates zones 3, 4, 5 and underestimates zones 8 and 9. The overestimation in zones 3, 4, 5 is mainly due to large basic, residential and service populations for a comparatively small stock. The underestimation in zone 8 and 9 arises from the inverse of these phenomena. The magnitude of basic, residential and service population is small for the amount of stock available. The overall simulation can be considered as satisfactory; the value of the coefficient of determination is R= 90.10.

b. *Residential submodel*

The residential location submodel takes the form:

$$R_j = \Sigma_i A_i E_i u F_j^r e^{-r} d_{ij}$$

The data used for A,E,u,F,dij are taken from the 1972 A-ARTTS. The comparison between real data, and simulation is given in table 2. Diagram 2 gives a graphic representation of the simulation. Generally speaking it would seem that the best fit was obtained for the outskirts of the region. The very high density of stocks in zone number one (centre of Athens) leads to a considerable overestimation. Another probable error could be the low value given to internal trips since this would create good accessibility for residential and service location. Two other zones to be noted are: zone number 6 (centre of Pireaus) and zone 9 (northen suburbs) where the model underestimates the residential population. Nevertheless, we can say that the overall results are good (R=82.89).

c. *Service submodel*

The service submodel takes the form:

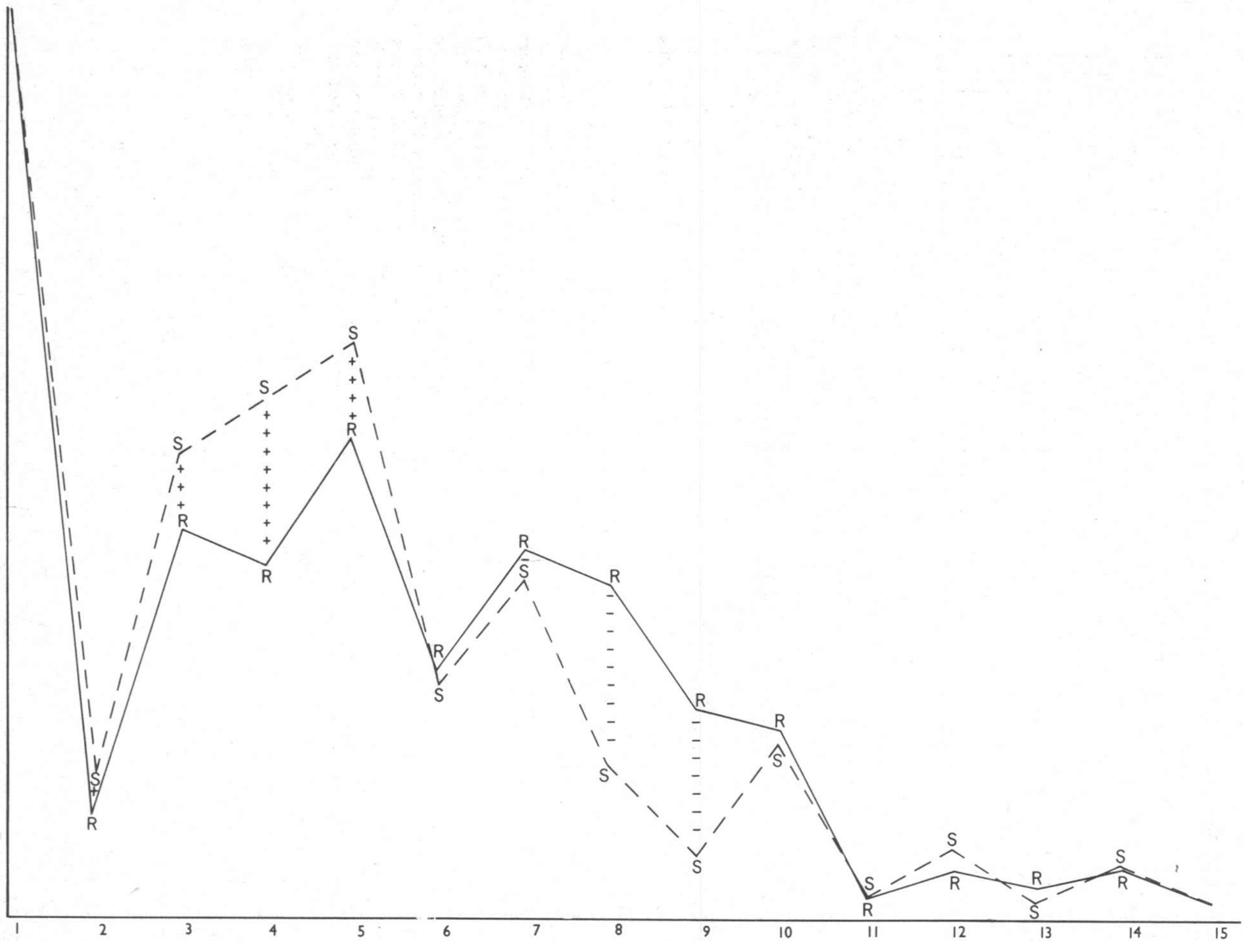
$$S_j = \Sigma_i A_i R_i v W_j^s e^{-s} d_{ij}$$

All the data for the calibration have been taken from the 1972 A-ARTTS.
Table 3 shows the comparison between data and

DIAGRAM 1

Stock Submodel

Maximum of the Scale: 1378.0000



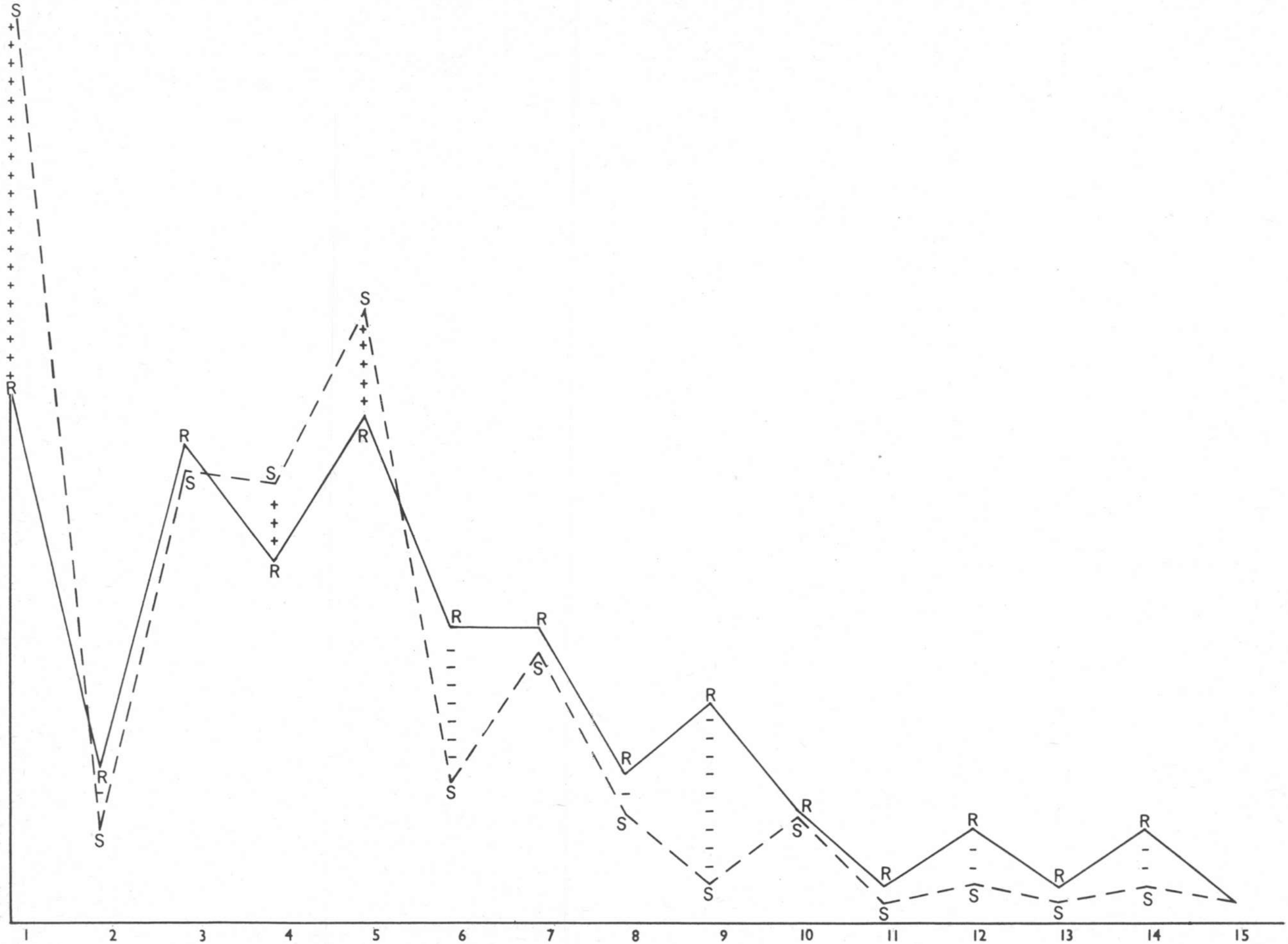
Min of Scale 9.0022

Hor. Scale= 15

Arith. Means: 376.87 374.43 Geom. Means: 1.00 1.00 Harm. Means: 71.71 54.09 St. Dev.: 357.67 384.07

Residential Submodel

Maximum of the Scale: 769049.8125



Min of Scale 366.7517 Hor. Scale=15

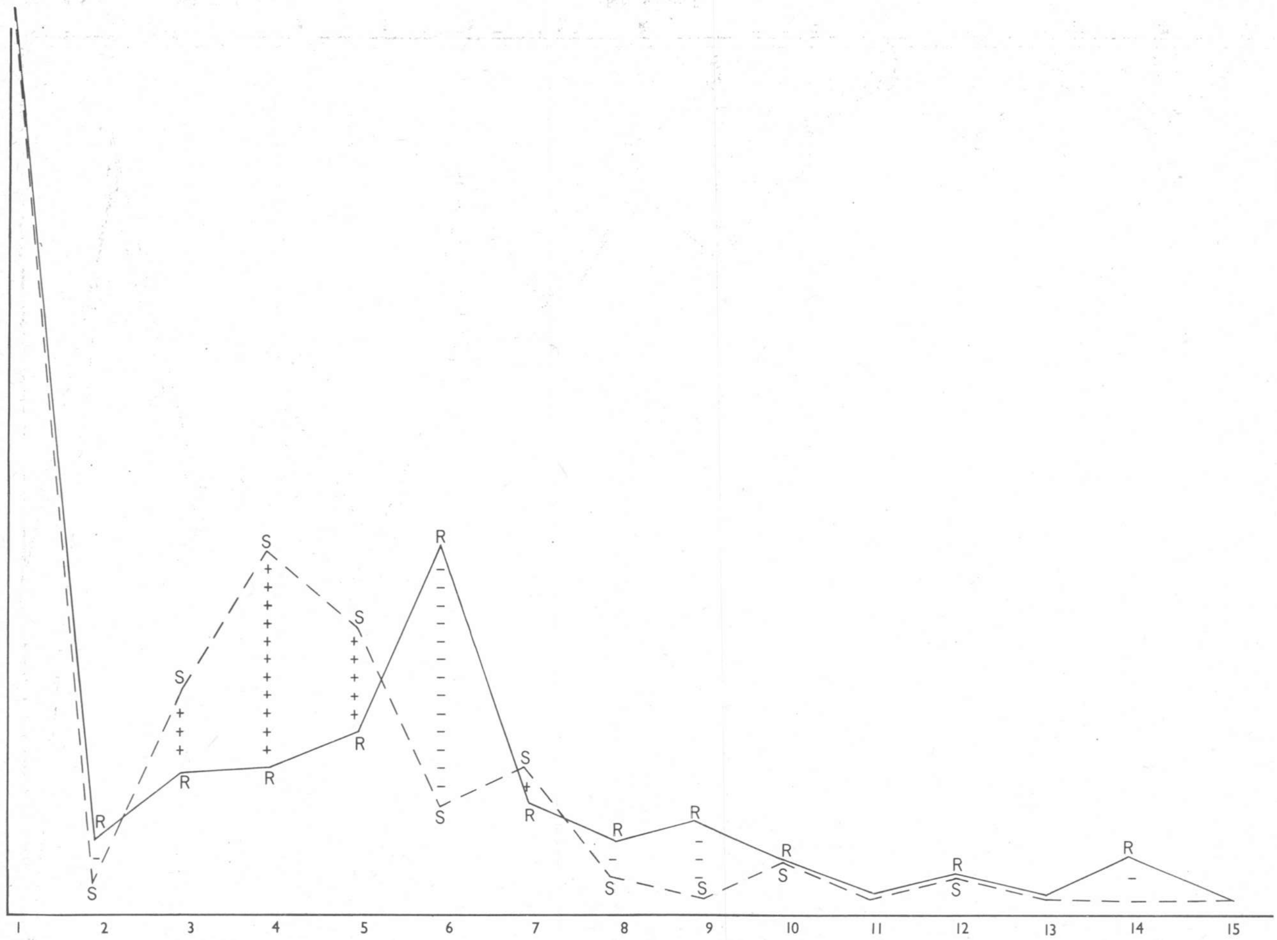
Arith. Means: — Geom. Means: 1.00 1.00 Harm. Means: 25 585.64 3432.35 St. Dev.: —

Correlation Coefficients: R=0.9105 R2=82.8975 T=7.9380

Service Employment Submodel

Maximum of the Scale: 126277.0000

DIAGRAM 3



Min of Scale 54.2574

Hor. Scale = 15

Arith. Means: 19096.5318973.02 Geom. Means: 1.00 1.00 Harm. Means: 2105.00 384.77 St. Dev.: 31088.4681608.17

	TABLE ONE			TABLE TWO			TABLE THREE		
	D.F.S.	S.F.S	R.	D.R.P.	S.R.P.	R.	D.S.E.	S.S.E.	R.
1	1378	1358	20	434501	769050	-334549	126277	123420	2857
2	136	215	- 79	115779	68683	47096	7529	2563	4966
3	607	712	-105	396473	370416	26057	17312	28660	-11348
4	547	782	-235	297221	336401	- 69180	18151	48667	-30516
5	749	877	-128	417620	513517	- 95897	23686	37539	-13853
6	369	349	20	235369	113519	121850	48866	14130	34736
7	554	512	42	241871	222377	19494	12968	17648	- 4674
8	521		246	22275	108625	84602	24023	7720	2849
4871									
9	316	91	225	176603	16463	160140	10637	1339	9298
10	280	253	27	82422	79076	3346	4639	4819	- 130
11	16	16	0	18240	1141	17099	1060	128	932
12	64	93	- 29	57080	16285	40795	2578	1513	2450
13	23	9	14	11425	367	11058	302	107	195
14	72	76	- 4	56953	11961	44992	3959	1164	2795
15	21	20	1	2823	1999	824	714	54	660

Where: D.F.S. = Floor Space Data
S.F.S. = Simulated Floor Space
D.R.P. = Residential Simulation Data
S.R.P. = Simulated Residential Population
D.S.E. = Service Employment Data
S.S.E. = Simulated Service Employment
R. = Residuals

TABLE 4. *Journey to Work Matrix*

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
1	62695	5587	30123	29481	41208	9070	18686	6835	1345	6431	91	1322	29	975	160	213438
2	2449	222	1179	1149	1619	352	772	268	53	259	3	51	1	38	6	8371
3	16122	1436	7942	7611	10639	2391	4604	1791	346	1658	23	335	7	251	43	55199
4	29970	2862	14400	14566	20421	4517	8620	3317	634	3025	45	624	14	460	79	103354
5	17831	1595	8597	8709	12271	2706	5138	1971	378	1807	27	389	8	277	46	61660
6	12442	1102	6135	6120	8588	1905	3571	1403	262	1277	19	275	5	194	33	43331
7	12437	1128	5910	5860	8191	1806	3712	1360	266	1333	18	260	6	196	31	42514
8	2356	210	1142	1122	1572	350	679	265	50	239	3	49	1	36	6	8080
9	2512	227	1197	1162	1625	358	725	271	56	271	3	52	1	38	6	8504
10	5186	477	2486	2419	3385	746	1563	560	117	569	7	106	2	80	13	17716
11	557	49	268	273	392	86	159	60	11	56	0	12	0	8	1	1932
12	2871	254	1352	1328	1935	431	816	314	60	284	4	65	1	44	7	9766
13	536	48	258	249	348	78	162	57	12	60	0	11	0	8	1	1828
14	2392	211	1146	1108	1556	345	699	262	49	242	3	50	1	39	6	8109
15	262	23	130	126	175	39	74	30	5	27	0	5	0	4	0	900
	170618	15431	82265	81283	113925	25180	49330	18764	3644	17538	246	3606	76	2648	438	

TABLE 5. *Journey to Services Matrix*

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
1	340088	6994	78345	128318	98138	36397	48202	7615	3712	13157	331	4112	290	3202	140	760041
2	30122	655	6981	11297	8850	3185	4560	682	352	1282	28	359	27	282	12	68674
3	161552	3322	40115	61690	47181	18636	22221	3829	1773	6306	154	1879	141	1535	76	372410
4	156303	3185	36007	65111	50248	18917	21955	3661	1640	5763	172	1818	128	1415	71	366394
5	217413	4525	49044	91937	72022	26872	30723	5077	2302	8113	258	2911	176	2041	97	518511
6	47259	954	11770	20408	15797	6001	6598	1171	488	1833	56	660	41	453	22	113511
7	97467	2115	21724	36596	28295	10557	15298	2262	1063	4302	93	1154	98	965	39	222368
8	36683	754	8682	14391	11073	4270	5183	909	388	1377	35	450	30	353	18	84596
9	7389	160	1662	2657	2032	756	1050	161	90	333	6	87	7	64	3	16457
10	34763	786	7960	12805	9823	3665	5622	757	442	1649	33	391	38	322	14	79870
11	475	9	110	203	167	61	65	10	5	18	0	7	0	4	0	1134
12	7212	145	1564	2593	2243	862	980	162	75	251	8	109	6	65	2	16277
13	160	3	37	58	44	17	26	3	2	8	0	1	0	1	0	360
14	5344	107	1220	1927	1496	566	787	121	53	199	5	63	5	58	2	11953
15	847	16	218	346	260	105	116	22	9	33	0	10	0	9	0	1991
	1143077	23730	265439	450737	347669	130867	163386	26382	12394	44624	1179	14011	987	10769	496	

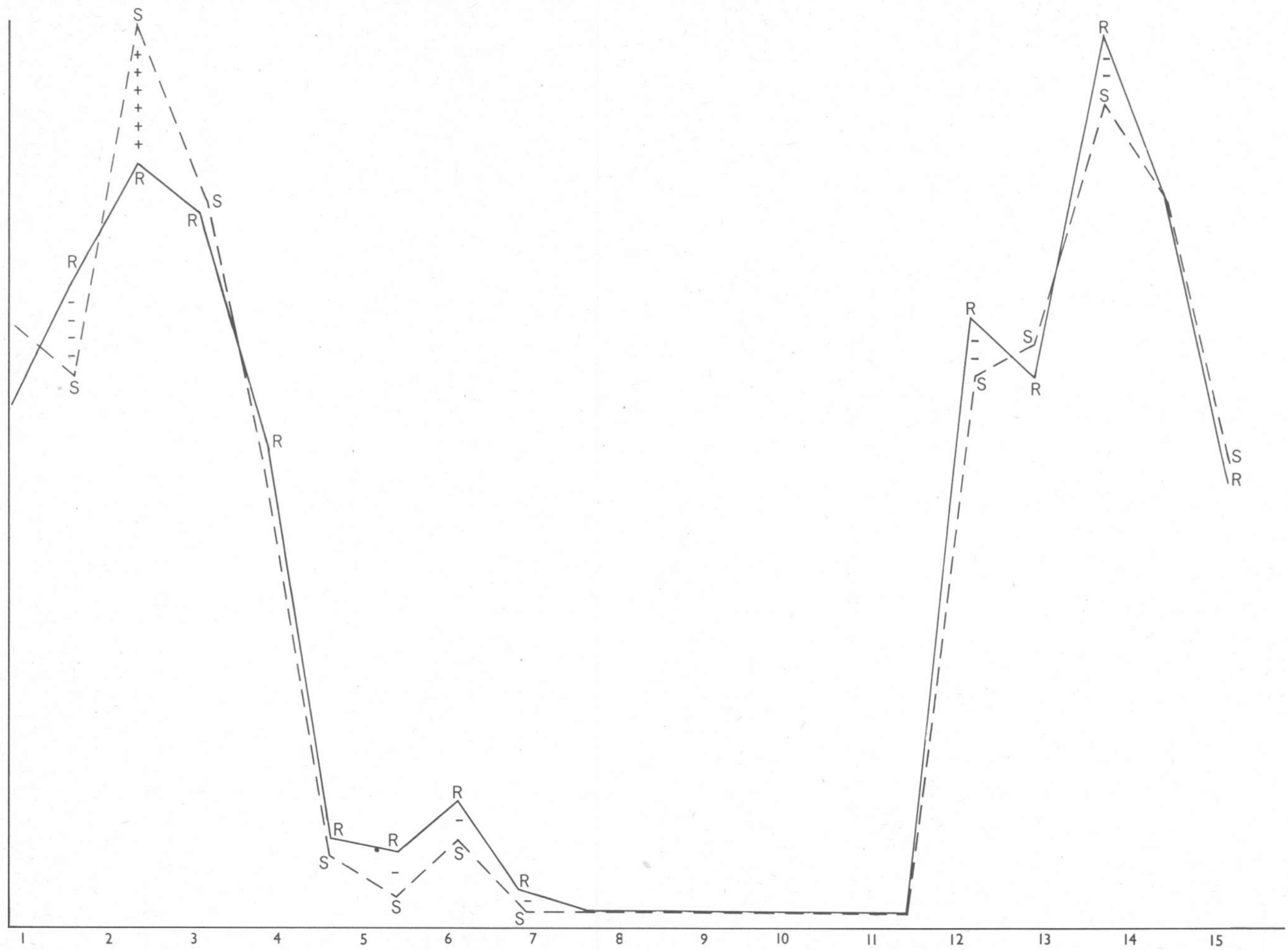
TABLE 6. *Total Trips Matrix*

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
1	638606	40232	234342	298698	300176	105994	153309	46213	18588	57537	3012	20125	2601	16102	2009	1937544
2	40232	2147	12904	18748	15936	7005	9063	2310	1325	3543	242	1433	228	1168	135	116419
3	234342	12904	80259	109761	96689	41716	52140	14574	7331	20226	1344	7980	1219	6597	814	687896
4	298698	18748	109761	145368	146852	52191	71633	21959	8566	26546	1478	9278	1298	7430	971	920487
5	300176	15936	96689	146652	126176	55517	66455	17716	9501	25340	1938	11032	1630	8648	1041	834447
6	105994	7005	41716	52191	55517	18473	26092	8493	2930	9717	487	3348	384	2543	343	335233
7	153309	9063	52140	71633	66455	26092	36767	9988	4701	14127	816	5086	773	4227	496	455673
8	46213	2310	14574	21959	17716	8493	9988	2592	1508	3834	293	1706	269	1400	169	133024
9	18588	1325	7331	8566	9501	2930	4701	1598	524	1834	71	528	62	408	55	57932
10	57537	3543	20226	26546	25340	9717	14127	3884	1834	5489	295	1834	287	1511	187	172307
11	3012	242	1344	1478	1938	487	816	293	71	295	8	78	4	55	8	10129
12	20125	1433	7980	9278	11032	3348	5086	1706	528	1834	78	612	57	438	59	63594
13	2601	228	1219	1208	1630	384	773	269	62	287	4	57	2	46	6	8776
14	16102	1168	6597	7430	8648	2543	4227	1400	408	1511	55	438	46	365	50	50988
15	2009	135	814	971	1041	343	496	169	55	187	8	59	6	50	6	6349
	1937544	116419	687896	920487	884447	335233	455673	133924	57982	172307	10129	63594	8776	50988	6349	

Total Trips Frequency Distribution

DIAGRAM 4

Maximum of the Scale: 26.7464



Min of Scale 0.0 Hor. Scale= 20

Arith. Means: 9.78 9.71 Geom. Means: 1.00 1.00 Harm. Means: 0.00 0.00 St. Dev.: 9.54 9.79

R2=97.9103 T =29.0409

simulation, the graphic representation of which is given by diagram 3. A good simulation of residents gives a similarly good distribution of services in all the zones except zone 1. The behaviour here is peculiar since although we have a perfect fit for stocks and services, residential population is overestimated. The overall results can be considered good with (R=82.95).

d. *Trips distribution*

Can be divided into three components:
1. Journeys to work
2. Journeys to services
3. General flow distribution.

All three refer to public transportation trips.

1. Journeys to work

Table 4 gives the distribution of journeys from work to home. The mean trip length is 31 minutes, which is one minute less than the total mean trip length for all purposes (see Appendix for its calculation). The model underestimates this value: 28.30 minutes.

2. Journeys to services

Table 5 gives the journey to services distribution. The mean trip length for journeys to services is 32 minutes, equal to the total trip length. The simulation value is underestimated 26.42 minutes.

3. General flow distribution

It can be seen in table 6. It expresses the sum of flows to basic and service employments. The total mean trip simulated value is 27.36 minutes as opposed to 32 minutes given. The total mean frequency of trips is shown in diagram 4.

e. *General conclusions*

The run of the simple static model was an attempt to analyse and better understand the spatial organization of Athens Region. As with all models of its kind it has limitations which must be considered in any judgement of its capacity to simulate an urban system.

A brief description of the limitations can be stated as follows:

The model provides a simulation of the urban reality without taking into consideration the dynamic changes in the structure with time.

It is not possible for the model builder to include all the relevant variables. A preferential choice is made among the most relevant of them. This can include a source of error because of factors which have not been taken into consideration.

Data definition and collection constitutes another source of error. Data are not always available in the type and form required. The adaptation of «general» data into the particular data structure that the model requires always carries a certain amount of inaccuracy.

Finally, all models tend to be of fairly general applicability. The degree of their generality though can be considered either as positive or negative. The positive side is that the model can be used as an explorative tool in more than one city describing their structural components. Immediate consequences: the reapproval of the validity of the theoretical basis on which the model operates.

On the other hand in being more concerned with the general than with the particular the model may be inaccurate with regard to certain peculiarities of the particular study region. Inaccuracies of this kind can have considerable consequences in that they indicate where local factors predominate over the broad structural relations that are represented in the model.

As a general point we could say that the model's results are satisfactory. It does not attempt to explain the reasons for the growth of Athens, or the existing regional inequalities, or even the behaviour and characteristics of a particular group of people living in a specific zone. However, it gives a general description of the structure of the relevant variables that are evident in the region.

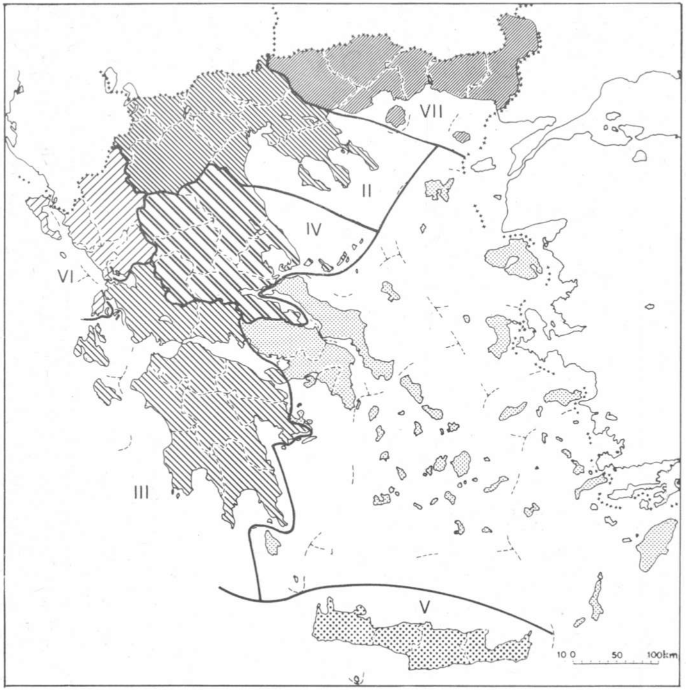
The merit of this general description lies in the fact that it can be used as a basis for other studies.

V. an outline of future work

Regions or cities do not exist in isolation. They constitute a minor part of a general system of mutual interrelations. Equilibrium of the system can be reached only if the elements constituting it are in equilibrium among them. As Echenique (1974) points out, a city reaches its internal equilibrium given certain external conditions. If

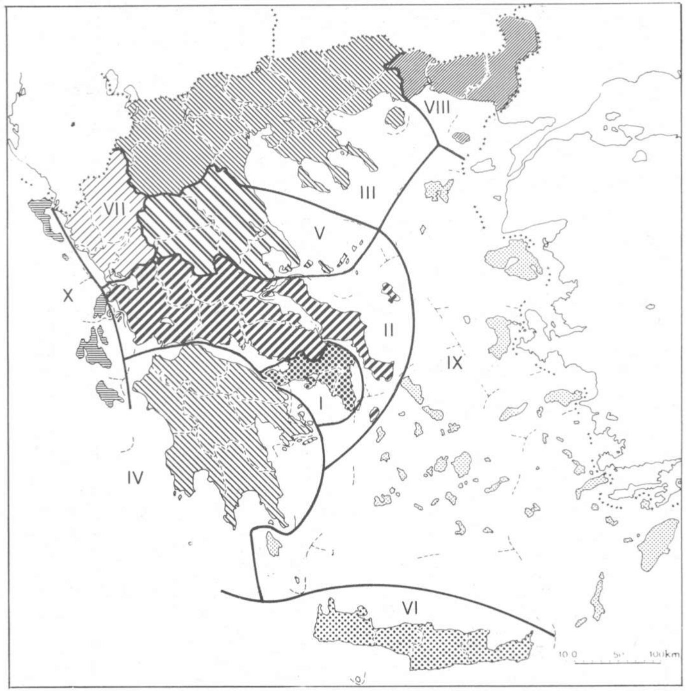
Map 6.

Administrative Regions



I Attica/Rest of Central Greece and Aegean Islands
II Central Western Macedonia
III Peloponnesos/Rest of Western Central Greece and Ionian Islands
IV Thessaly
V Crete
VI Epirus and Rest of Ionian Islands
VII Eastern Macedonia and Thrace

Statistical Regions



I Greater Athens Area
II Rest of Central Greece/Euboea
III Macedonia
IV Peloponnesos
V Thessaly
VI Crete
VII Epirus
VIII Thrace
IX Aegean Islands
X Ionian Islands

these conditions change then the internal equilibrium of the city will change. This statement provides the basis of future work.

We can distinguish three main levels of resolution.

The first of macro-level describes the interregional structure of the country.

The second or intermediate level represents the metropolitan area of the capital using as input the macro-level output.

The third or micro-level constitutes a behavioural analysis of a particular group of migrants in the metropolitan area.

An attempt will be made at the macro-level to define the most relevant variables and relationships pertaining to the inter-regional equilibrium. The main interest of the research is going to be the study of the intra-regional migration towards Athens and its effects on the internal structure of the city. For that purpose the whole of the country will be divided into regions. Map 6 gives an idea of the existing divisions. In each of these regions we will examine the relevant variables (investment, population, employment possibilities, differential salaries, etc.) which lead to the intra-regional movements with particular emphasis on the migration into Athens. An account will be given of the socioeconomic and political factors which resulted in the differentiation between regions. Special emphasis will be granted to the testing of the most recent regional policies aimed at effecting decentralisation (creation of regional growth poles).

Having obtained figures for the migrants in Athens we will disaggregate the totals according to socioeconomic groups. Their initial location will be determined by existing land values for each socioeconomic group. Correspondingly a disaggregated static model will be used to describe the changes in the structure of the region arising from this distribution, at different points in time. This stage covers the intermediate level of research.

At the third or micro-level, a study will be made of the residential mobility of migrants with particular emphasis on the group who locates initially in land falling outside the Master Plan Control Area.

There are two main reasons for this interest. Firstly, being peculiar to the area, this behaviour is not adequately reflected in existing models, and secondly, this constitutes the single most important mode of location in the expansion of the city. This should not be confused with similar phenomena occurring in European or Latin American cities (squatters, baracados, etc.) in that, while it is legal to purchase the land, it is illegal to build on it. The reasons for this situation date back to the 1922 migration from Asia Minor when almost 400,000 people settled in the outskirts of the city.

The present mechanism of location may be described in the following way.

Cheap agricultural land is purchased by developers and divided into grid square plots. The division is made without regard to future incorporation of the settlement in a large suburban area. Neither is any provision made for the introduction of services such as water, electricity, sewage, public transportation, etc. The single attraction of the land is its low price. For that reason it is mainly bought by poor migrants coming from agricultural regions. Shelters are built illegally and with the passage of time a considerable settlement develops. The inhabitants of these areas introduce primary service themselves, such as, water or electricity. It is only as a result of pressure from the inhabitants that the settlement is legalised. The results of the legalisation may be grouped into three categories:

The land value rises by a factor of three or four.

The central government provides basic services like schools, public transportation, churches, etc.

With rising land values, inhabitants have the option of selling their property and move closer to their employment, friends or services. The latter point forms the basis for the proposed study since it is the main reason for residential mobility of the particular migrant group.

VI. appendices

1. The main purpose of the run of the automatically calibrated model was to provide the best parameters for the calibration of the simple static model. A full description of the model is given elsewhere (Baxter, Williams 1974). We will comment here on some aspects of its calibration mainly with regards to the required data.

The data required for the run of the model were:
the land available for development, basic employment, service employment, residential population, floorspace for basic and service employments and residential population for each zone of the study area.

The parameters needed were the following four:
The stock parameter initialised to zero.
The mean trip length to work and to services.
The power index initialised to zero.
An accessibility matrix of the transportation routes of the area is also necessary.

VARIABLES

Number	Mean	S.D.	B with 4	Alpha	A	S.E.	T
1	20142.7227	23687.2639	0.9295	0.0961	0.0014	0.0005	3.1297
2	19096.5195	31088.4809	0.9199	0.5128	0.0058	0.0003	19.9731
3	176906.812	146885.187	0.9005	0.4858	0.0012	0.0000	25.6295
4	367.2661	349.7139					

Intercept 23.9236
Multiple Correlation 0.9992
Standard Error of Estimate 15.9972

Source of Variance	Degrees of Freedom	Sum of squares	Mean square	F
Regression	3	1831681.00	610560.312	2385.8484
Residuals	11	2815.0000	255.9091	

Entity	Observed	Model	Residual
1	1878.00	1384.10	- 6.10
2	210.00	209.54	0.46
3	617.00	620.49	- 3.49
4	547.00	550.24	- 3.24
5	680.00	678.08	1.92
6	637.00	620.22	16.78
7	421.00	413.88	7.12
8	224.00	201.53	22.47
9	270.00	299.72	-29.72
10	176.00	164.61	11.39
11	26.00	53.71	-27.71
12	123.00	116.53	6.47
13	41.00	41.33	- 0.33
14	131.00	122.50	8.50
15	28.00	32.52	- 4.52

PARAMETERS STOCK -0.186 RESIDENTIAL -0.025 SERVICE -0.043 POWER 1.47

	FLOOR AREAS				PEOPLE			
	Service employment		Residential population		Service employment		Residential population	
	Real	Model	Real	Model	Real	Model	Real	Model
1	37441.	29092.	177363.	112420.	126277.	69723.	434501.	315705.
2	2232.	1496.	47261.	43964.	7529.	3585.	115779.	110776.
3	5133.	10199.	161840.	137766.	17312.	24444.	396473.	326420.
4	5382.	28658.	121326.	177066.	18151.	68684.	297221.	475702.
5	7023.	30523.	170472.	262553.	23686.	73155.	417620.	682021.
6	14489.	11817.	96078.	106729.	48866.	28321.	235369.	287999.
7	38450.	4716.	98732.	92763.	12968.	11303.	241871.	194583.
8	2289.	1526.	44341.	59829.	7720.	3656.	108625.	129502.
9	3154.	382.	72689.	25071.	10637.	916.	176603.	40731.
10	1390.	689.	33645.	30192.	4689.	1651.	82422.	43538.
11	314.	14.	7446.	2005.	1060.	34.	18240.	2413.
12	746.	131.	23391.	12971.	2578.	313.	57080.	15467.
13	90.	9.	4664.	983.	302.	21.	11425.	981.
14	1174.	160.	23248.	14138.	3959.	383.	56953.	19998.
15	212.	18.	1152.	3635.	714.	43.	2823.	5180.

Unfortunately there were no data available for the floorspaces taken separately for basic and service employment and residential population. The required floorspaces were calculated from the following equations:

$$F_i^B = g_i a_b B_i \quad (1)$$

$$F_i^S = g_i a_s S_i \quad (2)$$

$$F_i^R = g_i a_s R_i \quad (3)$$

where:

$F_i^B =$ floorspace for basic employment in zone i,

$F_i^S =$ floorspace for service employment in zone i,

$F_i^R =$ floorspace for residential population in zone i,

$a_b, a_s, a_r =$ multipliers

g_i = parameters

The values for g_i, a_b, a_s, a_r, were obtained by the means of a regression analysis between the following variables:

$$F_i^{tot} = g_i \; (a_b B_i + a_s S_i + a_r R_i) \quad (4)$$

where:

F_i^{tot} = total floorspace in zone i.

Using equations 1, 2, 3, values for F_i^B, F_i^S, F_i^R, were thus obtained. The diagrams in page 173 provide the output of the regression analysis and the automatically calibrated model respectively.

2. The mean trip length was calculated by the following equation:

$$\frac{\Sigma_i \Sigma_j T_{ij} t_{ij}}{\Sigma_i \Sigma_j T_{ij}} = 32.32 \text{ min}$$

where:

$T_{ij} =$ origine-destination matrix

$t_{ij} =$ accessibility matrix

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