UTILIZATION OF THE EMPIRIC LAND USE FORECASTING MODEL FOR INVESTIGATIONS OF URBAN DEVELOPMENT PLANNING STRATEGIES

by

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CHAPTER I

INTRODUCTION

Because of the increasing complexity in the patterns of urban growth and development, our cities today require the efforts of dedicated urban planners, engineers and administrators. One of the great challenges that faces our cities' administrators is the preparation of plans for the cities' future that will include simultaneous changes in both land use and transportation facilities.

In the past, a plan or forecast of future patterns of land uses normally has been prepared somewhat independently of planned transportation facilities (8). An important missing link in the metropolitan plan-making process has been the effect that transportation facilities themselves have in shaping the land use pattern, and by considering this effect, the planner probably will note a greater usage of transportation facilities, since it is known that transportation facilities often attract land uses which require such facilities. Because of this heightened use, it is imperative that the planner and engineer plan transportation facilities to accommodate not only those land use activities already in place and those expected or planned for urban expansion, but also those activities which will be induced to redistribute themselves spatially under the influence of the proposed transportation facilities (8).

Planning Process

The difficult task of setting goals and objectives is the heart of the planning process. Today, most of our planning efforts revolve around the theory of formulating goals in terms of physical development, which in reality reflects social and economic objectives. From the evolution of these goals comes the formulation of plans, usually consisting of maps and statements which describe the desired condition of the area at some future date. These plans traditionally are based on a series of studies and analyses investigating population and employment characteristics, behavorial characteristics (such as travel habits and recreation patterns), land use characteristics, and physical standards of various types (including facility service levels, density standards, aesthetic criteria, etc.) (8). After carefully considering all of this material to the best of his ability, the planner chooses, on a subjective basis, one of a series of preliminary comprehensive plans he has drawn for the area. Additional corrections and updating are performed on the chosen plan which then is presented for approval.

A new awareness of the shortcomings in the planning process has forced the modern urban planner to examine alternatives more carefully. Confronted with an almost infinite number of possible alternative plans, the planner finds himself almost completely deficient in techniques of comparative analysis (8). Because of this deficiency, he now is turning to mathematical models and the high speed electronic computer for assistance. Thus, a mathematical model that could be fully integrated into the continuing planning process becomes very important.

Land Use Forecasting Procedures

In order to properly forecast land use values for the future, collection and processing of a detailed and comprehensive set of small area, time series socio-economic data for a large metropolitan area is required. This first step of data collection is a difficult and time-consuming process. Sophisticated regional planning models, whose value lies partly in that they force the user to define his input and output terms precisely and systematically, generally require large amounts of data for their application (9). The next step is to summarize and classify such data into specified groups so as to be usable in the appropriate forecasting model. Once the data are classified properly and used as input to the appropriate mathematical land use model, future land use variables can be obtained.

The EMPIRIC Model

A model that can be fully integrated into the continuing planning process of a metropolitan area is the

EMPIRIC Land Use Forecasting Model (9). The model does not apply optimization techniques nor does it restrict freedom of choice; rather, it attempts to make planning a more meaningful procedure by simulating the likely functional or performance characteristics deriving from alternative policies, plans and program (9). It should be understood that the EMPIRIC Land Use Forecasting Model is not a substitute for planning, but an aid in the planning process.

Inherent in the EMPIRIC Land Use Forecasting Model is the capability both of reproducing significant parts of the environment and of predicting the future distribution of land use activities given present land uses, estimates of future regional land use totals, and present and anticipated transportation, water, and sanitary facilities as inputs. This capability is necessary in order to provide information for judging alternative plans in terms of a set of desired goals or objectives.

The EMPIRIC Land Use Forecasting Model basically has two main uses. The first use is to predict, for various planning purposes, the future values of urban population, employment, and related variables. One such purpose is for input into traffic forecasting models (9). The testing of alternative regional plans for their functional utility is the second use of the model. The model will allow the planner to analyze, test, and evaluate the input of alternative policy decisions regarding transportation, zoning, open space, utilities, etc. and thus enable him to present to decision makers a series of clear cut public policy choices together with the implications of each.

Purpose of Research

It is the purpose of this research to investigate the uses of the EMPIRIC Land Use Forecasting Model for developing better and more rational plan alternatives. This investigation requires two studies, the first dealing with the selection of certain regional plans describing the use of transportation, zoning, open space, utilities, etc., and the subsequent determination of subregional land use values for the forecast period. The second study deals with the selection of a regional transportation (travel time) improvement plan that will induce growth in subregional land use variables that will bring their intensities as close to a priori goals as possible. The studies are presented in Chapter IV following a discussion of land use models in general and the EMPIRIC Model in particular in Chapters II and III, respectively. The results of these studies are found in Chapter V.

CHAPTER II

LITERATURE REVIEW

Most urban transportation planning studies during the past fifteen years have produced, or are producing, estimates of future land use in all subregions of the metropolitan areas, mainly with the objective in mind of estimating future traffic demand. Land use in this context refers to intensities of use (population and economic activity) as well as classification of use. Methods employed for these land use estimates have ranged from intuitive projections to systematic techniques based on quantitative reasoning. Since there are numerous land use forecasting models, many of them using similar techniques, this review, taken from Highway Research Record No. 88 (10), will be confined to a general discussion of the merits and disadvantages of previous models.

1. Most models predict the future state of the system rather than increments of change in the system. The difficulty with this is that short-term projections could be in great error. For example, if we wanted to forecast the system a year from now, we would do well to utilize information on the present state of the system and make small changes; a model which works from first principles

would tend to introduce its statistical errors into the projections and probably produce results considerably different from those of today. However, as longer term projections are made, the present state of the system is less of an indication of the future state, and such projection may have some merit, particularly in a very gross sense for large areas.

2. Most of the models rely on an exogenous prediction of total manufacturing employment in the region. Some models also use this variable as a predictor of total population, which then serves as another control total. Retail employment usually does not have a control total and depends on population of individual zones. In most instances there is no difficulty in relating regional control totals to the sum of individual zonal values since it is only a question of adjusting in one step the individual zonal figures by a proportionality factor to make their total add up to the exogenous control total.

3. Most of the models make some adjustments for zonal capacities of population and employment. These are usually in the form of past observed values for population per residential acre times the

number of residential acres, and similar figures for employment. The population density figures and residential acres are often set by existing zoning and subdivision control regulations. The problem here is that zoning laws are subject to change, especially under demand pressures, and to set an absolute, inviolate, capacity limitation requires some assurance of its applying in the future. Zonal capacities are essential to the forecasting process, but they have to be recognized as assumptions about governmental regulations which may change in the future.

4. There is a tendency in the various models to predict manufacturing employment and land use first and to use this information as input to the population distribution phase which, in turn, is used as input to the retail employment distribution phase. There appears to be a definite logic in distributing retail employment after population; indeed some empirical evidence is available in various studies of food and general merchandizing employment on the lag of retailing establishment decentralization after the decentralization of population. The arguments for predicting manufacturing employment before

population are not so convincing. It is argued that there are only a limited number of locations which are suitable for certain types of industries and that these are relatively independent of population. This is held to follow from the fact that travel is becoming faster and that industry will not have much trouble recruiting workers wherever it locates, as long as it can pay a good wage.

5. It generally seems to be recognized that direct data flow from the end of one forecasting period to the beginning of the next is necessary, if not within the model, then at least by some type of manual updating. This is necessary because the inertia of an urban system is such that any forecast which disregards the immediately previous state of the system may predict sudden and perhaps oscillatory changes in land use which are not reflected in real life.

6. None of the models comprises a fully integrated formulation which allows the simultaneous forecasting of all urban variables pertinent to regional planning studies; that is, each of the models is either one submodel, dealing with one set of variables such as residential, industrial, or commercial activities, or a number of such

submodels which are applied serially to obtain the desired output values. An attempt to apply any set of submodels for comprehensive urban forecasts suffers from two weaknesses: (1) assumptions must be made about which submodels should be run first, i.e., which variables are "primary" and which are "secondary" in locational characteristics; and (2) relationships and parameters must be determined separately for each submodel, leading to questions (which are difficult to answer) concerning reliability of the models when applied in concert. Thus, there appears to be some advantage in a model which handles all variables simultaneously and consequently allows the derivation of a self-consistent set of parameters. However, such a model may suffer other difficulties, such as parametric instability and difficulty of interpretation. While it is a laudable goal, the fully integrated model may prove to be difficult to achieve as an operational technique.

7. All of the models reviewed show some dependence on travel accessibilities, whether explicitly in terms of travel times to various types of activities in other zones, or implicitly in terms of distance to the center of the urban region. The use of

distance as a measure of accessibility precludes model sensitivity to actual or proposed changes in transportation systems, which generally have little effect on travel distances but may have profound effects on travel times, costs, and convenience levels.

The EMPIRIC Model, to be detailed in the next chapter, overcomes many of the deficiencies outlined above and, at this date, appears to be the most reliable land use prediction model available.

CHAPTER III

EXPLANATION OF THE EMPIRIC MODEL

The EMPIRIC Land Use Model has been formulated to satisfy several criteria for models which arise from the recognition of deficiencies in past modeling efforts. The first order criteria are the abilities:

1. To recognize the simultaneous and interacting nature of metropolitan development;
2. To take planned changes in the transportation system (both highway and transit) and use these changes as direct inputs;
3. To output important categories of population, employment, and car ownership variables, thus providing data for forecasting trip origins, destinations, and modal splits; and
4. To provide forecasts for sufficiently small areas to allow meaningful forecasting of trip origins, destinations, and modal splits.

Criteria of a second order are:

1. The model should be able to accept important non-transportation policy decisions as inputs. The model output should be a systematic estimate of how a region would develop under the influence of regional growth or decline rates and relative

planning policies, not only with respect to transportation but also to utilities, zoning, open space, etc.

2. The model should be developed in accordance with reasonable budget limits on operating (analysis) costs.
3. Input and output to the model should be compatible with other needs, for example, input transportation networks should be the same as those needed for traffic work.

Theory of the EMPIRIC Model

The EMPIRIC Land Use Forecasting Model is based on the concept that changes in regional patterns of population and employment are the results of locational decisions by family units and by commercial and industrial establishments and that these decisions are functions of public development policies as well as of existing development patterns and trends (6). The model uses systematic interrelations among development patterns of urban activities to provide a basis for the prediction of these locational decisions.

Also considered in the model theory is the general idea that growth in a zone containing families within a particular range of income will be correlated positively with growth in other zones containing families within similar or slightly higher income ranges, thereby illustrating the pattern of upward economic mobility as well as the tendencies of similar income classes to cluster in the same geographic areas. Families in classes of widely separated incomes would tend to locate considerable distances from one another (6).

Lower income groups would be expected to locate close to their places of employment and to shopping areas. Since they would own fewer automobiles they would require more transit service than the higher income groups. Middle and upper middle income groups would be expected to locate in more exclusive residential areas than the lower income groups, especially because of the latter groups' inability to pay higher rents and transportation costs. However, higher income groups still would be expected to locate in areas that have good accessibilities to other areas. The highest income group would probably be relatively insensitive to accessibility in their search for other residential amenities, mainly because of their ability to pay the higher transportation costs.

All industries would be expected to try to locate in areas that have high accessibilities to the population: to the lower income groups for a ready labor supply for manufacturing and to the middle and upper income groups for potential customers and for employees for retail and services employment. Also, improvement in water supply and sewage disposal service in an area would be expected to be associated with growth of population and employment categories in that area.

General Description of the EMPIRIC Model

The EMPIRIC Land Use Model is designed primarily to satisfy the need for zonal or subregional distributions of future year land use activities, which could then be used as inputs to a traffic prediction model. Inputs to the EMPIRIC Model for purposes of forecasting, are exogenously forecasted regional totals of the variables to be forecast in the model (i.e., those to be distributed to the various constituent subregions of the region), data describing the region at the beginning of the forecast interval, and a statement of the various alternative development policies to be tested (8). Outputs from the model are the values of the subregional land use variables for the forecast period.

A detailed description of all input and output variables is shown in Tables I-VI. Variables measured at the forecast (future) year are succeeded by (t). Variables measured at the present year are succeeded by (t-1). Subscripts g and h are used to define the applicable subregions (zones). The discussion of the actual relationships

TABLE I

BASIC INPUTS TO THE EMPIRIC MODEL

Present Land Use Variables, $V_{ih}(t-1)$

$V_{1h}(t-1)$ = Number of families with an annual income less than \$5,000.

$V_{2h}(t-1)$ = Number of families with an annual income between \$5,000 and \$9,999.

$V_{3h}(t-1)$ = Number of families with an annual income between \$10,000 and \$14,999.

$V_{4h}(t-1)$ = Number of families with an annual income equal to or greater than \$15,000.

$V_{5h}(t-1)$ = Number of persons in manufacturing and construction employment (S.I.C. Codes 15-39).

$V_{6h}(t-1)$ = Number of persons in wholesale, transportation, communication, utilities and government employment (S.I.C. Codes 1-14, 40-50, 91-99).

$V_{7h}(t-1)$ = Number of persons in retail employment (S.I.C. Codes 52-59).

$V_{8h}(t-1)$ = Number of persons in service employment (S.I.C. Codes 70-89).

$V_{9h}(t-1)$ = Number of persons in finance, insurance, and real estate employment (S.I.C. Codes 60-67).

Present Land Area Variables

NAP_h = Net residential area, in acres.

NAM_h = Net manufacturing area, in acres.

NAR_h = Net retail area, in acres.

ODA_h = Other developed area, in acres.

DA_h = Developable area, in acres.

UA_h = Total used area = $NAP_h + NAM_h + NAP_h + ODA_h$

GA_h = Gross area = $UA_h + DA_h$

TABLE II

BASIC INPUTS TO THE EMPIRIC MODEL

Present Controllable Variables

$TA_{gh}(t-1)$ = travel time by automobile from subregion g to subregion h, in minutes.

$TT_{gh}(t-1)$ = travel time by transit from subregion g to subregion h, in minutes.

$w_h(t-1)$ = water supply index, ranging from 1 through 7, indicating type of water supply service.

$s_h(t-1)$ = sewage disposal index, ranging from 1 through 5, indicating type of sewage disposal service.

Water Supply Index

Code Number	Type of System
1	Individual wells.
2	Combination of individual wells and municipal supply.
3	Municipal surface supply.
4	Combination of municipal surface and ground supply.
5	Municipal ground supply.
6	Municipal and MDC supply.
7	MDC supply.

Sewage Disposal Index

Code Number	Type of System
1	Septic tank.
2	Combination septic tanks and municipal system.
3	Municipal system.
4	Combination of septic tanks and/or municipal system and MDC system.
5	MDC system.

TABLE III

BASIC INPUTS TO THE EMPIRIC MODEL

Future Total Land Use Variables, $T_i(t)$

$T_1(t)$	=	Total number of families with an annual income less than $5,000.
$T_2(t)$	=	Total number of families with an annual income between $5,000 and $9,999.
$T_3(t)$	=	Total number of families with an annual income between $10,000 and $14,999.
$T_4(t)$	=	Total number of families with an annual income equal to or greater than $15,000.
$T_5(t)$	=	Total number of persons employed in manufacturing and construction employment.
$T_6(t)$	=	Total number of persons in wholesale, transportation, communication, utilities, and government employment.
$T_7(t)$	=	Total number of persons employed in retail employment.
$T_8(t)$	=	Total number of persons employed in service employment.
$T_9(t)$	=	Number of persons employed in finance, insurance, and real estate employment.

Future Controllable Variables

$w_h(t)$	=	Water supply index, ranging from 1 through 7, indicating type of water supply service.
$s_h(t)$	=	Sewage disposal index, ranging from 1 through 5, indicating type of sewage disposal service.
$TA_{gh}(t)$	=	Travel time by automobile from subregion g to subregion h, in minutes.
$TT_{gh}(t)$	=	Travel time by transit from subregion g to subregion h, in minutes.

TABLE IV

TRANSFORMED INPUTS TO THE EMPIRIC MODEL

<u>Present Activity Variables</u> $(U_{zh}(t-1))$

$$U_{1h}(t-1) = V_{1h}(t-1) + V_{2h}(t-1) + V_{3h}(t-1) + V_{4h}(t-1)$$

= total families

$U_{2h}(t-1) = V_{1h}(t-1) + V_{2h}(t-1)$ = number of families with an annual income less than \$10,000.

$U_{3h}(t-1) = V_{3h}(t-1) + V_{4h}(t-1)$ = number of families with an annual income greater than \$10,000.

$$U_{4h}(t-1) = V_{5h}(t-1) + V_{6h}(t-1) + V_{7h}(t-1) + V_{8h}(t-1)$$

$+ V_{9h}(t-1)$ = total employment.

<u>Present Transformed Controllable Variables</u> $(W_{kh}(t-1))$

$$W_{1h}(t-1) = UA_h(t-1) \cdot s_h(t-1)$$

$$W_{2h}(t-1) = UA_h(t-1) \cdot w_h(t-1)$$

$$W_{3h}(t-1) = \sum_{g=1}^{G} UA_h(t-1)\ U_{1g}(t-1)\ \text{EXP}\ (-B \cdot TA_{hg}(t-1))$$

$$W_{4h}(t-1) = \sum_{g=1}^{G} UA_h(t-1)\ U_{4g}(t-1)\ \text{EXP}\ (-B \cdot TA_{hg}(t-1))$$

$$W_{5h}(t-1) = \sum_{g=1}^{G} UA_h(t-1)\ U_{3g}(t-1)\ \text{EXP}\ (-B \cdot TA_{hg}(t-1))$$

$$W_{6h}(t-1) = \sum_{g=1}^{G} UA_h(t-1)\ U_{1g}(t-1)\ \text{EXP}\ (-B \cdot TT_{hg}(t-1))$$

$$W_{7h}(t-1) = \sum_{g=1}^{G} UA_h(t-1)\ U_{4g}(t-1)\ \text{EXP}\ (-B \cdot TT_{hg}(t-1))$$

$$W_{8h}(t-1) = \sum_{g=1}^{G} UA_h(t-1)\ U_{2g}(t-1)\ \text{EXP}\ (-B \cdot TT_{hg}(t-1))$$

TABLE V

TRANSFORMED INPUTS TO THE EMPIRIC MODEL

Future Transformed Controllable Variables ($W_{kh}(t)$)

$$W_{1h}(t) = UA_h(t) \cdot s_h(t)$$

$$W_{2h}(t) = UA_h(t) \cdot w_h(t)$$

$$W_{3h}(t) = \sum_{g=1}^{G} UA_h(t-1)\ U_{1g}(t-1)\ EXP\ (-B \cdot TA_{hg}(t))$$

$$W_{4h}(t) = \sum_{g=1}^{G} UA_h(t-1)\ U_{4g}(t-1)\ EXP\ (-B \cdot TA_{hg}(t))$$

$$W_{5h}(t) = \sum_{g=1}^{G} UA_h(t-1)\ U_{3g}(t-1)\ EXP\ (-B \cdot TA_{hg}(t))$$

$$W_{6h}(t) = \sum_{g=1}^{G} UA_h(t-1)\ U_{1g}(t-1)\ EXP\ (-B \cdot TT_{hg}(t))$$

$$W_{7h}(t) = \sum_{g=1}^{G} UA_h(t-1)\ U_{4g}(t-1)\ EXP\ (-B \cdot TT_{hg}(t))$$

$$W_{8h}(t) = \sum_{g=1}^{G} UA_h(t-1)\ U_{2g}(t-1)\ EXP\ (-B \cdot TT_{hg}(t))$$

Land Developability Variables ($L_{jh}(t-1)$)

$$L_{1h}(t-1) = NAP_h(t-1) \left[GA_h(t-1) - UA_h(t-1)\right] / GA_h(t-1)$$

$$L_{2h}(t-1) = NAM_h(t-1) \left[GA_h(t-1) - UA_h(t-1)\right] / GA_h(t-1)$$

$$L_{3h}(t-1) = NAR_h(t-1) \left[GA_h(t-1) - UA_h(t-1)\right] / GA_h(t-1)$$

TABLE VI

OUTPUTS FROM THE EMPIRIC MODEL

Future Land Use Variables ($V_{ih}(t)$)

$V_{1h}(t)$ = Number of families with an annual income less than $5,000.

$V_{2h}(t)$ = Number of families with an annual income between $5,000 and $9,999.

$V_{3h}(t)$ = Number of families with an annual income between $10,000 and $14,999.

$V_{4h}(t)$ = Number of families with an annual income equal to or greater than $15,000.

$V_{5h}(t)$ = Number of persons in manufacturing and construction employment (S.I.C. Codes 15-39).

$V_{6h}(t)$ = Number of persons in wholesale, transportation, communication, utilities and government employment (S.I.C. Codes 1-14, 40-50, 91-99).

$V_{7h}(t)$ = Number of persons in retail employment (S.I.C. Codes 52-59).

$V_{8h}(t)$ = Number of persons in service employment (S.I.C. Codes 70-89).

$V_{9h}(t)$ = Number of persons in finance, insurance, and real estate employment (S.I.C. Codes 60-67).

Future Additional Submodel Land Use Variables ($S_{mh}(t)$)

$S_{1h}(t)$ = Total number of families.

$S_{2h}(t)$ = Population.

$S_{3h}(t)$ = Number of automobiles.

$S_{4h}(t)$ = School enrollment, grades K-8.

$S_{5h}(t)$ = School enrollment, grades 9-12.

$S_{6h}(t)$ = Median family income multiplied by total families.

involved within the model is delayed until the details of the rather complex nature of the variables are examined. An example of the model is given in Chapter IV.

General Discussion of Model Inputs

The independent (input) variables in the EMPIRIC Model equations are generally divided into controllable variables and uncontrollable variables. Controllable variables are defined as variables whose future locations and intensities are controllable by the planner and thus subject to the policy decisions of urban government. Uncontrollable variables are those variables which are not controllable by the planner and thus are not subject to public policy decisions. These controllable and uncontrollable variables are further described as present basic and transformed inputs, and future basic and transformed inputs, as shown in Tables I - V. There is a need for transformation of some of the present and future basic inputs so that these inputs can be used properly in the model. A discussion of each of these types of inputs follows.

Present land use variables are divided into two categories, one composed of four population variables and the other composed of five employment variables. The population variables are stratified by family income, while the employment variables are defined as the numbers of persons employed in a particular industry, by place of employment, based on the Standard Industrial Classification Codes (15).

Present land area variables are variables designed to measure the capacity and propensity of a zone for growth of a particular type of activity. It would be possible to use these land area variables as controllable variables if sufficient control could be exercised by the planner over development by means of zoning, urban renewal, or purchase and development of land by the government. However, governmental control over development is limited: zoning is a regulatory power and does not always provide the incentive for development, and urban renewal and governmental purchase cover relatively small areas. Therefore, the land area variables are used as uncontrollable variables, and as a measure of the capacity of a zone to house growths of particular types of activities.

Present controllable variables are those variables related to public utilities, described by means of the quality of water supply and sewage disposal service. The level of service used in the model is calculated on a weighted basis, using a 1 through 7 scale for water supply service and a 1 through 5 scale for sewage disposal service. The code description used in the model is shown in Table II.

Future total land use variables are the regional totals in the forecast period for each land use variable. Just as the present land use variables, the future total land use variables are broken down into population and employment variables with the same detailed descriptions.

Future controllable variables are the same variables as the present controllable variables, except their value is based on the forecast period instead of the present time period.

The present and future basic variables are changed now to transformed present and future variables. This transformation is necessary so that the basic variables can be modified into different entities for proper use in the model. Explanation of the present and future transformed variables follows.

Present activity variables are those variables used to determine the accessibility of a zone to a particular activity. There are four activities used in this model: total families, number of families with an income of less than $10,000, number of families with an income greater than $10,000, and total employment. Also included in the present activity variables are the travel time variables for both automobile and rapid transit. It is these travel times which are most influential on the design of the transportation system, and it is through this system that the regional planner can exert the greatest influence upon the shaping of the environment (6). Transportation variables used in the EMPIRIC Model are called accessibilities. The accessibility of a zone g to an "activity" is defined as:

$$\sum_{h=1}^{H} U_{zh} e^{-B \cdot TA_{gh}(t-1)} \qquad (3\text{-}1)$$

where

U_{zh} = the quantity of present activity variable z in zone h,

H = total number of zones,

e = base of natural logarithms,

$TA_{gh}(t-1)$ = travel time by automobile from zone g to zone h in minutes,

B = an empirically derived factor usually between .005 and .15.

Present transformed controllable variables are divided into three basic groups: utilities service, vehicle accessibility of a zone to an activity, and transit accessibility to an activity. Before the utilities service variables are used in the model, they are multiplied by the used area of the zone. Likewise, each of the six accessibilities, three by automobile and three by rapid transit, are multiplied by the used area, UA, of the zone.

Future transformed controllable variables are similar to the present transformed controllable variables, with the exception of the travel times between the zones in the six accessibility equations and the time periods in the utilities service variables. It is emphasized that for the six accessibility equations, the only difference between the present transformed controllable variables and the future transformed controllable variables is the travel time between zones. These forecast travel times are obtained from the forecast year networks. Thus, changes in accessibility are due entirely to changes in travel times between zones.

Land developability variables are made up of the present land area variables and are transformed to measure the capacity of a zone for population growth and manufacturing and retail employment. The model does not include an explicit measurement of zoning because of the difficulty in collecting the data required for calibration and because zoning can have greatly varying degrees of effectiveness in controlling development in the various cities and towns of a region. Open space and recreation are not inputs to the model but are used by adjusting the land developability variables, so as to reduce the amount of land available for development.

General Discussion of Model Outputs

Nine dependent (output) variables are determined from the model; they are four population variables and five employment variables similar to the ones shown in Table I where the four population variables are broken down according to family income as follows: families with an annual income of less than $5,000; families with an annual income of between $5,000 and $9,999; families with an annual income of between $10,000 and $14,999; and families with an annual income of $15,000 and over. All incomes are measured in present year dollars.

The five employment variables are defined as the numbers of persons employed in a particular industry by place of employment. The Standard Industrial Classification Codes are used to define the particular type of industry. These employment variables are broken down into the following groups: manufacturing and construction (S.I.C. Codes 15-39); retail trade (S.I.C. Codes 52-59); finance, insurance and real estate (S.I.C. Codes 60-67); services (S.I.C. Codes 70-89); and others, including government, wholesale trade, transportation, communication, utilities, mining, agriculture, forestries and fisheries (S.I.C. Codes 01-14, 40-50, 91-99).

Several other variables are forecasted separately from the nine dependent variables. They are: total population, which is highly correlated with numbers of families within the various income ranges, automobile ownership, school enrollment - grades kindergarten through 8th, and school enrollment - grades 9 through 12. These variables are forecasted in a submodel and are based on the results of the nine output variables in the main model.

<u>Mathematical Description of the EMPIRIC Model</u>

All variables in the equations are expressed as shares of regional totals, and the model predicts changes in shares of activities between the base year and forecast year in each of the zones (subregions) into which the region is divided. In describing the model in mathematical terms a number of quantities must be defined:

$$R_{ih}(t-1) = \frac{V_{ih}(t-1)}{\sum_{h=1}^{H} V_{ih}(t-1)} \qquad (3\text{-}2)$$

$$R_{ih}(t) = \frac{V_{ih}(t)}{T_i(t)} \qquad (3\text{-}3)$$

$$\Delta R_{ih} = \frac{V_{ih}(t)}{T_i(t)} - \frac{V_{ih}(t-1)}{\sum_{h=1}^{H} V_{ih}(t-1)} \qquad (3\text{-}4)$$

$$Z_{kh}(t-1) = \frac{W_{kh}(t-1)}{\sum_{h=1}^{H} W_{kh}(t-1)} \qquad (3\text{-}5)$$

$$Z_{kh}(t) = \frac{W_{kh}(t)}{\sum_{h=1}^{H} W_{kh}(t)} \qquad (3\text{-}6)$$

$$\Delta Z_{kh} = \frac{W_{kh}(t)}{\sum_{h=1}^{H} W_{kh}(t)} - \frac{W_{kh}(t-1)}{\sum_{h=1}^{H} W_{kh}(t-1)} \qquad (3-7)$$

$$M_{jh}(t-1) = \frac{L_{jh}(t-1)}{\sum_{h=1}^{H} L_{jh}(t-1)} \qquad (3-8)$$

where

$R_{ih}(t-1)$ = share of present land use variable i at time period t-1, in subregion h.

$R_{ih}(t)$ = share of future land use variable i at time period t, in subregion h.

ΔR_{ih} = change in share of land use variable i, subregion h.

$Z_{kh}(t-1)$ = share of present transformed controllable variable k at time period t-1, in subregion h.

$Z_{kh}(t)$ = share of future transformed controllable variable k at time period t, in subregion h.

ΔZ_{kh} = change in share of the transformed controllable variable k, in subregion h.

$M_{jh}(t-1)$ = share of land developability variable j. at time period t-1, in subregion h.

The equations comprising the EMPIRIC Model now can be stated in a general form:

$$f(\Delta R, R(t-1), \Delta Z, Z(t-1), Z(t), M(t-1)) = 0 \qquad (3-9)$$

or in a specific form:

$$\sum_{i=1}^{N} a_{ip} \Delta R_{ih} + \sum_{i=1}^{N} b_{ip} R_{ih}(t-1) + \sum_{k=1}^{MM} c_{kp} \Delta Z_{kh}$$

$$+ \sum_{k=1}^{MM} d_{kp} Z_{kh}(t-1) + \sum_{k=1}^{MM} e_{kp} Z_{kh}(t)$$

$$+ \sum_{j=1}^{3} f_{jp} M_{jh}(t-1) = 0 \qquad (3\text{-}10)$$

This specific equation is a typical equation for each future land use variable p and for each subregion h. This equation also implies that the growth of a future land use variable p in subregion h is proportional to the <u>growth</u> of the remaining land use variables i in subregion h, the present <u>amount</u> of the land use variables i in subregion h, and the amount of other controllable and land developability variables k and j, respectively.

The coefficients a_{ip}, b_{ip}, c_{kp}, d_{kp}, e_{kp}, and f_{jp} are determined using simultaneous multiple linear regression techniques. Once the model has been calibrated, it is operated recursively for forecasting purposes. For each of the land use variables in each subregion there is one equation, and the system of equations is solved separately for each subregion. At full utilization, the model has N equations per subregion of the form previously discussed, whose simultaneous solution for a given forecasting period will provide growths or declines in subregional activity levels during this interval.

The formulation of the variables enables the growths or declines of land use levels to be handled quite easily. Once the changes in shares are forecasted, the model adds these changes to the shares at the beginning of the forecast interval to obtain the new zonal or subregional shares and then multiplies the new shares by regional totals at the end of the forecast interval to obtain the actual land use levels in each zone. Interpreting this statement mathematically, we find the actual land use levels by using a rearranged version of equation 3-4 as shown below:

$$V_{ih}(t) = \left[\Delta R_{ih} + \frac{V_{ih}(t-1)}{\sum_{h=1}^{H} V_{ih}(t-1)} \right] T_i(t) \qquad (3\text{-}11)$$

EMPIRIC Land Use Model Equations

The equations comprising the EMPIRIC Model and submodel are shown in Tables VII and VIII, with equations 1 through 9 comprising the main model and equations 10 through 13 comprising the submodel. All variables in both the main model and submodel are formulated as subregional shares of activities or as change in subregional shares. Variables measured at the forecast year are succeeded by (t), and variables measured at the base year are succeeded by (t-1). Variables representing changes between the base year and forecast year are preceded by (Δ). All (t) and (t-1)

TABLE VII

EMPIRIC LAND USE MODEL EQUATIONS

<u>Main Model</u>

<u>Equation 1:</u> $\Delta R_{ih} = .637\Delta R_{2h} - .295\Delta R_{3h} + .018\Delta R_{8h}$
$+ .133R_{1h}(t-1) - .109R_{3h}(t-1) + .044Z_{2h}(t-1) - .298\Delta Z_{4h}$
$- .068Z_{4h}(t-1)$

<u>Equation 2</u>: $\Delta R_{2h} = .530\Delta R_{1h} + .337\Delta R_{3h} + .022\Delta R_{7h}$
$+ .060\Delta R_{8h} - .101R_{2h}(t-1) + .036R_{8h}(t-1) + .044Z_{1h}(t)$
$+ .025M_{1h}(t-1) + .302\Delta Z_{4h} + .114\Delta Z_{6h}$

<u>Equation 3</u>: $\Delta R_{3h} = - .125\Delta R_{1h} + .627\Delta R_{2h} + .294\Delta R_{4h}$
$- .224R_{3h}(t-1) + .196Z_{1h}(t-1) + .145\Delta Z_{1h}$

<u>Equation 4</u>: $\Delta R_{4h} = - .282\Delta R_{2h} + .603\Delta R_{3h} - .278R_{4h}(t-1)$
$+ .145Z_{2h}(t-1) + .118Z_{1h}(t-1) + .046M_{1h}(t-1) - .384\Delta Z_{5h}$
$+ .093\Delta Z_{7h}$

TABLE VIII

EMPIRIC LAND USE MODEL EQUATIONS

Main Model

Equation 5: $\Delta R_{5h} = .220\Delta R_{6h} - .302R_{5h}(t-1) - .015R_{9h}(t-1)$

$+ .138M_{2h}(t-1) + .278\Delta Z_{8h} + .121Z_{3h}(t-1)$

Equation 6: $\Delta R_{6h} = .456\Delta R_{5h} + .081\Delta R_{7h} - .132\Delta R_{9h}$

$+ .106R_{5h}(t-1) - .194R_{6h}(t-1) - .144\Delta Z_{4h} + .095Z_{6h}(t-1)$

Equation 7: $\Delta R_{7h} = .440\Delta R_{6h} - .117R_{4h}(t-1) + .126R_{6h}(t-1)$

$- .363R_{7h}(t-1) + .165M_{3h}(t-1) + .213\Delta Z_{3h} - .064Z_{6h}(t-1)$

Equation 8: $\Delta R_{8h} = - .252\Delta R_{6h} - .510R_{8h}(t-1) + .022R_{9h}(t-1)$

$+ .620\Delta Z_{2h} + .240\Delta Z_{1h} + .564\Delta Z_{6h} + .390Z_{3h}(t-1)$

Equation 9: $\Delta R_{9h} = -.614\Delta R_{6h} + .020R_{8h}(t-1)$

$- .159R_{9h}(t-1) + .110Z_{6h}(t-1)$

Submodel

Equation 10: $S_{2h}(t) = .944Q_{1h}(t) + .016Z_{2h}(t) + .034Z_{7h}(t)$

Equation 11: $S_{3h}(t) = .871Q_{6h}(t) + .164Z_{2h}(t) - .042Z_{6h}(t)$

Equation 12: $S_{4h}(t) = .918Q_{1h}(t) + .154Z_{2h}(t) - .065Z_{6h}(t)$

Equation 13: $S_{5h}(t) = .874Q_{1h}(t) + .095Z_{1h}(t) + .037Z_{6h}(t)$

variables are formulated as subregional shares, and the (Δ) variables are formulated as changes in subregional shares.

For the submodel, let

$$Q_{mh}(t) = \frac{S_{mh}(t)}{\sum_{h=1}^{H} S_{mh}(t)} \qquad (3\text{-}12)$$

where $S_{mh}(t)$ = future additional submodel land use variable m, in subregion h, at time period t.

Observations Based on Makeup of EMPIRIC Land Use Model Equations

A number of observations can be made upon examination of the model equations. They are as follows:

1. Knowing that the magnitudes of the coefficients of the variables reflect the relative strengths of the causal influences on the growths of the output variables, one can see that the accessibility variables are the most important of the controllable variables. This observation is significant, because there seems to be greater control over the transportation system at the regional level than over other controllable variables relating to the development and physical arrangement of land patterns. For the most part, land development policies are determined at the local level by the citizens of the localities affected. Transportation policies cannot be isolated at the subregional level. The function of transportation is to

connect places which have differing transportation desires, and major transportation policies must be decided on a regional level (6). At best, planners can plan and promote transportation improvements which reinforce developmental decisions made at a local level (6).

2. The uncontrollable variables, that is, those over which there is no direct planning control, are generally more influential in establishing locational patterns than are the controllable variables. Growth in each of the family income groups is very strongly related to growth in the adjacent income groups. In three of the five employment equations, one of the other output employment variables is the strongest variable. Incorporations of this nature provide realism to this type of simultaneous model.

3. In all of the equations, the value of the output variable at the beginning of the forecast interval is one of the more important determinants of growth. It is known that the growth of a particular activity in a zone is significantly influenced by the amount of activity already present in that zone. Employment growth is found to be dependent more heavily on existing employment than is population growth on existing population levels.

4. A negative coefficient modifying growth in vehicle accessibility in the low income equation indicates that these low income families do not have resources to take their full share of the advantages of improvements in the regional highway system. The highest income group also exhibited a negative sign for this variable. This could mean that this group would rather pay the higher costs of transportation in order to reside in the suburbs. The very large income groups showed the concern for improved highways which many have taken for granted. Also, it can be seen that the middle and high income groups, in a very small but noticeable way, take advantage of transit and commuter railroad service charges.

CHAPTER IV

MODEL APPLICATION

The purpose of this research is to investigate the uses of the EMPIRIC Land Use Forecasting Model for developing better and more rational plan alternatives. Two applications in the form of objectives are required to accomplish this investigation. The first objective in research with the EMPIRIC Land Use Model is to explore the reliability of the model in forecasting values of subregional land use variables given values for the input variables specified in Tables I, II, and III of Chapter III. This objective deals more with the mechanical aspects of the model than with model theory.

The second objective in research with the EMPIRIC Land Use Model is to treat the future vehicle travel times between zones, $TA_{gh}(t)$, as decision variables and to find the values of these times which will cause development in each zone $(V_{ih}(t))$ that is as close to a priori goals as possible. According to the model, changes in interzonal travel times cause changes in the land use variables. Consequently, if certain zonal goals for land use variables are held desirable by regional decisionmakers, the question arises as to what broad changes in the transportation system (interpreted as changes in vehicle travel time) will be necessary to achieve these desired goals. To answer this question is the second objective of this research.

Application No. 1 - Trial

In the beginning of the research, it was hoped that data could be collected for the southwestern part of Virginia, placed into the model, and checked for accuracy. Since it would have been difficult to obtain this enormous amount of information in a short period of time, it was decided to use a hypothetical region with hypothetical data for its subregions. Every effort was made to assume data that were as practical and realistic as possible. It should be noted that since the model itself was highly complex in nature, trying to select meaningful and consistent data for the subregions was an arduous task.

A region of three traffic zones (subregions) was selected and is shown in Figure 1. Two of the zones were purposely made nearly identical in area and land use characteristics whereas the third zone was selected with land use area and characteristics considerably different from the other two zones, this action being done in a deliberate effort to check the model's forecasting ability and accuracy. The variables used as model application inputs are shown in Table X. Both present and future travel times between the zones were selected to provide a change

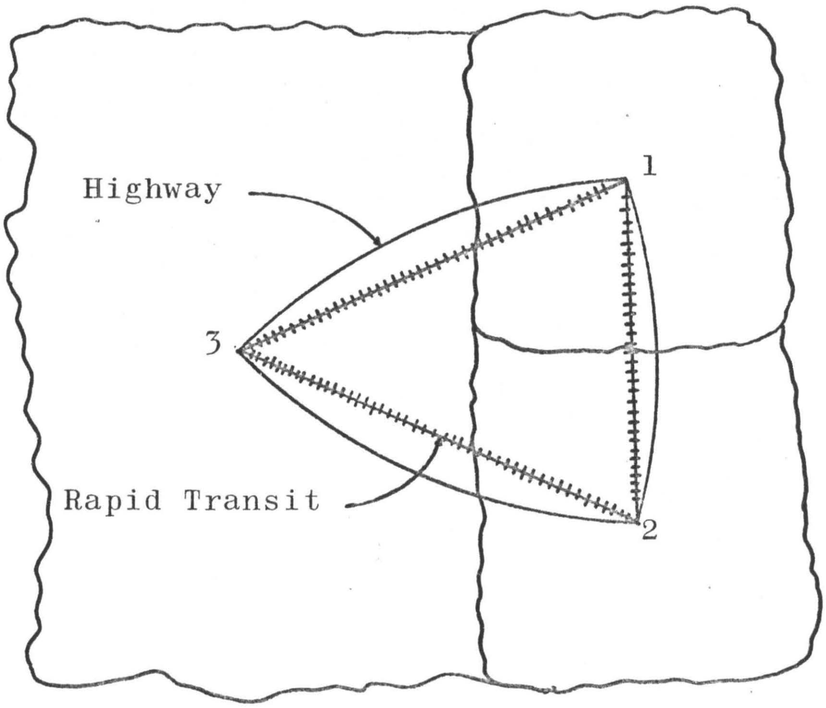

Figure 1. Hypothetical Plan of Region With Three Subregions Used in Application No. 1.

TABLE IX

TRAVEL TIMES BETWEEN ZONES IN MINUTES

USED AS INPUTS TO APPLICATION NO. 1*

Zones (g-h)	Vehicle		Rapid Transit	
	$TA_{gh}(t-1)$	$TA_{gh}(t)$	$TT_{gh}(t-1)$	$TT_{gh}(t)$
1-2	15	10	12	10
1-3	24	18	21	18
2-3	24	20	21	20

*$TA_{gh} = TA_{hg}$; $TT_{gh} = TT_{hg}$

TABLE X

ADDITIONAL MODEL APPLICATION NO. 1 INPUTS

Input Variables	Zone 1	Zone 2	Zone 3	Region Time Period (t)
$V_{1h}(t-1)$	1,000	1,000	500	1,000
$V_{2h}(t-1)$	2,000	2,000	500	6,000
$V_{3h}(t-1)$	500	500	1,500	4,000
$V_{4h}(t-1)$	500	500	2,000	4,000
$V_{5h}(t-1)$	2,000	2,000	500	5,000
$V_{6h}(t-1)$	1,000	1,000	2,000	5,000
$V_{7h}(t-1)$	1,000	1,000	1,500	4,400
$V_{8h}(t-1)$	1,000	1,000	1,000	3,750
$V_{9h}(t-1)$	1,000	1,000	1,000	3,750
$NAP_h(t-1)$	5,000	4,000	5,000	-
$NAM_h(t-1)$	15,000	18,000	5,000	-
$NAR_h(t-1)$	10,000	8,000	5,000	-
$UA_h(t-1)$	30,000	30,000	20,000	-
$GA_h(t-1)$	32,000	32,000	64,000	-
$L_{1h}(t-1)$	313	250	3,440	-
$L_{2h}(t-1)$	940	1,130	3,440	-
$L_{3h}(t-1)$	625	500	3,440	-
$w_h(t-1)$	7	7	7	-
$s_h(t-1)$	5	5	5	-
$w_h(t)$	7	7	7	-
$s_h(t)$	5	5	5	-
$S_{1h}(t)$	4,000	4,000	4,500	15,000
$S_{2h}(t)$	15,000	15,000	15,000	56,250
$S_{3h}(t)$	3,000	4,000	6,000	17,000
$S_{4h}(t)$	2,000	3,000	2,000	10,000
$S_{5h}(t)$	4,000	3,000	4,000	14,000
$S_{6h}(t)$	32×10^6	32×10^6	45×10^6	150×10^6

TABLE XI

CALCULATION FOR TRAVEL ACCESSIBILITY
FOR EQUATION 1, ZONE 1, APPLICATION NO. 1

From Equation (3-7), for any zone h:

$$\Delta Z_{4h} = \frac{W_{4h}(t)}{\sum_{h=1}^{H} W_{4h}(t)} - \frac{W_{4h}(t-1)}{\sum_{h=1}^{H} W_{4h}(t-1)}$$

Therefore for zone 1:

$$\Delta Z_{41} = \frac{W_{41}(t)}{\sum_{h=1}^{H} W_{4h}(t)} - \frac{W_{41}(t-1)}{\sum_{h=1}^{H} W_{4h}(t-1)}$$

and from Table V:

$$W_{4h}(t) = \sum_{g=1}^{G} UA_h(t-1)\ U_{4g}\ EXP(-B \cdot TA_{hg}(t))$$

Therefore for zone 1, with g defining all zones:

$$W_{41}(t) = \sum_{g=1}^{G} UA_1(t-1)\ U_{4g}(t-1)\ EXP(-B \cdot TA_{1g}(t))$$

$$= 30{,}000 \left[6000e^0 + 6000e^{-(.05)(10)} + 6000e^{-(.05)(18)}\right]$$

$$= (30{,}000)(6000) \left[e^0 + e^{-(.05)(10)} + e^{-(.05)(18)}\right]$$

$$W_{41}(t) = (30{,}000)(6000)(2.01) = 36.18 \times 10^7$$

and

$$\sum_{h=1}^{H} W_{4h}(t) = \sum_{h=1}^{H} \sum_{g=1}^{G} UA_h(t-1)\ U_{4g}(t-1) EXP(-B \cdot TA_{hg}(t))$$

$$= (30{,}000) \left[6000e^0 + 6000e^0 + 6000e^0 + 6000e^{-(.05)(10)}\right.$$

$$+ 6000e^{-(.05)(10)} + 6000e^{-(.05)(18)}$$

$$+ 6000e^{-(.05)(18)} + 6000e^{-(.05)(20)}$$

$$\left. + 6000e^{-(.05)(20)}\right]$$

$$= 30{,}000(6000)\left[3e^0 + 2e^{-(.05)(10)} + 2e^{-(.05)(18)}\right.$$

$$\left. + 2e^{-(.05)(20)}\right]$$

$$\sum_{h=1}^{H} W_{4h}(t) = (30{,}000)(6000)(5.75) = 102.75 \times 10^7$$

TABLE XII

CALCULATION FOR TRAVEL ACCESSIBILITY FOR EQUATION 1, ZONE 1, APPLICATION NO. 1

From Table IV:

$$W_{41}(t-1) = \sum_{g=1}^{G} UA_1(t-1)\ U_{4g}(t-1)\ EXP(-B \cdot TA_{1g}(t-1))$$

$$= 30{,}000 \left[6000e^{0} + 6000e^{-(.05)(15)} + 6000e^{-(.05)(24)}\right]$$

$$= (30{,}000)(6000)\left[e^{0} + e^{-(.05)(15)} + e^{-(.05)(24)}\right]$$

$$W_{41}(t-1) = (30{,}000)(6000)(1.77) = 31.86 \times 10^{7}$$

and:

$$\sum_{h=1}^{H} W_{4h}(t-1) = \sum_{h=1}^{H} \sum_{g=1}^{G} UA_h(t-1)\ U_{4g}(t-1) EXP(-B \cdot TA_{hg}(t-1))$$

$$= 30{,}000 \left[6000e^{0} + 6000e^{0} + 6000e^{0} + 6000e^{-(.05)(15)} + 6000e^{-(.05)(15)} + 6000e^{-(.05)(24)} + 6000e^{-(.05)(24)} + 6000e^{-(.05)(25)} + 6000e^{-(.05)(24)}\right]$$

$$= (30{,}000)(6000)\left[3e^{0} + 2e^{-(.05)(15)} + 4e^{-(.05)(24)}\right]$$

$$\sum_{h=1}^{H} W_{4h}(t-1) = (30{,}000)(6000)(5.14) = 92.52 \times 10^{7}$$

which leads to:

$$\Delta Z_{41} = \frac{36.18 \times 10^{7}}{102.75 \times 10^{7}} - \frac{31.86 \times 10^{7}}{92.52 \times 10^{7}} = .350 - .344 = .006$$

TABLE XIII

CALCULATION OF EQUATION 1, ZONE 1, APPLICATION NO. 1

From Table VII, using equation 1, for any zone h:

$$\Delta R_{ih} = .637\Delta R_{2h} - .295\Delta R_{3h} + .018\Delta R_{8h} + .133R_{1h}(t-1)$$
$$- .109R_{3h}(t-1) + .044Z_{2h}(t-1) - .298\Delta Z_{4h}$$
$$- .068Z_{4h}(t-1),$$

and using the relationships discussed previously in Chapter III:

$$\frac{V_{1h}(t)}{T_1(t)} - \frac{V_{1h}(t-1)}{\sum_{h=1}^{H} V_{1h}(t-1)} = .637\left[\frac{V_{2h}(t)}{T_2(t)} - \frac{V_{2h}(t-1)}{\sum_{h=1}^{H} V_{2h}(t-1)}\right]$$
$$-.295\left[\frac{V_{3h}(t)}{T_3(t)} - \frac{V_{3h}(t-1)}{\sum_{h=1}^{H} V_{3h}(t-1)}\right] + .018\left[\frac{V_{8h}(t)}{T_8(t)} - \frac{V_{8h}(t-1)}{\sum_{h=1}^{H} V_{8h}(t-1)}\right]$$
$$+.133\left[\frac{V_{5h}(t-1)}{\sum_{h=1}^{H} V_{5h}(t-1)}\right] - .109\left[\frac{V_{2h}(t-1)}{\sum_{h=1}^{H} V_{2h}(t-1)}\right] + .044\left[\frac{W_{2h}(t-1)}{\sum_{h=1}^{H} W_{2h}(t-1)}\right]$$
$$- .298\Delta Z_{4h} - .068Z_{4h}(t-1),$$

and using Zone 1 as an example, with values shown in Tables X and XII:

$$\frac{V_{11}(t)}{1000} - \frac{1000}{2500} = .637\left[\frac{V_{21}(t)}{6000} - \frac{2000}{4500}\right]$$
$$- .295\left[\frac{V_{31}(t)}{4000} - \frac{500}{2500}\right] + .018\left[\frac{V_{81}(t)}{3750} - \frac{1000}{3000}\right] + .133\left[\frac{1000}{2500}\right]$$
$$- .109\left[\frac{500}{2500}\right] + .044\left[\frac{210,000}{560,000}\right] - .298(.006) - .068(.344),$$

and placing all the land use variables on the left side of the equation, with the right hand side a constant, the final equation is:

$$V_{11}(t) - .106V_{21}(t) + .074V_{31}(t) - .0048V_{81}(t) = 191$$

TABLE XIV

FINAL EQUATIONS FOR ZONES 1, 2, AND 3, APPLICATION NO. 1*

Zone 1

1. $V_{11} - .106\ V_{21} + .074\ V_{31} - .0048\ V_{81} = 191$
2. $-3.18\ V_{11} + V_{21} - .505\ V_{31} - .03\ V_{71} - .096\ V_{81} = 730$
3. $-.5\ V_{11} + .425\ V_{21} - V_{31} + .294\ V_{41} = 323$
4. $.188\ V_{21} - .603\ V_{31} + V_{41} = 977$
5. $V_{51} - .247\ V_{61} = 1758$
6. $-.407\ V_{51} + V_{61} - .092\ V_{71} + .176\ V_{91} = 475$
7. $-.387\ V_{61} + V_{71} = 367$
8. $.189\ V_{61} + V_{81} = 985$
9. $.461\ V_{61} + V_{91} = 1793$

Zone 2

1. $V_{12} - .106\ V_{22} + .074\ V_{32} - .0048\ V_{82} = 194$
2. $-3.18\ V_{12} + V_{22} - .505\ V_{32} - .03\ V_{72} - .096\ V_{82} = 713$
3. $-.5\ V_{12} + .425\ V_{22} - V_{32} + .294\ V_{42} = 323$
4. $.188\ V_{22} - .603\ V_{32} + V_{42} = 987$
5. $V_{52} - .247\ V_{62} = 1781$
6. $-.407\ V_{52} + V_{62} - .092\ V_{72} + .176\ V_{92} = 484$
7. $-.387\ V_{62} + V_{72} = 343$
8. $.189\ V_{62} + V_{82} = 971$
9. $.461\ V_{62} + V_{92} = 1793$

Zone 3

1. $V_{13} - .106\ V_{23} + .074\ V_{33} - .0048\ V_{83} = 295$
2. $3.18\ V_{13} - V_{23} + .505\ V_{33} + .03\ V_{73} + .096\ V_{83} = 1100$
3. $.5\ V_{13} - .425\ V_{23} + V_{33} - .294\ V_{43} = 1316$
4. $.188\ V_{23} - .603\ V_{33} + V_{43} = 891$
5. $V_{53} - .247\ V_{63} = 504$
6. $-.407\ V_{53} + V_{63} - .092\ V_{73} + .176\ V_{93} = 2044$
7. $-\ .387\ V_{63} + V_{73} = 645$
8. $.139\ V_{63} + V_{83} = 2367$
9. $.461\ V_{63} + V_{93} = 2355$

*The V's are understood to be future values. The (t) index has been omitted for simplicity.

in the travel time variables from the present time period to the forecast period. These times are shown in Table IX.

After selection of the region and zones, travel accessibilities were calculated. A typical calculation is shown in Table XI. This calculation was performed for each equation that contained either vehicle or rapid transit accessibilities, or both. Equations then were written for each zone (nine equations per zone) for a total of 27 equations, as shown in Table XIII. Typical examples of relevant calculations in this step are given in Table XII. In order to calculate the future land use variables for each zone, the nine equations for each zone were solved simultaneously through the use of a computer program. Results for Application No. 1 will be given in Chapter V.

Application No. 2 - Goal Programming

A region of six traffic zones was selected for application No. 2, with the regional plan as shown in Figure 2. Travel times and their use in this objective are shown in Table XV.

In order to accomplish this objective, several assumptions and algebraic manipulations had to be made. The first manipulation involved the elimination of the problem of working with a power of e. This manipulation can be stated mathematically as:

$$Y_{gh} = e^{-B \cdot TA_{gh}(t)} \qquad (4\text{-}1)$$

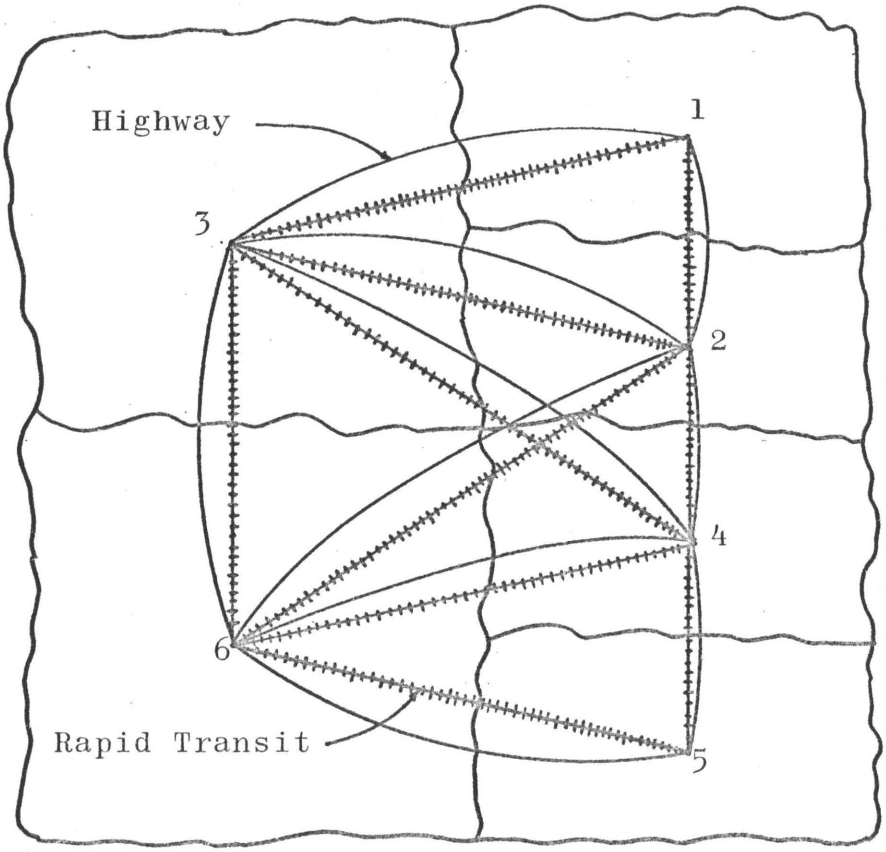

Figure 2. Hypothetical Plan of Region With Six Subregions Used in Application No. 2.

TABLE XV

TRAVEL TIMES BETWEEN ZONES IN MINUTES USED AS INPUTS TO APPLICATION NO. 2*

Zones	Vehicle		Rapid Transit	
	$TA_{gh}(t-1)$	$TA_{gh}(t_{70})$*	$TT_{gh}(t-1)$	$TT_{gh}(t)$
1-2	15	5	12	10
1-3	24	10	21	18
1-4	30	10	28	25
1-5	45	15	40	38
1-6	39	13	35	32
2-3	24	10	21	20
2-4	15	5	12	10
2-5	30	10	28	25
2-6	24	10	21	18
3-4	24	10	21	18
3-5	39	13	35	32
3-6	30	10	28	25
4-5	15	5	12	10
4-6	24	10	21	18
5-6	24	10	21	18

*These vehicle travel times are based on speed of 70 mph between zones and are not necessarily the travel times in the desired objective.

$TA_{gh} = TA_{hg}$; $TT_{gh} = TT_{hg}$

Since there were six zones in the region, there were 30 different values of Y_{gh}. Therefore, to simplify the problem, Y_{gh} was assumed equal to Y_{hg}, thus eliminating one-half of the travel time variables. (This assumption is logical if carried over a 24-hour period.) B was assumed to equal .1 for all travel accessibilities. For reasons of practicality, upper and lower limits were placed on the interzonal travel times. Present travel times were used as the lower limits, and 70 mph was used as the speed to determine the upper limits. These assumptions can be stated mathematically as:

$$D_{gh} = e^{-B \cdot TA_{gh}(t-1)} \qquad (4-2)$$

where D_{gh} is the lower limit based on present travel time, and

$$E_{gh} = e^{-B \cdot TA_{gh}(t_{70})} \qquad (4-3)$$

where E_{gh} is the upper limit using a speed of 70 mph to define travel time (t_{70}).

It should be noted that as travel time decreases, the upper limit is approached; conversely, when travel time increases, the lower limit is approached.

Referring to Tables VII and VIII, it can be seen that five of the nine equations in the main model contain travel time components. Since the future travel times as well as future land use variables are unknown, any equation, p, of the form of Equation (3-10), Chapter III, should be written for any zone h in the form:

$$\sum_{i=1}^{9} a_{ip} V_{ih}(t) + \frac{\sum_{g=1}^{H} r_{gh} Y_{gh}}{\sum_{g=1}^{H} \sum_{h=1}^{H} r_{gh} Y_{gh}} = C_{ih}, \qquad (4\text{-}4)$$

where $V_{ih}(t)$ = amount of future land use variable i in zone h,

a_{ip} = coefficient as in Equation (3-10),

C_{ih} = constant composed of all nonvariable elements in Equation (3-10) added together,

and

$$r_{gh} = UA_h(t-1) \cdot U_{zh}(t-1), \qquad (4\text{-}5)$$

for the particular z used in each equation p.*

Equation 4-4 can be rewritten as:

$$\sum_{g=1}^{H} \sum_{h=1}^{H} r_{gh}Y_{gh} \sum_{i=1}^{9} a_{ip} V_{ih}(t) + \sum_{g=1}^{H} r_{gh}Y_{gh}$$

$$- C_{ih} \sum_{g=1}^{H} \sum_{h=1}^{H} r_{gh}Y_{gh} = 0 \qquad (4\text{-}6)$$

In an effort to solve for the various Y_{gh} and $V_{ih}(t)$ variables, a nonlinear program of the following form was derived:

$$\text{Min } F = \sum_{i=1}^{I} \sum_{h=1}^{H} \left[V_{ih}(t) - G_{ih} \right]^2 , \qquad (4\text{-}7)$$

---

*See Tables VII and VIII for the particular z used in each equation.

subject to:

$$\sum_{g=1}^{H} \sum_{h=1}^{H} r_{gh} Y_{gh} \sum_{i=1}^{9} a_{ip} V_{ih}(t) + \sum_{g=1}^{H} r_{gh} Y_{gh}$$

$$- C_{ih} \sum_{g=1}^{H} \sum_{h=1}^{H} r_{gh} Y_{gh} = 0, \quad \text{(all i, h)} \qquad (4\text{-}8)$$

$$\sum_{h=1}^{H} V_{ih}(t) = T_i(t), \quad \text{(all i)} \qquad (4\text{-}9)$$

$$D_{gh} \leq Y_{gh} \leq E_{gh}, \quad \text{(all g, h)} \qquad (4\text{-}10)$$

$$V_{ih}(t),\ Y_{gh} \geq 0 \quad \text{(all i, g, h)} \qquad (4\text{-}11)$$

where

G_{ih} = goal for land use variables i in zone h and

$T_i(t)$ = future total land use variable i.

The reason for squaring the difference between each future zonal land use variable and its goal in the criterion function is to keep each variable as close to its respective goal as possible, not allowing large negative values of $V_{ih}(t)$ as would be the case if the differences were not squared.

Equation (4-9) is necessary because the sum of the future subregional land use variables should equal the future regional total for each type of land use variable. Equation (4-11) is written to insure only non-negative variables in the program. Equations (4-8) and (4-10) have been explained previously.

Equation (4-8) is nonlinear with a large number of cross products and individual terms, a situation which creates considerable difficulty in obtaining a solution, especially when there are numerous traffic zones involved. To eliminate this problem, the following substitution is made:

$$\text{Let } VA_z = \sum_{g=1}^{H} \sum_{h=1}^{H} r_{gh} Y_{gh} \quad (4\text{-}12)$$

$$= \sum_{g=1}^{H} \sum_{h=1}^{H} UA_h(t-1) U_{zg}(t-1) Y_{gh} \quad (4\text{-}13)$$

Upper and lower limits on the travel times, as shown in equations (4-2) and (4-3) are used as limiting values for VA_z, and a particular value is chosen at about the midpoint of the upper and lower limits. An example of this calculation is shown in Table XVI. Just as in the nonlinear problem, B is assumed equal to .1 for all travel accessibilities.

Equation (4-8) now may be rewritten as:

$$VA_z \sum_{i=1}^{9} a_{ip} V_{ih}(t) + \sum_{g=1}^{H} r_{gh} Y_{gh} = C_{ih} VA_z \quad \text{(all i, h)} \quad (4\text{-}14)$$

This equation is linear, and the problem of cross products of variables is eliminated, which thus sets the scene for the use of goal programming.

Goal programming is a linear programming technique that takes into account fixed goals and variables which one would desire to be as close to these goals as possible in the

TABLE XVI

CALCULATION OF VA_z, APPLICATION NO. 2

Let VA_{z1} = value of VA_z at lower limit;

$$B = .1; \quad U_{4g} = 150{,}000; \quad UA_h = 15{,}000;$$

$$VA_{z1} = \sum_{h=1}^{H} \sum_{g=1}^{G} UA_h(t-1)\ U_{4g}(t-1)\ EXP(-B \cdot TA_{hg}(t-1)$$

$$= (15{,}000)(150{,}000) \left[(6e^{0} + 6e^{-(.1)(15)} + 12e^{-(.1)(24)} + 6e^{-(.1)(30)} + 4e^{-(.1)(39)} + 2e^{-(.1)(45)}\right]$$

$$VA_{z1} = (15{,}000)(150{,}000)(9.13) = 205 \times 10^{8}$$

Let VA_{z2} = value of VA_z at upper limit*;

$$B = .1; \quad U_{4g} = 150{,}000; \quad UA_h = 15{,}000;$$

$$VA_{z2} = \sum_{h=1}^{H} \sum_{g=1}^{G} UA_h(t-1)\ U_{4g}(t-1)\ EXP(-B \cdot TA_{hg}(t))$$

$$= (15{,}000)(150{,}000) \left[6e^{0} + 6e^{-(.1)(5)} + 18e^{-(.1)(10)} + 9e^{-(.1)(13)} + 2e^{-(.1)(15)}\right]$$

$$VA_{z2} = (15{,}000)(150{,}000)(17.80) = 400 \times 10^{8}$$

Therefore, $VA_z = \dfrac{VA_{z1} + VA_{z2}}{2} = \dfrac{(205 + 400)(10^{8})}{2} = 302.5 \times 10^{8}$

*Travel time based on interzone speed of 70 mph.

future. To understand goal programming, consider the following equation:

$$V_{ih}(t) \pm X_{ih}(t) = G_{ih}(t), \qquad (4\text{-}15)$$

where $X_{ih}(t)$ is added if the goal is greater than the present value of the land use variable, $V_{ih}(t-1)$, and $X_{ih}(t)$ is subtracted if the situation is reversed. In other words, $X_{ih}(t)$ is a positive variable representing the difference between the present value of the land use variable and the goal. Thus, by minimizing the value of the X(t)'s in Equation (4-15), the variables come closer to the desired goals. This objective can be stated mathematically in a criterion function as follows:

$$\text{Minimize } F = \sum_{h=1}^{H} \sum_{i=1}^{9} X_{ih}, \qquad (4\text{-}16)$$

which is a neat linear combination. As a consequence of this linearization and the one performed in Equations (4-12) to (4-14) a strictly linear program is obtained:

$$\text{Minimize } F = \sum_{h=1}^{H} \sum_{i=1}^{9} X_{ih}(t), \qquad (4\text{-}17)$$

subject to:

$$VA_z \sum_{i=1}^{9} q_{ih} V_{ih}(t) + \sum_{g=1}^{H} r_{gh} Y_{gh} = C_{ih} VA_z, \quad \text{(all i, h)} \qquad (4\text{-}18)$$

$$\sum_{h=1}^{H} V_{ih}(t) = T_i(t), \qquad \text{(all i)} \qquad (4\text{-}19)$$

$$D_{gh} \leq Y_{gh} \leq E_{gh}, \qquad \text{(all g, h)} \qquad (4\text{-}20)$$

$$\sum_{g=1}^{H} \sum_{h=1}^{H} UA_h(t-1)\, U_{zg}(t-1) Y_{gh}(t) = VA_z \qquad (z=1,\ 3,\ 4) \qquad (4\text{-}21)$$

$$V_{ih}(t),\ Y_{gh},\ X_{ih} \geq 0 \qquad \text{(all i, g, h)} \qquad (4\text{-}22)$$

It is noted that although there are three values of z defined for equation (4-21), only one equation is used for Application No. 2. The reason for this is because $U_{1g} = U_{3g} = U_{4g}$ for this application.

It should be understood that once the values of Y_{gh} and $V_{ih}(t)$ are obtained, another trial using a different VA_z is necessary, this process continuing until a VA_z is found which gives an overall minimum of F. To find the next VA_z to use, remember that each linear programming problem has associated with it another linear programming problem called its dual. This dual indicates the sensitivity to a unit change in the right hand side (of each equation) of the value of the criterion function.

Therefore, to establish a new trial value for each VA_z, it is necessary to note the sign of the dual corresponding to each previous VA_z, increasing the new VA_z if the dual is negative, and vice versa. In essence, what eventually is needed is to find ψ where:

$$\psi = \min_{VA_z\text{'s}} F \qquad (z = 1,\ 3,\ 4) \qquad (4\text{-}23)$$

Linear programming was used in an effort to find the 15 travel time variables and the 54 land use variables which would give a minimum ψ. Since the solution of the problem involved the determination of the values of the 69 variables, a minimum of six traffic zones was needed in order to provide a feasible example. The inputs for the six traffic zones pictured in Figure 2 are given in Tables XV, XVII, XVIII, and XIX, while the presentation of results is delayed until Chapter V.

TABLE XVII

ADDITIONAL MODEL APPLICATION NO. 2 INPUTS, LAND USE VARIABLES*

Variables	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Total for Region
$V_{1h}(t-1)$	25,000	25,000	25,000	25,000	25,000	25,000	151,500
$V_{2h}(t-1)$	50,000	50,000	50,000	50,000	50,000	50,000	303,000
$V_{3h}(t-1)$	12,500	12,500	12,500	12,500	12,500	12,500	75,700
$V_{4h}(t-1)$	12,500	12,500	12,500	12,500	12,500	12,500	75,700
$V_{5h}(t-1)$	60,000	60,000	60,000	60,000	60,000	60,000	363,600
$V_{6h}(t-1)$	40,000	40,000	40,000	40,000	40,000	40,000	242,400
$V_{7h}(t-1)$	25,000	25,000	25,000	25,000	25,000	25,000	151,500
$V_{8h}(t-1)$	20,000	20,000	20,000	20,000	20,000	20,000	121,200
$V_{9h}(t-1)$	5,000	5,000	5,000	5,000	5,000	5,000	30,300

*Travel times between zones used as inputs for Application No. 2 are given in Table XV.

TABLE XVIII

ADDITIONAL MODEL APPLICATION NO. 2 INPUTS, NON-LAND USE VARIABLES*

Variables	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Total for Region
$NAP_h(t-1)$	10,000	10,000	10,000	10,000	10,000	10,000	-
$NAM_h(t-1)$	2,500	2,500	2,500	2,500	2,500	2,500	-
$NAR_h(t-1)$	2,500	2,500	2,500	2,500	2,500	2,500	-
$UA_h(t-1)$	15,000	15,000	15,000	15,000	15,000	15,000	-
$GA_h(t-1)$	30,000	30,000	60,000	30,000	30,000	60,000	-
$L_{1h}(t-1)$	5,000	5,000	7,500	5,000	5,000	7,500	-
$L_{2h}(t-1)$	1,250	1,250	1,875	1,250	1,250	1,875	-
$L_{3h}(t-1)$	1,250	1,250	1,875	1,250	1,250	1,875	-
$w_h(t-1)$	7	7	7	7	7	7	-
$s_h(t-1)$	5	5	5	5	5	5	-
$w_h(t)$	7	7	7	7	7	7	-
$s_h(t)$	5	5	5	5	5	5	-

*Travel times between zones used as inputs for Application No. 2 are given in Table XV.

TABLE XIX

ADDITIONAL MODEL APPLICATION NO. 2 INPUTS

Variables	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
$G_{1h}(t)$	*-25,000	-25,000	-25,000	+25,000	-25,000	+25,000
$G_{2h}(t)$	+50,000	+50,000	-50,000	-50,000	+50,000	-50,000
$G_{3h}(t)$	-12,500	-12,500	-12,500	-12,500	-12,500	-12,500
$G_{4h}(t)$	-12,500	-12,500	+12,500	+12,500	-12,500	+12,500
$G_{5h}(t)$	-60,000	-60,000	+60,000	+60,000	+60,000	+60,000
$G_{6h}(t)$	-40,000	-40,000	+40,000	+40,000	+40,000	+40,000
$G_{7h}(t)$	-25,000	-25,000	-25,000	-25,000	+25,000	-25,000
$G_{8h}(t)$	+20,000	+20,000	-20,000	-20,000	-20,000	-20,000
$G_{9h}(t)$	+ 5,000	+ 5,000	- 5,000	- 5,000	- 5,000	- 5,000

*- = "equal to or greater than"

\+ = "equal to or less than"

CHAPTER V

RESULTS AND CONCLUSIONS

In order to calculate the future land use variables for Application No. 1 as discussed in Chapter IV, the nine equations for each zone are solved simultaneously through the use of a computer program. Results for Application No. 1 are given in Tables XX and XXI. Linear programming is used to find the 15 travel time variables and the 54 land use variables for Application No. 2 as discussed in Chapter IV. Results for Application No. 2 are given in Table XXII and XXIII.

Conclusions for Application No. 1

It can be readily seen that the EMPIRIC Model did distribute the forecasted regional land use values for each subregion. It was observed that the changes in growth in zones 1 and 2 were nearly identical to each other, and quite different from zone 3. This further proves the theory that zonal growth or decline is heavily dependent on activities already present in the zone.

There was considerable growth in zone 3, in both population and in employment. The growth in the middle and upper income population and in manufacturing and construction, retail, and service employment was substantial. The increase in the middle and upper income population

TABLE XX

MODEL OUTPUTS FOR APPLICATION NO. 1

Main Model

Land Use Variables	Zone 1	Zone 2	Zone 3	Total for Region*
$V_{1h}(t)$	400	401	251	1052
$V_{2h}(t)$	2529	2512	1060	6101
$V_{3h}(t)$	850	845	2242	3937
$V_{4h}(t)$	1014	1024	2044	4082
$V_{5h}(t)$	2045	2073	1102	5220
$V_{6h}(t)$	1161	1182	2420	4763
$V_{7h}(t)$	816	800	1581	3196
$V_{8h}(t)$	766	748	1910	3424
$V_{9h}(t)$	1258	1248	1240	3746

*The totals for the region are not model outputs, but are placed in the table for comparison with future total land use variable inputs shown in Table X.

TABLE XXI

MODEL OUTPUTS FOR APPLICATION NO. 1

Submodel

Submodel Variables	Zone 1	Zone 2	Zone 3	Total for Region
$S_{1h}(t)$	4,793	3,782	5,597	14,172
$S_{2h}(t)$	17,844	17,804	20,828	56,476
$S_{3h}(t)$	5,205	5,209	6,776	17,190
$S_{4h}(t)$	3,157	3,090	3,993	10,240
$S_{5h}(t)$	4,413	4,412	5,381	14,206
$S_{6h}(t)$	48.3×10^6	37.3×10^6	71.4×10^6	-

groups in this zone would indicate a general movement of these groups to the suburbs from the crowded urban area. An increase in the above noted employment indicates the need for these jobs in this zone to take care of the increased population. There was also a considerable increase in the number of children in the kindergarten to eighth grade levels. This further indicates the strong desire for the young, middle, and above income families to move to the suburbs.

Also noted was the effect of a change in the transportation system on the distribution of land use values in the zone. A decrease in travel time of about 25 per cent for the forecast year was selected, and this change was observed to have only a minor effect on the land use variables. The travel accessibilities were the only interzonal relationships in the land use model; thus, if the zones were quite large, the effect of one zonal activity or another activity would be reduced.

It was observed that the model performed better with the population variables than the employment variables insofar as the comparison of sums of predicted land use variables and future total land use variables actually used as inputs. In particular, retail employment was predicted with significantly greater differences than the population variables. As it turned out, all of the population and employment variables for the sum of the three zones were within 95 per cent of the future regional totals with the noted exception of retail employment which was within 70 per cent of the regional total. The reason for this is that employment activities usually are relatively more difficult to predict with a statistical model such as the EMPIRIC Model. The model tends to be best at locating large numbers of small units such as households, rather than lumpy activities that have spotty distribution patterns and tend to locate region wide in relatively few and large clusters of activity.

Another point to be stressed is the need for the constraint which relates the sum of the future land use variables to the regional total, as in equations (4-9) and (4-19), and which leads to the second application.

Results for Application No. 2

Using the criterion function and constraints for the linear program explained in Chapter IV, it was determined that a "no feasible solution" was obtained through the use of a computer program. In an effort to arrive at a feasible solution, the regional constraints on the land use variables, equation (4-19), were removed. When a "no feasible solution" was obtained as a result of this modification, the upper limits of the travel time constraints, equation (4-20), were modified to a value of 1.0 (TA_{gh}=0). As a result of this modification, a feasible solution was obtained and the results of Application No. 2 are shown in Tables XXII and XXIII.

Conclusions for Application No. 2

Referring to Table XXII and comparing land use variable outputs to present land use variables, it can be seen that there are growths and declines in land uses in the subregions. The reason for the value of land use variable V_{65} being equal to zero is unknown. The future regional totals are close to the present regional totals, with the exception of the sum of land use variable V_{6h}, which contains variable V_{65}. Referring to Table XXIII, the output travel times were very similar to the input travel times, with the exception of Y_{34} and Y_{46}, which were 1.0 (interzonal travel time = 0).

One can see that goal programming can be used to determine subregional land use variables and travel times between those subregions that are practical and within limits of realism, but not entirely accurate. Since two modifications to the linear program were necessary to achieve a feasible solution, proper selection of subregional land use goals is very important in order to achieve accurate subregional land use variables and practical travel

TABLE XXII

MODEL OUTPUTS FOR APPLICATION NO. 2

Land Use Variables	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Total for Region
$V_{1h}(t)$	26,511	26,418	24,795	23,165	26,476	24,993	152,358
$V_{2h}(t)$	47,763	47,288	55,898	57,757	48,598	56,271	313,575
$V_{3h}(t)$	12,663	12,718	13,336	13,274	12,743	13,387	78,121
$V_{4h}(t)$	14,503	14,929	12,022	10,458	14,316	12,034	78,262
$V_{5h}(t)$	62,475	63,257	58,795	57,691	47,304	58,446	347,968
$V_{6h}(t)$	46,076	48,052	34,543	30,883	0	34,685	194,238
$V_{7h}(t)$	25,323	25,280	25,758	25,069	12,926	25,719	140,075
$V_{8h}(t)$	19,294	19,145	20,737	21,308	25,099	20,779	126,362
$V_{9h}(t)$	4,563	4,441	5,438	5,759	8,100	5,427	33,728

TABLE XXIII

MODEL OUTPUTS FOR APPLICATION NO. 2

Y_{gh}	Travel Time (TA_{gh}) in Minutes
Y_{12} = .224	15.0
Y_{13} = .091	24.0
Y_{14} = .050	30.0
Y_{15} = .011	45.0
Y_{16} = .020	39.0
Y_{23} = .091	24.0
Y_{24} = .224	15.0
Y_{25} = .050	30.0
Y_{26} = .091	24.0
Y_{34} =1.000	0.0
Y_{35} = .091	20.0
Y_{36} = .202	16.0
Y_{45} = .224	15.0
Y_{46} =1.000	0.0
Y_{56} = .131	20.3

times between subregions. Therefore, one can conclude that the land use goals as used in this application are unattainable through the use of a practical transportation system.

Because of the complexity of the EMPIRIC Land Use Model, realistic data must be used as inputs to the model that will reflect the interaction between urban and transportation planning. Since the inputs to the model in this application are hypothetical, there is the possibility that the inputs do not reflect the true nature of the interaction between land use and transportation. For example, the value for utility service (water and sewage) should reflect the plans of the subregion's administration. If these values are unrealistic, the future value of the subregional land use variables also could be unrealistic. Similar reasoning can be applied in the selection of realistic subregional land use goals that can be met by a practical and realistic transportation system.

The EMPIRIC Land Use equations as shown in Tables VII and VIII are not entirely consistent. If there are no changes in land use variables, transportation policies and utility services, the equations should describe the present state of the subregion. An examination of the equations reveals the description of the existing state of the subregion to be not completely accurate. This inconsistency could explain why the sum of the future subregional land use variables does not equal the future regional value; yet this sum does for the most part fall within reasonable and practical limits, as shown in Application No. 1.

Only one calculation of VA_z is used in this application, the reason for this being explained in Chapter IV. Therefore, the results of Application No. 2 do not represent a complete search that would be necessary to find the overall optimal solution for ψ.

It should be noted that the model contained both +1 and -1 values for the land use variables in the criterion function when a feasible solution was obtained. If the criterion function contained all +1 or -1 values for the land use variables, the model would produce an infeasible solution if it contained the regional constraint equation (4-9).

In this research, land use variable goals were assumed as a sense of direction, and the model was used to see if the transportation system would satisfy these goals in a practical manner. Another use of the model would be to assume exact values for each future land use variable, and then determine what changes in transportation and utilities service would be required to satisfy the selection of the land use variables.

Since this research did not include a study of this use, it is not known what changes or manipulations to the model will be necessary to arrive at a practical solution to the problem. However, this second case could be justification for further research with the EMPIRIC Model.

This research has determined the necessity of obtaining accurate and realistic input data for the EMPIRIC Model prior to any application. In this respect, this research has formulated a sense of direction for the urban planners, engineers and administrators in the preparation of plans for the cities' future that will include simultaneous changes in both land use and transportation facilities.

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UTILIZATION OF THE EMPIRIC LAND USE FORECASTING MODEL FOR INVESTIGATIONS OF URBAN DEVELOPMENT PLANNING STRATEGIES

by

John Tilden Harrison

Abstract

The purpose of this research was to use the EMPIRIC Land Use Forecasting Model to investigate urban development planning strategies. These investigations required two applications, the first dealing with the selection of certain regional plans describing the use of transportation, zoning, open space, utilities, etc., and the subsequent determination of subregional land use values for the forecast period. The second application dealt with the selection of a regional transportation (travel time) improvement plan that would induce growth in subregional land use variables that would bring their intensities as close to a priori goals as possible. The EMPIRIC Land Use Forecasting Model was used because it appeared to be the most reliable land use prediction model available.

The first objective was accomplished by the solution of simultaneous linear equations, with nine equations for each of the three traffic zones. It was determined that the EMPIRIC Model did determine the future subregional land use variables with a high degree of reliability.

Goal programming was used to accomplish the second objective, and through a series of manipulations, a linear program was developed that would determine future transportation plans if realistic subregional land use variables were selected as goals.

It can be said that the EMPIRIC Land Use Forecasting Model is a definite aid in the urban planning process, and from its use, plans for a city's future can be formulated that will include simultaneous changes in both land use and transportation facilities.