Relation of Land Use/Land Cover to Resource Demands

Cristopher Clayton

NASA Cooperative Agreement NAG 2-20
March 1981
Relation of Land Use/Land Cover to Resource Demands

Cristopher Clayton
University of California,
Santa Barbara, CA 93106

Prepared for
Ames Research Center
under Contract NAG 2-20

NASA
National Aeronautics and
Space Administration
Ames Research Center
Moffett Field, California 94035
**RELATION OF LAND USE/LAND COVER TO RESOURCE DEMANDS**

**SPECIFIC EMPHASIS:**
- RESIDENTIAL ENERGY DEMAND

**SPECIFIC TASK:**
- INVESTIGATE PREDICTIVE (FORCASTING) MODELS

**SUB-TASKS:**
1. ECONOMETRIC MODELS OF RESIDENTIAL ENERGY DEMAND
2. EVALUATION OF DETERMINANTS OF RESIDENTIAL ENERGY DEMAND VIS A VIS DERIVABILITY FROM REMOTELY SENSED DATA
3. DATA BASES - ORGANIZATION AND INTEGRATION
4. RESIDENTIAL LAND USE AND REMOTE SENSING, i.e., LAND USE/LAND COVER CLASSIFICATION
5. LAND USE/LAND COVER CHANGE DETECTION
6. LAND USE/LAND COVER PREDICTIVE MODELLING
ECONOMETRIC MODELS OF RESIDENTIAL ENERGY DEMAND

PURPOSE: ISOLATE THE MAJOR DETERMINANTS OF DEMAND FOR ENERGY

UTILITY: PREDICT CONSEQUENCES OF (i) NATURAL CHANGES SUCH AS
CLIMATIC FLUCTUATIONS, AND (ii) DELIBERATE POLICY
ACTIONS BY DECISION-MAKERS SUCH AS PRICING POLICIES

FORM: REGRESSION FRAMEWORK -

\[ Y = a + b_1X_1 + b_2X_2, \ldots, + b_nX_n, \]

WHERE \( Y \) (DEPENDENT VARIABLE) = ENERGY DEMAND, \( X_i \)
(INDEPENDENT VARIABLES) = FACTOR DETERMINING ENERGY
DEMAND, \( n \) = NUMBER OF INDEPENDENT VARIABLES, AND
\( a \) and \( b_i \) ARE MODEL PARAMETERS.

NOTE: (i) INDEPENDENT VARIABLES (\( X_i \)) ARE KNOWN TO
INFLUENCE SIGNIFICANTLY THE VALUE OF \( Y \)

(ii) PARAMETER 'a' IS A CONSTANT OF PROPORTIONALITY AND PARAMETER 'b' INDICATES THE CHANGE
IN Y COMMENSURATE WITH A UNIT CHANGE IN X, i.e.,
MEASURE OF ELASTICITY

EXAMPLE: \( Y = 3.0 -0.7X_1 + 0.3X_2, \)

WHERE \( Y \) = ENERGY DEMAND, \( X_1 \) = PRICE OF
ENERGY, AND \( X_2 \) = HOUSEHOLD INCOME

SIGNIFICANT INDEPENDENT VARIABLES:

PRICE OF FUEL (ELASTICITY OF DEMAND)

HOUSEHOLD INCOME (ELASTICITY OF DEMAND WITH REGARD TO INCOME)

PRICE OF SUBSTITUTE FUELS (CROSS ELASTICITY WITH REGARD TO
ALTERNATIVE FUELS)

HOUSEHOLD SIZE

CLIMATIC CHARACTERISTICS

PRICE OF HOUSEHOLD APPLIANCES SUCH AS HEATING AND COOLING
APPARATUS
ENERGY DEMAND DETERMINANTS AND REMOTE SENSING

DETERMINANTS: PHYSICAL VS. NON-PHYSICAL ENVIRONMENTAL ATTRIBUTES

PHYSICAL ATTRIBUTES: THEY ARE SCALE-DEPENDENT. ANDERSON LEVELS I AND II CAN BE DERIVED FROM LANDSAT DATA.

URBAN LAND USE/LAND COVER ATTRIBUTES: RESIDENTIAL - HIGH DENSITY
- MEDIUM/LOW DENSITY
OPEN SPACE
COMMERCIAL/INDUSTRIAL/INSTITUTIONAL
TRANSPORTATION - HIGHWAYS
- RAILROADS
- AIRPORTS

THIS IS INADEQUATE. IT IS NECESSARY TO HAVE ADDITIONAL COLLATERAL INFORMATION. SUCH INFORMATION (SOCIO-ECONOMIC AND DEMOGRAPHIC ATTRIBUTES OF A POPULATION) IS OFTEN IN TABULAR FORM. IMAGE, MAP, AND TABULAR DATASETS MUST BE INTEGRATED INTO A GEO-BASED INFORMATION SYSTEM.
<table>
<thead>
<tr>
<th>Digital Codes</th>
<th>First-Order Land Use/Land Cover</th>
<th>Second-Order</th>
<th>Third-Order</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 11</td>
<td>Urban and built-up land</td>
<td>Residential</td>
<td></td>
</tr>
<tr>
<td>1 12</td>
<td></td>
<td>Commercial</td>
<td></td>
</tr>
<tr>
<td>1 13</td>
<td></td>
<td>and services</td>
<td></td>
</tr>
<tr>
<td>1 14</td>
<td></td>
<td>Industrial</td>
<td></td>
</tr>
<tr>
<td>1 15</td>
<td></td>
<td>Extractive</td>
<td></td>
</tr>
<tr>
<td>1 16</td>
<td></td>
<td>Transportation, communications, and utilities</td>
<td></td>
</tr>
<tr>
<td>1 17</td>
<td></td>
<td>Utilities</td>
<td></td>
</tr>
<tr>
<td>1 18</td>
<td></td>
<td>Institutional</td>
<td></td>
</tr>
<tr>
<td>1 19</td>
<td></td>
<td>Strip and clustered development</td>
<td></td>
</tr>
<tr>
<td>1 191</td>
<td></td>
<td>Mixed urban</td>
<td></td>
</tr>
<tr>
<td>1 192</td>
<td></td>
<td>Open and other urban</td>
<td>Solid-waste dump</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cemetery</td>
</tr>
<tr>
<td>2 21</td>
<td>Agricultural land</td>
<td>Cropland and pasture</td>
<td></td>
</tr>
<tr>
<td>2 211</td>
<td></td>
<td>Nonirrigated cropland</td>
<td></td>
</tr>
<tr>
<td>2 212</td>
<td></td>
<td>Irrigated cropland</td>
<td></td>
</tr>
<tr>
<td>2 213</td>
<td></td>
<td>Pasture</td>
<td></td>
</tr>
<tr>
<td>2 22</td>
<td></td>
<td>Orchards, groves, and other horticultural areas</td>
<td></td>
</tr>
<tr>
<td>2 23</td>
<td></td>
<td>Feeding operations</td>
<td></td>
</tr>
<tr>
<td>2 24</td>
<td></td>
<td>Other agricultural land</td>
<td></td>
</tr>
<tr>
<td>3 31</td>
<td>Rangeland</td>
<td>Grass</td>
<td></td>
</tr>
<tr>
<td>3 32</td>
<td></td>
<td>Savannas</td>
<td></td>
</tr>
<tr>
<td>3 33</td>
<td></td>
<td>Chaparral (taken as brushland)</td>
<td></td>
</tr>
<tr>
<td>3 34</td>
<td></td>
<td>Desert shrub</td>
<td></td>
</tr>
<tr>
<td>4 41</td>
<td>Forest land</td>
<td>Deciduous</td>
<td></td>
</tr>
<tr>
<td>4 411</td>
<td></td>
<td>Deciduous/intermittent crown</td>
<td></td>
</tr>
<tr>
<td>4 42</td>
<td></td>
<td>Evergreen (coniferous and other)</td>
<td></td>
</tr>
<tr>
<td>4 421</td>
<td></td>
<td>Coniferous/solid crown</td>
<td></td>
</tr>
<tr>
<td>4 422</td>
<td></td>
<td>Coniferous/intermittent crown</td>
<td></td>
</tr>
<tr>
<td>4 43</td>
<td></td>
<td>Mixed forest land</td>
<td></td>
</tr>
<tr>
<td>5 51</td>
<td>Water</td>
<td>Streams and waterways</td>
<td></td>
</tr>
<tr>
<td>5 52</td>
<td></td>
<td>Lakes</td>
<td></td>
</tr>
<tr>
<td>5 53</td>
<td></td>
<td>Reservoirs</td>
<td></td>
</tr>
<tr>
<td>5 54</td>
<td></td>
<td>Bays and estuaries</td>
<td></td>
</tr>
<tr>
<td>5 55</td>
<td></td>
<td>Other water</td>
<td></td>
</tr>
<tr>
<td>6 61</td>
<td>Nonforested wetland</td>
<td>Vegetated</td>
<td></td>
</tr>
<tr>
<td>6 62</td>
<td></td>
<td>Bare</td>
<td></td>
</tr>
<tr>
<td>7 71</td>
<td>Barren land</td>
<td>Salt flats</td>
<td></td>
</tr>
<tr>
<td>7 72</td>
<td></td>
<td>Beaches</td>
<td></td>
</tr>
<tr>
<td>7 73</td>
<td></td>
<td>Sand other than beaches</td>
<td></td>
</tr>
<tr>
<td>7 74</td>
<td></td>
<td>Bare exposed rock</td>
<td>Hillslopes</td>
</tr>
<tr>
<td>7 741</td>
<td></td>
<td>Other barren land</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tundra</td>
<td>Tundra</td>
<td></td>
</tr>
<tr>
<td>8 81</td>
<td>Permanent snow and icefields</td>
<td>Permanent snow and icefields</td>
<td></td>
</tr>
<tr>
<td>MINNEAPOLIS(^1)</td>
<td>HOUSTON(^2)</td>
<td>MILWAUKEE(^3)</td>
<td>LOS ANGELES(^4)</td>
</tr>
<tr>
<td>-------------------</td>
<td>-------------</td>
<td>---------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>Commercial Core</td>
<td>Commercial/ Industrial/ Transportation</td>
<td>Commerce/ Industry</td>
<td>Commercial/ Industrial/ Institutional</td>
</tr>
<tr>
<td>Industrial Core</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Commercial/ Industrial Strip</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High Density Single Family Res.</td>
<td>Residential</td>
<td>Inner City</td>
<td>Med./High Density Residential Low Density Residential</td>
</tr>
<tr>
<td>Low Density Single Family Res.</td>
<td>Residential (New)</td>
<td>wooded Suburbs</td>
<td></td>
</tr>
<tr>
<td>Mixed Single Family Res.</td>
<td>Mixed Residential</td>
<td>New Suburbs</td>
<td></td>
</tr>
<tr>
<td>Urban Open Extractive</td>
<td></td>
<td></td>
<td>Undeveloped Urban Green Space Flood Channels &amp; Extractive</td>
</tr>
<tr>
<td>Woody Veg. Non Woody Veg.</td>
<td>Woody Veg. Trees Grassy Rural</td>
<td>Chapparal Grassland Agricultural</td>
<td>Trees Marsh</td>
</tr>
<tr>
<td>Water</td>
<td>Water</td>
<td>Water</td>
<td>Water</td>
</tr>
</tbody>
</table>

\(^1\)Source: Brown and Sizer, 1973  
\(^2\)Source: Dornbach and McKain, 1973  
\(^3\)Source: Mausel, Todd, and Baumgardner, 1974  
\(^4\)Source: Bryant, 1976  
\(^5\)Source: Hannah, Thomas, and Esparza, 1975
### URBAN ACTIVITIES IDENTIFIABLE AT FOUR LEVELS OF INTERPRETATION

<table>
<thead>
<tr>
<th>ERTS-1 Satellite Imagery</th>
<th>High Altitude Photography RB-57, 1:120,000</th>
<th>High Altitude Photography RB-57, 1:60,000</th>
<th>Medium Altitude Photography Black-and-White, 1:15,640</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core Residential/Commercial</td>
<td>Individual Structures Residential Areas</td>
<td>Single Family Residential Swimming Pools Apartment Complex Mobile Home Park</td>
<td>Housing Types High Rise Structures Garden Apartments</td>
</tr>
<tr>
<td>Excavations Airports</td>
<td>Excavating Industry Airport Terminal Building Aircraft Hangars</td>
<td>Junk Yard Extracting Industry Fabricating Processing Gas Storage</td>
<td>Power Boat — Wake Park</td>
</tr>
<tr>
<td></td>
<td>Highways</td>
<td>Highways Interchanges Divided Highways Bridges Rest Areas</td>
<td>Power Plant — Coal Piles Overhead Crane Water Pipes Open Storage Area</td>
</tr>
</tbody>
</table>

GEO-BASED INFORMATION SYSTEMS

DEFINITION: INTEGRATION OF DATASETS HAVING AREAL COLLECTION UNITS OF VARIED SIZE, SHAPE, AND FORMAT.

FORMAT: LANDSAT IMAGE - REGULAR CELL-BASED (PIXEL)
M.S.S. BANDS 4, 5, 6, AND 7 AND BAND RATIOS

MAP FORMAT - POINT DIMENSION, e.g., ELEVATION, RAINFALL, INTERSECTION LINE DIMENSION, e.g., WATERCOURSE, ROAD, TRANSMISSION LINE AREA DIMENSION, e.g., CENSUS TRACT, NEIGHBORHOOD, LAND USE/LAND COVER CATEGORY

TABULAR FORMAT - IRREGULAR AREAL UNIT FOR WHICH SOCIO-ECONOMIC INFORMATION IS AVAILABLE, e.g., AVERAGE FAMILY SIZE, AVERAGE FAMILY INCOME, AND AVERAGE NUMBER OF AUTOS PER FAMILY

EXAMPLE: I.B.I.S. (IMAGE BASED INFORMATION SYSTEM)
Conceptualized Formation of an IBIS Data Base.
LAND USE/LAND COVER CLASSIFICATION

**** ACCURATE CLASSIFICATIONS OF REMOTELY SENSED DATA IS CENTRAL TO ALL APPLICATIONS TO WHICH THESE DATA ARE PUT. ****

**** MANY ANALYSES AND MODELS ADD THEIR OWN VARIANCE TO THE DATA AND, THUS, IT IS CRITICAL TO BEGIN WITH HIGHLY ACCURATE DATA THAT CAN WITHSTAND SOME DEGRADATION DURING THE DERIVATION OF FINAL PRODUCTS. ****

ISSUES ASSOCIATED WITH THE ATTAINMENT OF ACCEPTABLE LEVELS OF ACCURACY:

1. CLASSIFICATION SCHEME USED (DESIGNED FOR USE WITH REMOTELY SENSED DATA OR NOT).
2. SPECTRAL AND SPATIAL FEATURE SELECTION AND POSSIBLE NEED TO REDUCE DIMENSIONALITY.
3. IMAGE RADIOMETRIC (SUN ANGLE AND HAZE) AND GEOMETRIC (REGISTRATION) CHARACTERISTICS OF RAW AND PROCESSED REMOTELY SENSED DATA. GEOMETRIC TRANSFORMATIONS INVOLVE RE-SAMPING.
4. TEMPORAL SEQUENCE OF COVERAGE.
5. GENERATION OF CLASS TRAINING STATISTICS AND AMPLING TECHNIQUES.
6. OPTIMAL USE OF COLLATERAL DATA SUCH AS TERRAIN DATA WHICH CAN BE TREATED AS AN ADDITIONAL CHANNEL.
LAND USE/LAND COVER CHANGE DETECTION

AIM:
1. IDENTIFY THOSE PICTURE ELEMENTS THAT HAVE CHANGED OVER TIME
2. A. DISTINGUISH CHANGE THAT IS OF INTEREST FROM THAT WHICH IS NOT
   B. CLASSIFICATION OF THE CHANGES OF INTEREST

METHODOLOGY:
1. IMAGE DIFFERENCING
2. IMAGE RATIOING
3. CLASSIFICATION COMPARISON
4. PREPROCESSING PRIOR TO CHANGE DETECTION
5. CHANGE VECTOR ANALYSIS

1. IMAGE DIFFERENCING.
   A. PRECISELY REGISTER SCENES OF SAME AREA FOR TWO DATES
   B. SUBTRACT ONE IMAGE FROM THE OTHER ON A PIXEL-BY-PIXEL BASIS
   C. CREATE FREQUENCY DISTRIBUTIONS OF RADIANCE CHANGE FOR EACH BAND
   D. LOCATE THRESHOLD BOUNDARIES ON DISTRIBUTION TO SEPARATE CHANGE
      AND NO-CHANGE PIXELS (OFTEN DONE INTERACTIVELY BY AN INTERPRETER
      FAMILIAR WITH THE AREA)

2. IMAGE RATIOING.
   A. RATIO TRANSFORMATIONS TEND TO REMAIN INVARIANT UNDER VARYING
      CONDITIONS SUCH AS SHADOW, SUN ANGLE, AND SEASONAL REFLECTANCE
      DIFFERENCES
   B. NORMALIZED RATIO VALUES ON A PIXEL-BY-PIXEL BASIS IN ONE BAND
      ARE REPRESENTED BY A FREQUENCY DISTRIBUTION
   C. THRESHOLD SELECTION TAKES PLACE. RATIO VALUES SIGNIFICANTLY
      DIFFERENT FROM 1.0 ARE CONSIDERED CHANGE PIXELS
IMAGE DIFFERENCING
CHANGE DETECTION METHOD

TIME 1
LANDSAT SCENE

REGISTER SCENES

TIME 1
SUBSET

(BAND 5)
PIXEL BY PIXEL
SUBTRACTION
TIME 1 - TIME 2
+ CONSTANT (255)

RANGE
10
MINUS
TIME 1

10 - 40 + 255 = 225

RESIDENTIAL

TIME 2
SUBSET

TIME 2
LANDSAT SCENE

REGISTER SCENES

RESIDENTIAL

PIXEL OF CHANGE

T

225

255
3. CLASSIFICATION COMPARISON.
   A. SUCCESS DEPENDS SIGNIFICANTLY UPON ACCURATE CLASSIFICATION OF LAND USE/LAND COVER
   B. CLASSIFICATION OF MULTI-DATE, MULTI-SPECTRAL DATA WITH HOPE THAT A "CHANGE" CATEGORY WILL EMERGE
   C. LAYERED CLASSIFICATION REQUIRES MULTI-STAGE DECISION LOGIC. CLASSIFICATION STRATEGY IS BEST PERCEIVED AS A TREE DIAGRAM
   D. CLUSTERING COMPARISON. UNSUPERVISED CLASSIFICATION OF SCORES FOR TWO DATES AND COMPARISON OF THE RESULTING GROUPINGS

4. PREPROCESSING PRIOR TO CHANGE DETECTION.
   A. LOW FREQUENCY FILTERING - IMAGE SMOOTHING TO ENHANCE AREAS OF HOMOGENEITY AT EXPENSE OF HIGH FREQUENCY DETAIL
   B. HIGH FREQUENCY FILTERING - THIS ENHANCEMENT TECHNIQUE PRODUCES A SHARP VISUAL IMAGE BUT CONTAINS MORE "NOISE". GREATER EDGE ENHANCEMENT HIGHLIGHTING DISCONTINUITIES IN THE DATA
   C. PRINCIPAL COMPONENT ANALYSIS - REDUCES THE DIMENSIONALITY OF THE DATA BY COLLAPSING A SET OF CORRELATED VARIABLES INTO A SMALLER SET OF ORTHOGONAL VARIABLES

5. CHANGE VECTOR ANALYSIS.
   A. WHEN LAND CHANGES ITS SPECTRAL APPEARANCE MAY CHANGE. PLOT THE VALUE OF TWO SPECTRAL VARIABLES (BANDS) FOR AN AREA BEFORE AND AFTER CHANGE ON A GRAPH
   B. VECTOR HAS BOTH MAGNITUDE AND DIRECTION:
      (i) MAGNITUDE INDICATES AMOUNT OF CHANGE;
      (ii) DIRECTION INDICATES TYPE OF CHANGE
   C. POSSIBILITY OF USING STANDARD DEVIATIONAL ELLIPSE ANALYSIS
A. SPECTRAL CHANGE VECTOR

B. LITTLE OR NO CHANGE

C. CHANGE (e.g., CLEARED FOR SUBDIVISION)

D. CHANGE (e.g., REGROWTH OF NATURAL VEGETATION)
LAND USE PATTERNs ARE A RESULT OF MISGUIDED SUBSIDIES, INSTITUTIONAL STRUCTURES, TECHNICAL CHANGE, CULTURAL LAG TIME AND, TO SOME EXTENT NON-QUANTIFIABLE INFLUENCES OF PUBLIC PREFERENCES. ALL THESE PARAMETERS INTERRELATE TO PRODUCE A PATTERN.

THE PATTERN IS COMPRISED OF A SET OF STATES (LAND USE CATEGORIES) AND THEIR INTERRELATIONSHIPS (SPATIAL PROXIMITIES OR RULES GOVERNING THEIR INTERCHANGABILITY). CONSIDER MODELS THAT ATTEMPT TO DESCRIBE AND EXPLAIN THE LAND USE CHANGE PROCESS. CONSIDER IN TURN:

A. A TYPOLOGY OF LAND USE CHANGE MODELS
B. OPERATIONAL MODELS INCORPORATING REMOTELY SENSED DATA
C. SUGGESTED MODEL EXTENSIONS
A. A TYPOLOGY OF LAND USE CHANGE MODELS.

I. INDEPENDENT MODEL.

LAND USE IN CELL g_{ij} AT TIME t+dt IS IN NO WAY RELATED TO THE LAND USE IN CELL g_{ij} AT TIME t.

II. DEPENDENT MODEL (MARKOV MODEL).

LAND USE IN CELL g_{ij} AT TIME t+dt DEPENDS ON PREVIOUS LAND USE IN CELL g_{ij} AT TIME t.

\[
g_{ij}^{t+dt} = F(g_{ij}^t)
\]

III. HISTORICAL MODEL (TIME SERIES OR LAGGED VARIABLE MODEL)

LAND USE IN CELL g_{ij} AT TIME t+dt DEPENDS ON THE SEVERAL PREVIOUS LAND USES IN CELL g_{ij}.

\[
g_{ij}^{t+dt} = F(g_{ij}^t, g_{ij}^{t-dt}, g_{ij}^{t-2dt}, \ldots, g_{ij}^{t-kdt})
\]

IV. MULTIVARIATE MODEL (MULTIPLE LINEAR REGRESSION AND DISCRIMINANT ANALYSIS)

LAND USE IN CELL g_{ij} IS DEPENDENT ON SEVERAL OTHER VARIABLES ALSO AT CELL g_{ij}.

\[
g_{ij}^{t+dt} = F(u_{ij}^t, v_{ij}^t, w_{ij}^t, \ldots, z_{ij}^t)
\]

V. GEOGRAPHICAL MODEL

LAND USE IN CELL g_{ij} IS DEPENDENT ON LAND USE IN OTHER CELLS.

\[
g_{ij}^{t+dt} = F(g_{i+p, j+q}^t)
\]

A. EXTRAPOLATION-FILTERING MODEL

\[
g_{ij}^t = F(g_{i+p,j+q}^t)
\]

THIS MODEL CAN BE CHARACTERIZED BY A GEOGRAPHICAL QUIZ.
B. DYNAMIC GEOGRAPHICAL

\[ g_{ij}^{t+dt} = \dot{g}_{ij} \]

WHERE \( n_{ij} \) DENOTES ALL OF THE LAND USES IN THE NEIGHBORHOOD OF LOCATION \( i,j \).

THE MODEL HAS TWO PARAMETERS: (i) \( n \) - NEIGHBORHOOD, (ii) \( F \) - FUNCTION

(i) NEIGHBORHOOD. THIS IS IMPORTANT BECAUSE IT DEFINES THE GEOGRAPHICAL DOMAIN OF INFLUENCE. ONE COULD ASSUME THAT NEIGHBORHOOD DEFINITION VARIES BY CELL BUT IT IS EASIER AT ASSUME SPATIAL NEIGHBORHOOD STATIONARITY. ALTERNATIVELY, ONE COULD ALLOW NEIGHBORHOOD TO VARY IN SIZE, SHAPE, AND ORIENTATION AND BE A FUNCTION OF THE LOCATION OF THE CELL, i.e., \( p,q = F(i,j) \)

(ii) FUNCTION. ASSUME 5 LAND USE TYPES AND A CELL NEIGHBORHOOD OF 5, i.e., \((i,j), (i-1,j), (i+1,j), (i,j-1), \) and \((i,j+1)\). THUS, THERE ARE 5 STATES (S) AND 5 NEIGHBORS (N).

A TRANSITION RULE SHOWS THAT ONE MUST CONSIDER \( S^N = 3125 \) CASES TO COVER ALL POSSIBILITIES.

ASSUME SPATIAL ISOPTROPY, i.e., POSITIONING OF NEIGHBORS DOES NOT COUNT AND SPATIAL STATIONARITY. THIS MEANS THAT THE SAME ENVIRONMENT (NEIGHBORHOOD) RESULTS IN THE SAME CONSEQUENCES OR THAT THE RULES DO NOT DEPEND ON WHERE YOU ARE. COMPARE CHESS \( \text{\&} \) RULES ARE PIECE-SPECIFIC BUT APPLY UNIFORMLY AT ANY LOCATION ON THE BOARD.
\[
\begin{array}{cccc}
A & A & A & B \\
A & A & A & B \\
A & B & B & A \\
B & B & A & A \\
B & B & A & A \\
\end{array}
\]

\[
R \quad R
\]

\[
RAI \quad \rightarrow \quad RC1
\]

\[
C \quad C
\]

\[
RICRA \quad \rightarrow \quad C
\]

\[
(2R, 1I, 1C, A) \quad \rightarrow \quad C
\]
B. OPERATIONAL MODELS INCORPORATING REMOTELY SENSED DATA

I. LANDSCAPE MODELLING.

DEFINITION: LANDSCAPE MODELLING ORGANIZES AND OVERLAYS INFORMATION FROM EXISTING MAPS, TABULAR SOURCES, AND THE ANALYSIS OF REMOTE SENSING IMAGERY INTO A COMPUTER FRAMEWORK.

AIM: THE CURRENT THRUST OF LANDSCAPE MODELLING IS THE PROJECTION AND DISPLAY IN A MAP FORM OF THE FUTURE LANDSCAPE WHICH WOULD RESULT FROM THE CONTINUATION OF CURRENT LAND MANAGEMENT PRACTICES OR THE LACK THEREOF.

METHODOLOGY:
1. CELL-BY-CELL COMPARISON TO DETECT CHANGE
2. MATRIX SHOWING FREQUENCY OF CHANGE BETWEEN CLASSES
3. CONSTRUCTION OF TRANSITION PROBABILITY MATRIX
4. MARKOV CHAIN MODELLING TO PREDICT FUTURE AGGREGATE CHANGE
5. IDENTIFICATION OF DETERMINANTS OF CHANGE THROUGH DISCRIMINANT ANALYSIS
6. APPLICATION OF DISCRIMINANT MODEL TO ALL CELLS TO ESTIMATE NEXT MOST PROBABLE CHANGE
7. ALLOCATE CHANGE BASED ON PRIORITY RANKING OF CELLS
EXISTING MAPS

SOCIO-ECONOMIC DATA

REMOTE SENSING IMAGERY

ANALYSIS

DIGITAL LANDSCAPE MODEL

LAND-USE MODELING

INPUTS:
- TOPOGRAPHIC MAPS
- VEGETATION MAPS
- SOILS MAPS
- GEOLOGIC MAPS
- TRANSPORTATION MAPS
- CENSUS TRACT MAPS OF POPULATION
- FAMILY COUNT
- HOUSING
- CAR OWNERSHIP
- SATELLITE IMAGES
  - DIGITAL
  - OPTICAL
  - AIRCRAFT IMAGES
- PHOTOINTERPRETATION
- COMPUTER PATTERN CLASSIFICATION

COMPUTES:
- SLOPE AND ASPECT PLANES
- SOCIOECONOMIC DENSITY PLANES
- MINIMUM-DISTANCE PLANES
- TRANSPORTATION ACCESS PLANES
- SOLAR-RADIATION PLANES
- LANDSAT TRANSFORMATIONS

OUTPUTS:
- FUTURE LAND-USE SCENARIOS
- SITE DEVELOPMENT PLANS
- POWER PLANT SITE COMPARISONS
- ZONING ALTERNATIVES
  AND MANY OTHER APPLICATIONS TO ECONOMICS, HYDROLOGY, PLANNING, ENERGY, ETC.

SIMPLE SCHEMATIC REPRESENTATION OF THE LANDSCAPE MODELING CONCEPT.
7 LAND-USE SUBMODEL VARIABLES:
- 1963 Photo Land-Use
- 1970 Photo Land-Use
- 1972 to 1973 USGS Photo Land-Use
- Two 1963 to 1970 Land-Use Changes
- Two 1963 to 1970 Alphanumeric Coded Land-Use Changes

9 PHYSIOGRAPHIC SUBMODEL VARIABLES:
- Topographic Elevation
- Topographic Slope
- Topographic Aspect
- USGS Surficial Geology
- Solar Insolation for Landsat Imagery
- Four Landsat MSS ÷ Insolation Ratios

5 TRANSPORTATION SUBMODEL VARIABLES:
- Composite Minor-Road MD
- Composite Major-Road MD
- Freeway MD
- Freeway Interchange MD
- Built-Up Urban-Area MD

17 SOCIOECONOMIC SUBMODEL VARIABLES:
- Four Population/Housing Densities
  Per Acre
- Five Population/Family/Housing-Unit Totals
- 1969 Mean Family Income
- Median Housing-Unit Rent/Value
- One-/Two-/Three-Car Family Totals
- Total Census Tract Acreage
- Average Number of Cars Per Family

10 LANDSAT IMAGE SUBMODEL VARIABLES:
- MSS-4 (Visible Green)
- MSS-5 (Visible Red)
- MSS-6 (Solar Infrared)
- MSS-7 (Solar Infrared)

CONCEPTUAL DIAGRAM OF THE LANDSCAPE MODEL OF THE DENVER STUDY AREA.
CHANGES IN DENVER LAND USE, 1963 TO 1970. Entries show the number of 10 acre cells of each 1963 land use that converted to another land use by 1970. A blank denotes that no conversion occurred between the respective land uses during the period covered. Entries along the principal diagonal represent the number of cells of the land use that did not change to another land use between 1963 and 1970.

<table>
<thead>
<tr>
<th>1963 Land-Use Type</th>
<th>Code</th>
<th>Converting to 1970 Land Use</th>
<th>1963 Land-Use totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>11 Residential</td>
<td></td>
<td>11 12 13 14 15 16 17 18 19 20 21 22 23 24 41 51 52 53 55 61 73 75</td>
<td></td>
</tr>
<tr>
<td>12 Commercial and services</td>
<td></td>
<td>1089 6</td>
<td></td>
</tr>
<tr>
<td>13 Industrial</td>
<td></td>
<td>882 1</td>
<td></td>
</tr>
<tr>
<td>14 Extractive</td>
<td></td>
<td>444 6</td>
<td></td>
</tr>
<tr>
<td>15 Transportation, commun-</td>
<td></td>
<td>729</td>
<td></td>
</tr>
<tr>
<td>ication, and utilities</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16 Institutional</td>
<td></td>
<td>3079 14 15</td>
<td></td>
</tr>
<tr>
<td>17 Strip and clustered</td>
<td></td>
<td>1350</td>
<td></td>
</tr>
<tr>
<td>development</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18 Mixed urban</td>
<td></td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>19 Open and other</td>
<td></td>
<td>239 52 46 35 51 42 39 31 262</td>
<td></td>
</tr>
<tr>
<td>urban land</td>
<td></td>
<td>3175 46 1</td>
<td></td>
</tr>
<tr>
<td>21 Cropland and pasture</td>
<td></td>
<td>394 27 125 139 72 31 262</td>
<td></td>
</tr>
<tr>
<td>22 Orchards and other</td>
<td></td>
<td>351 14558 2 4 22 17</td>
<td></td>
</tr>
<tr>
<td>horticultural areas</td>
<td></td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>23 Feeding operations</td>
<td></td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>24 Other agricultural land</td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>25 Deciduous forest land</td>
<td></td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>26 Streams and waterways</td>
<td></td>
<td>3 1</td>
<td></td>
</tr>
<tr>
<td>27 Lakes</td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>28 Reserv. is</td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>29 Other water</td>
<td></td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>30 Vegetated nonforested</td>
<td></td>
<td>95 592</td>
<td></td>
</tr>
<tr>
<td>wetland</td>
<td></td>
<td>158</td>
<td></td>
</tr>
<tr>
<td>31 Sand other than beaches</td>
<td></td>
<td>171 171</td>
<td></td>
</tr>
<tr>
<td>32 Other barren land</td>
<td></td>
<td>52</td>
<td></td>
</tr>
<tr>
<td>1963 Land-Use totals</td>
<td></td>
<td>1872 1887</td>
<td></td>
</tr>
</tbody>
</table>

1970 Land-Use totals: 7030 1182 1061 636 863 3159 1655 0 3562 14624 6 2 7 18 101 641 175 5 171 52 1303.
DENVER LAND-USE PROBABILITY TRANSITION MATRIX, 1963 TO 1970. Entries in the matrix denote the fraction of each 1963 land use that converted to another land use in 1970 as computed from table 4. A blank in the matrix denotes that no conversion occurred between the respective land uses during the period covered. A 1.0 in the matrix denotes that the area of that land use either did not change or increased by conversion to it from another land use between 1963 and 1970. Entries less than 0.001 are indicated by a dash.

<table>
<thead>
<tr>
<th>1963 Land-Use Type</th>
<th>Code</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
<th>19</th>
<th>21</th>
<th>22</th>
<th>23</th>
<th>24</th>
<th>41</th>
<th>51</th>
<th>52</th>
<th>53</th>
<th>55</th>
<th>61</th>
<th>73</th>
<th>75</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>11</td>
<td>0.996</td>
<td>0.002</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.002</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Commercial and services</td>
<td>12</td>
<td>0.002</td>
<td>0.988</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.005</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Industrial</td>
<td>13</td>
<td>0.003</td>
<td>0.001</td>
<td>0.994</td>
<td>0.001</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Extractive</td>
<td>14</td>
<td>0.006</td>
<td>0.011</td>
<td>0.959</td>
<td>-</td>
<td>0.013</td>
<td>-</td>
<td>0.011</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Transportation, communications and utilities</td>
<td>15</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Institutional</td>
<td>16</td>
<td>0.004</td>
<td>0.001</td>
<td>-</td>
<td>0.995</td>
<td>-</td>
<td>0.004</td>
<td>-</td>
<td>0.005</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Strip and clustered development</td>
<td>17</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Mixed urban</td>
<td>18</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Open and other urban land</td>
<td>19</td>
<td>0.064</td>
<td>0.014</td>
<td>0.013</td>
<td>0.009</td>
<td>0.014</td>
<td>0.011</td>
<td>0.010</td>
<td>0.849</td>
<td>0.012</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Cropland and pasture</td>
<td>21</td>
<td>0.025</td>
<td>0.002</td>
<td>0.009</td>
<td>0.004</td>
<td>0.002</td>
<td>0.016</td>
<td>0.022</td>
<td>0.909</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Orchards and other horticultural areas</td>
<td>22</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Feeding operations</td>
<td>23</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Other agricultural land</td>
<td>24</td>
<td>0.030</td>
<td>0.242</td>
<td>0.394</td>
<td>0.061</td>
<td>0.091</td>
<td>0.152</td>
<td>0.030</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Deciduous forest land</td>
<td>41</td>
<td>0.016</td>
<td>0.141</td>
<td>0.031</td>
<td>-</td>
<td>0.002</td>
<td>0.005</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Streams and waterways</td>
<td>51</td>
<td>0.010</td>
<td>0.999</td>
<td>0.010</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Lakes</td>
<td>52</td>
<td>0.999</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Reservoirs</td>
<td>53</td>
<td>1.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Other water</td>
<td>55</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Vegetated nonforested wetland</td>
<td>61</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Sand other than beaches</td>
<td>73</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.813</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Other barren land</td>
<td>75</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.993</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
DENVER AGGREGATE LAND-USE PROJECTIONS BY A MARKOV TREND MODEL, 1963 TO 2068. Specific land-use total areas, such as those illustrated in figure 42, are detailed here. Photointerpreted second-order land-use changes between 1963 and 1970 were used to drive this generalized trend model for the 24- by 24-mile Denver Metropolitan Area. The basic assumption of the Markov model is that the rates of changes are constant over time for all land-use classes. This model can project only aggregate land-use areas and cannot spatially predict the actual sites of conversion.

<table>
<thead>
<tr>
<th>Land-Use Type</th>
<th>Measured Acres</th>
<th>Projected Acres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>64,210</td>
<td>70,500</td>
</tr>
<tr>
<td>Commercial and services</td>
<td>11,020</td>
<td>11,820</td>
</tr>
<tr>
<td>Industrial</td>
<td>8,870</td>
<td>10,610</td>
</tr>
<tr>
<td>Extractive</td>
<td>4,630</td>
<td>6,360</td>
</tr>
<tr>
<td>Transportation, communications, and utilities</td>
<td>7,290</td>
<td>8,650</td>
</tr>
<tr>
<td>Strip and clustered development</td>
<td>13,500</td>
<td>16,550</td>
</tr>
<tr>
<td>Mixed urban</td>
<td>40</td>
<td>0</td>
</tr>
<tr>
<td>Open and other urban</td>
<td>37,410</td>
<td>35,620</td>
</tr>
<tr>
<td>Cropland and pasture</td>
<td>160,090</td>
<td>146,240</td>
</tr>
<tr>
<td>Orchards and other</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Horticultural areas</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Feeding operations</td>
<td>330</td>
<td>300</td>
</tr>
<tr>
<td>Deciduous forest land</td>
<td>180</td>
<td>180</td>
</tr>
<tr>
<td>Streams and waterways</td>
<td>860</td>
<td>1,010</td>
</tr>
<tr>
<td>Lakes</td>
<td>5,930</td>
<td>6,410</td>
</tr>
<tr>
<td>Reservoirs</td>
<td>1,580</td>
<td>1,750</td>
</tr>
<tr>
<td>Other water</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Vegetated nonforested</td>
<td>1,710</td>
<td>1,710</td>
</tr>
<tr>
<td>Forest land</td>
<td>640</td>
<td>520</td>
</tr>
<tr>
<td>Reserve land</td>
<td>18,870</td>
<td>18,920</td>
</tr>
<tr>
<td>Grand Total</td>
<td>368,640</td>
<td>368,640</td>
</tr>
</tbody>
</table>

- Observation interval
- Region of possible reality
PREDICTION OF FUTURE TRENDS IN THE AMOUNT OF OPEN SPACE AND COMPETING LAND USE IN THE DENVER METROPOLITAN AREA. A constant matrix of transfers, \( P = \{ p_{ij} \} \), from land use, \( i \), to land use, \( j \), was assumed. Acreages displayed relate to the original area of 24- by 24-statute miles = 576 square statute miles.
PROPOSED COMBINATION MARKOV AND LINEAR DISCRIMINANT MODELS FOR IMPROVED SPATIAL-CHANGE PREDICTION. The Markov trend model provides the correct number of change cells by type. These can be selected from a sorted list of discriminant-computed posterior probabilities of change. The selected cells can be assembled into a map of future land use. Spatially registered Landsat digital imagery can serve as future land-use inputs in lieu of the 1963 to 1970 aerial photography.
II. SPATIAL ANALYSIS AND REGIONAL LAND USE PATTERNS.

DEFINITION: THE TERMS SPATIAL ANALYSIS AND SYNTHESIS ARE DEFINED AS THE SEPARATION OF A LAND USE PATTERN INTO INDIVIDUAL COMPONENTS (SPATIAL PROXIMITIES) AND THE RECONSTRUCTING OF THESE COMPONENTS FOR USE IN PROJECTING LAND USE PATTERNS.

AIM: NEED TO PROJECT FUTURE LAND USE PATTERNS.

METHODOLOGY: 1. BASED ON QUANTIFICATION OF A LAND USE PATTERN
2. OPERATION DEFINITION OF SPATIAL RELATIONSHIPS
3. DERIVATION OF A WEIGHTED INDEX BASED ON FREQUENCIES OF OCCURRENCE FOR EACH DISTANCE FROM ALL OTHER LAND USES
4. IDENTIFICATION OF "TRIGGERING" AND "CONSTRAINING" FACTORS
5. ALLOCATION PROCEDURE OF AGGREGATE DEMAND FOR LAND TO SPATIAL DOMAIN

OPERATION: 1. SELECTION OF 15 LAND USE/LAND COVER CLASSES CODED AS PRESENCE/ABSENCE ON CELL-BY-CELL BASIS
2. CREATION OF SPATIAL PROXIMITIES MATRIX FOR EACH LAND USE/LAND COVER CATEGORY WITH 19 DISTANCE INTERVALS. ACCOMPANIED BY A MAP SHOWING ISO-PROXIMITY LINES
3. TABLE OF PROXIMITY OCCURRENCES OF ANY LAND USE/LAND COVER CATEGORY TO ALL OTHER CATEGORIES BY DISTANCE INTERVALS
4. PROJECTION TECHNIQUE. MODEL MUST DISCRIMINATE UNDEVELOPED AREAS HAVING THE SAME SPATIAL CHARACTERISTICS AS AREAS CURRENTLY OCCUPIED BY A GIVEN LAND USE. THUS,
A cell without urban development found to possess the largest number of spatial attributes that most closely approximate the attributes of developed cells is assumed to develop in the same manner.

5. Cross reference files showing (i) cells containing a particular land use category; (ii) cells having high weighting for some category; (iii) land use category demand (expressed in acres or number of cells); (iv) cells containing constraining attributes.
DATA BASE COLLECTED ON A 500 METER BY 500 METER GRID
SEARCH FROM WATER

LEVELS

FREQUENCY

OF CELLS GREATER THAN NL 163
<table>
<thead>
<tr>
<th>LAND USES</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>34</td>
<td>90</td>
<td>82</td>
<td>77</td>
<td>106</td>
<td>66</td>
<td>91</td>
<td>74</td>
<td>53</td>
<td>43</td>
<td>19</td>
<td>16</td>
<td>13</td>
<td>8</td>
<td>8</td>
<td>4</td>
<td>2</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Institutions</td>
<td>176</td>
<td>379</td>
<td>125</td>
<td>45</td>
<td>40</td>
<td>20</td>
<td>11</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Low Density Housing</td>
<td>173</td>
<td>366</td>
<td>167</td>
<td>59</td>
<td>15</td>
<td>4</td>
<td>5</td>
<td>7</td>
<td>5</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>High Density Housing</td>
<td>87</td>
<td>229</td>
<td>144</td>
<td>93</td>
<td>83</td>
<td>26</td>
<td>23</td>
<td>14</td>
<td>13</td>
<td>7</td>
<td>8</td>
<td>6</td>
<td>9</td>
<td>3</td>
<td>6</td>
<td>8</td>
<td>12</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>Recreation</td>
<td>77</td>
<td>186</td>
<td>144</td>
<td>115</td>
<td>124</td>
<td>46</td>
<td>24</td>
<td>4</td>
<td>11</td>
<td>13</td>
<td>7</td>
<td>7</td>
<td>3</td>
<td>2</td>
<td>6</td>
<td>6</td>
<td>7</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>Railroads</td>
<td>83</td>
<td>184</td>
<td>115</td>
<td>92</td>
<td>103</td>
<td>63</td>
<td>62</td>
<td>51</td>
<td>26</td>
<td>7</td>
<td>8</td>
<td>6</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Industry</td>
<td>23</td>
<td>119</td>
<td>103</td>
<td>97</td>
<td>135</td>
<td>75</td>
<td>76</td>
<td>52</td>
<td>46</td>
<td>40</td>
<td>17</td>
<td>11</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Commerce</td>
<td>101</td>
<td>290</td>
<td>159</td>
<td>89</td>
<td>75</td>
<td>32</td>
<td>20</td>
<td>17</td>
<td>4</td>
<td>6</td>
<td>4</td>
<td>3</td>
<td>1</td>
<td>4</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Rural (major)</td>
<td>153</td>
<td>297</td>
<td>159</td>
<td>75</td>
<td>41</td>
<td>23</td>
<td>14</td>
<td>11</td>
<td>7</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Rural (minor)</td>
<td>46</td>
<td>107</td>
<td>78</td>
<td>69</td>
<td>101</td>
<td>50</td>
<td>52</td>
<td>35</td>
<td>43</td>
<td>30</td>
<td>37</td>
<td>31</td>
<td>33</td>
<td>24</td>
<td>16</td>
<td>9</td>
<td>6</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Controlled Access</td>
<td>5</td>
<td>10</td>
<td>8</td>
<td>5</td>
<td>7</td>
<td>15</td>
<td>14</td>
<td>19</td>
<td>11</td>
<td>13</td>
<td>8</td>
<td>15</td>
<td>14</td>
<td>19</td>
<td>15</td>
<td>18</td>
<td>12</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>Uncontrolled Access</td>
<td>133</td>
<td>240</td>
<td>125</td>
<td>95</td>
<td>78</td>
<td>29</td>
<td>18</td>
<td>14</td>
<td>17</td>
<td>15</td>
<td>9</td>
<td>8</td>
<td>6</td>
<td>6</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Transportation (interchanges)</td>
<td>5</td>
<td>26</td>
<td>34</td>
<td>36</td>
<td>64</td>
<td>52</td>
<td>50</td>
<td>38</td>
<td>47</td>
<td>65</td>
<td>51</td>
<td>48</td>
<td>36</td>
<td>40</td>
<td>27</td>
<td>27</td>
<td>21</td>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td>Transportation (interstates)</td>
<td>20</td>
<td>55</td>
<td>45</td>
<td>36</td>
<td>61</td>
<td>53</td>
<td>46</td>
<td>39</td>
<td>50</td>
<td>63</td>
<td>43</td>
<td>38</td>
<td>29</td>
<td>29</td>
<td>31</td>
<td>20</td>
<td>16</td>
<td>12</td>
<td>9</td>
</tr>
<tr>
<td>Sewer Service Areas</td>
<td>217</td>
<td>197</td>
<td>118</td>
<td>72</td>
<td>57</td>
<td>28</td>
<td>15</td>
<td>15</td>
<td>12</td>
<td>14</td>
<td>8</td>
<td>11</td>
<td>3</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Rivers</td>
<td>130</td>
<td>257</td>
<td>144</td>
<td>120</td>
<td>108</td>
<td>31</td>
<td>13</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

*Distances equal 500 meters.

CK/Imt 2/8/77 revised 11/23/77
Data base collected on a 500 meter by 500 meter grid

The 100 cells with the highest value
value and also on undeveloped areas.

Levels

Frequency 3180 100
The first 100 cells with the highest value.

Levels:

Frequency: 500: 100
C. SUGGESTED MODEL EXTENSION.

MODEL SHOULD POSSESS TWO MAJOR ATTRIBUTES:

I. ABILITY TO PREDICT THE MAGNITUDE OF AGGREGATE SYSTEM-WIDE LAND USE/LAND COVER CHANGE

II. ABILITY TO PREDICT THE MOST LIKELY GEOGRAPHICAL LOCATION WHERE CHANGE WILL OCCUR.

I. A. STOCHASTIC APPROACH.

ATTENTION SHOULD BE PAID TO HOW WELL THE PHENOMENA BEING MODELLED APPROXIMATE THE MATHEMATICAL AND STATISTICAL REQUIREMENTS OF THE MODEL, e.g., STATIONARITY OF THE TRANSITION PROBABILITIES AND ORDER OF THE PROCESS.

B. USE OF EXOGENOUS (TRIGGERING) VARIABLES WHICH ARE DERIVED FROM DEMOGRAPHIC/ECONOMIC MODELS DESIGNED TO PREDICT FUTURE LAND REQUIREMENTS. THIS APPROACH REQUIRES A DETERMINATION OF TRIGGERING FACTORS, CONSTRAINING FACTORS, AND SUITABILITY CRITERIA.

II. A. MULTIVARIATE APPROACH WHICH DETERMINES THE RELATIONSHIPS BETWEEN CHANGE AND A NUMBER OF INDEPENDENT VARIABLES VIA MULTIPLE REGRESSION AND DISCRIMINANT ANALYSIS.

B. USE OF LATERAL DEPENDENCIES AND THE CALCULATION OF CONDITIONAL PROBABILITIES ALONG THE LINES OF THE "GEOGRAPHICAL MODEL" DESCRIBED EARLIER. ATTENTION MUST BE PLACED ON THE DEFINITION OF THE CONCEPTS "NEIGHBORHOOD" AND "FUNCTION".
THE ABOVE CONCERN CAN BE FORMALLY EXPRESSED AS FollowS:

\[ p_k = f(p_k^T, p_k^N), \]

WHERE \( p_k^T \) IS THE TIME TRANSITION MATRIX DESCRIBING THE PROBABILITY THAT THE NEXT CELL STATE WILL BE \( K \), \( p_k^N \) IS THE CONDITIONAL PROBABILITY THAT CELL TYPE \( K \) WILL OCCUR, GIVEN THE STATES OF THE NEIGHBORING CELLS, AND \( f \) IS A FUNCTION THAT COMBINES THE TWO PROBABILITIES. THE EXACT SPECIFICATION OF THE FUNCTION CAN VARY, e.g.,

\[ f(p_k^T, p_k^N) = p_k^T \cdot p_k^N \] OR \[ f(p_k^T, p_k^N) = w_1 p_k^T + w_2 p_k^N, \] WHERE \( w_1 \) AND \( w_2 \) ARE APPROPRIATE WEIGHTS.
U.S. BUREAU OF THE CENSUS TABULAR INFORMATION FILES

PUBLIC UTILITY COMPANY REVENUE AREAS

REMTELY SENSED IMAGERY

AUTOMATIC OR MANUAL CLASSIFIER

THEMATIC LANDUSE MAP

ATTRIBUTE LIST PER PIXEL:
- CENSUS 01
- CENSUS 02
- CENSUS 03
- ENERGY 01
- ENERGY 02
- LANDUSE 01
- LANDUSE 02
- LANDUSE 03
The diagram outlines a process involving thematic landuse maps, landuse change models, socioeconomic attributes, and econometric energy demand models. It begins with imagery from two different time periods, $T_i$ and $T_{i+1}$, which are classified to generate thematic landuse maps with $K$ categories.

- The classified imagery is used to create a thematic landuse map for $T_i$ and another for $T_{i+1}$.
- These maps are then input into a landuse change model to predict future landuse for $T_{i+2}$.
- The predicted future landuse, along with socioeconomic attributes from censuses or estimates, feeds into an econometric energy demand model.
- The output from this model provides future energy demand: (A) aggregate; (B) spatial pattern.
MARKOV CHAIN MODELLING

APPLICATIONS: MODELLING MOVEMENT IN TERMS OF GEOGRAPHICAL MOVEMENT OR IN TERMS OF MOVEMENT FROM ONE "STATE" TO ANOTHER. A SYSTEM IS IN A PARTICULAR STATE AT ANY POINT IN TIME, i.e., HAS A PARTICULAR STRUCTURE OR SET OF RELATIONSHIPS AMONG THE PARTS.

MARKOV CHAIN MODELS ARE NEAT AND ELEGANT CONCEPTUAL DEVICES FOR DESCRIBING AND ANALYZING THE NATURE OF CHANGE AND MAY BE USED TO FORECAST FUTURE CHANGE.

PLANNERS AND ADMINISTRATORS CONCERNED WITH THE PRESENT AND FUTURE SPATIAL ORGANIZATION OF THE LANDSCAPE ARE INTERESTED IN THE PROBABILITIES OF CHANGE. THE MARKOV CHAIN MODEL IS A STOCHASTIC TYPE OF MODEL.

MODEL ELEMENTS: 1. TRANSITION PROBABILITY MATRIX WHERE ELEMENTS IN EACH ROW SUM TO 1.0. THE PRINCIPAL DIAGONAL OF THE SQUARE MATRIX INDICATES THE PROBABILITY OF NO CHANGE IN THE STATE.

2. INITIAL STATE VECTOR DESCRIBES THE STRUCTURE OF THE ENTIRE SYSTEM AT ANY POINT IN TIME, e.g., PERCENT OF LAND IN EACH OF A NUMBER OF LAND USE/LAND COVER CLASSES. THE ELEMENTS OF THE VECTOR SUM TO 1.0.

3. A CHANGE IN THE STATE VECTOR IS ACCOMPLISHED BY MULTIPLYING THE INITIAL STATE VECTOR BY SUCCESSIVELY HIGHER POWERS OF THE TRANSITION PROBABILITY MATRIX.

4. THE SIMPLE MODEL ASSUMES: (i) A CONSTANT POPULATION; (ii) A SET OF TRANSITION PROBABILITIES; (iii) THESE
PROBABILITIES REMAIN CONSTANT OR STATIONARY; AND
(iv) THE FIRST ORDER PROPERTY, i.e., THE SYSTEM
CHANGING FROM A GIVEN STATE $S_i$ AT TIME $t_0+1$ DEPENDS
ONLY ON THE STATE $S_i$ AT THE TIME $t_0$ AND IS INDEPENDENT
OF THE STATES OF THE SYSTEM PRIOR TO $t_0$.

5. PROPERTIES OF REGULAR FINITE MARKOV CHAINS.

(i) TRANSITION PROBABILITIES ARE NON-NEGATIVE AND THOSE
IN EACH ROW SUM TO 1.0 AND THE TRANSITION MATRIX
IS REGULAR IF FOR SOME POWER OF THE MATRIX THERE
ARE ONLY POSITIVE NUMBERS.

(ii) CONCEPT OF EQUILIBRIUM IS EXPRESSED IN TWO THEOREMS:
.a. IF $P$ IS A TRANSITION MATRIX FOR A REGULAR MARKOV
CHAIN THEN $-1$ THE POWERS OF $P$ APPROACH A MATRIX $A$
2 EACH ROW OF $A$ IS THE SAME PROBABILITY VECTOR '$a'
3 THE ELEMENTS OF '$a'$ ARE ALL POSITIVE

.b. IF $P$ IS A TRANSITION MATRIX FOR A REGULAR MARKOV
CHAIN AND $A$ AND '$a'$ ARE AS STATED ABOVE, THEN THE
UNIQUE VECTOR '$a'$ IS THE UNIQUE PROBABILITY
VECTOR SUCH THAT '$a'.P='a'. THE MATRIX $A$ IS
DEFINED AS THE LIMITING MATRIX.

(iii) THE LIMITING MATRIX DESCRIBES THE AVERAGE STATE OF THE
SYSTEM AND THE ASSOCIATED PROBABILITY VECTOR '$a'$ HOLDS
THE SYSTEM IN EQUILIBRIUM.

(iv) IN MARKOV CHAIN ANALYSIS, FOR MODELLING PURPOSES, THE
EQUILIBRIUM DISTRIBUTION IS OF INTEREST NOT AS A
FORECAST OF THE FUTURE STATE OF THE SYSTEM BUT AS A
PROJECTION OF WHAT WOULD BE IF THE OBSERVED PATTERN OF MOVEMENT CONTINUED UNHAMPERED.

(v) THE FUNDAMENTAL MATRIX (Z) DESCRIBES HOW THE SYSTEM APPROACHES EQUILIBRIUM FROM AN INITIAL DISTRIBUTION. IT CAN BE USED TO CALCULATE A MATRIX OF MEAN FIRST PASSAGE TIMES, i.e., THE TIME IT TAKES ON AVERAGE TO MOVE FROM ONE STATE TO ANOTHER.

QUESTIONS ABOUT THE APPLICATION OF THE MARKOV MODEL.

1. IDENTIFICATION OF THE SPECIFIC ORDER PROPERTY SHOULD BE MADE. MOST APPLICATIONS ASSUME A FIRST ORDER. CRITERIA EXIST TO TEST SUCH AN ASSUMPTION.

2. STATIONARITY OF THE PARAMETERS, i.e., THE ESTIMATED TRANSITION PROBABILITIES ARE FIXED OR CONSTANT THROUGHOUT THE PREDICTIVE PERIOD. STATISTICAL TESTS EXIST.
## Estimated probability transition matrix of commercial activities for downtown Denver.


<table>
<thead>
<tr>
<th>Transition from</th>
<th>Financial, real estate, and insurance</th>
<th>Professional services</th>
<th>General retail</th>
<th>Personal and commercial services</th>
<th>Eating and/or drinking</th>
<th>Parking</th>
<th>Entertainment</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.798 - 0.052 0.013 0.089 0.019 0.013 0.038 0.051 0.007</td>
<td>0.026 0.615 0.218 0.038 0.027 0.080</td>
<td>0.029 0.008 0.830 0.024 0.016 0.012 0.081</td>
<td>0.033 0.028 0.002 0.539 0.040 0.022 0.191 0.144</td>
<td>0.045 0.003 0.719 0.010 0.023 0.069 0.005 0.126</td>
<td>0.057 0.020 0.062 0.647 0.095 0.119</td>
<td>0.012 0.011 0.042 0.070 0.643 0.168 0.049</td>
<td>0.050 0.033 0.004 0.767 0.083 0.063</td>
</tr>
<tr>
<td></td>
<td>0.747 - 0.070 0.014 0.014 0.043 0.112</td>
<td>0.080 0.400 0.120 0.040 0.050 0.160 0.080</td>
<td>0.045 0.003 0.703 0.014 0.028 0.030 0.016 0.217</td>
<td>0.045 0.003 0.703 0.014 0.028 0.030 0.016 0.217</td>
<td>0.009 0.027 0.009 0.691 0.036 0.022</td>
<td>0.067 0.013 0.042 0.013 0.030 0.795 0.013 0.065</td>
<td>0.033 0.033 0.033 0.033 0.033 0.033 0.033 0.033</td>
<td>0.009 0.027 0.009 0.691 0.036 0.022</td>
</tr>
<tr>
<td></td>
<td>0.806 - - 0.015 0.029 0.045 0.059 0.045</td>
<td>- 0.625 0.042 0.208 0.125 -</td>
<td>- 1.000 - - - - -</td>
<td>- 0.919 0.054 - 0.027 -</td>
<td>- 0.830 0.024 0.016 0.012 -</td>
<td>0.067 0.013 0.042 0.013 0.030 0.795 0.013 0.065</td>
<td>0.033 0.033 0.033 0.033 0.033 0.033 0.033 0.033</td>
<td>0.067 0.013 0.042 0.013 0.030 0.795 0.013 0.065</td>
</tr>
<tr>
<td></td>
<td>0.474 - - - - - 0.042 0.014 0.043 0.112</td>
<td>0.026 0.615 0.218 0.038 0.027 0.080</td>
<td>0.029 0.008 0.830 0.024 0.016 0.012 0.081</td>
<td>0.033 0.028 0.002 0.539 0.040 0.022 0.191 0.144</td>
<td>0.045 0.003 0.719 0.010 0.023 0.069 0.005 0.126</td>
<td>0.057 0.020 0.062 0.647 0.095 0.119</td>
<td>0.012 0.011 0.042 0.070 0.643 0.168 0.049</td>
<td>0.050 0.033 0.004 0.767 0.083 0.063</td>
</tr>
<tr>
<td></td>
<td>0.974 - 0.025 0.002 0.010 0.007 0.798</td>
<td>0.095 0.667 - 0.048 0.190 -</td>
<td>0.095 - - - - - 0.984 -</td>
<td>0.095 - - - - - 0.984 -</td>
<td>0.095 - - - - - 0.984 -</td>
<td>0.095 - - - - - 0.984 -</td>
<td>0.095 - - - - - 0.984 -</td>
<td>0.095 - - - - - 0.984 -</td>
</tr>
<tr>
<td></td>
<td>0.754 - - - - - 0.042 0.014 0.043 0.112</td>
<td>0.033 0.001 0.066 0.005 0.009 0.072 0.012</td>
<td>0.033 0.001 0.066 0.005 0.009 0.072 0.012</td>
<td>0.033 0.001 0.066 0.005 0.009 0.072 0.012</td>
<td>0.033 0.001 0.066 0.005 0.009 0.072 0.012</td>
<td>0.033 0.001 0.066 0.005 0.009 0.072 0.012</td>
<td>0.033 0.001 0.066 0.005 0.009 0.072 0.012</td>
<td>0.033 0.001 0.066 0.005 0.009 0.072 0.012</td>
</tr>
</tbody>
</table>

*Key:* 1 financial, real estate, and insurance; 2 professional services; 3 commercial residential; 4 general retail; 5 personal and commercial services; 6 eating and/or drinking; 7 parking; 8 entertainment; 9 other.
GENERAL FORM OF A FIRST-ORDER MARKOV CHAIN MODEL

Image \( T_{i-2} \)  

\[ T_{i-2} \rightarrow T_{i-1} \rightarrow T_{i} \]

Cell Count Matrix  
\( (f_{ij}) \)

\[ \sum_{i} f_{ij} = \sum_{ij} f_{ij} \]

Transition Probability Matrix  
\( (P_{ij} = f_{ij} / \sum_{j} f_{ij}) \)

\[ \sum_{j} P_{ij} = 1.0 \]

State Vector at \( T_{i-1} \), where \( Q_{i} = \sum_{j} f_{ij} / \sum_{ij} f_{ij} \)

\( V_{T_{i-1}} = (Q_{1}, Q_{2}, \ldots, Q_{i}, \ldots, Q_{k}) \)

Estimated State Vector at \( T_{i} \)

\( \hat{V}_{T_{i}} = V_{T_{i-1}} \cdot [P] \)

GOODNESS-OF-FIT TEST

Estimated State Vector at \( T_{i} \)

\( V_{T_{i}} = (Q_{1}, Q_{2}, \ldots, Q_{i}, \ldots, Q_{k}) \)

known State Vector at \( T_{i} \)

<table>
<thead>
<tr>
<th>Commercial residential</th>
<th>Transition to (second period)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Financial, real estate, and insurance</td>
<td>1-00</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Professional services</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Commercial residential</td>
<td>0-051</td>
<td>0-795</td>
<td>-</td>
<td>-</td>
<td>0-103</td>
<td>-</td>
<td>0-051</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>General retail</td>
<td>-</td>
<td>-</td>
<td>1-00</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1-00</td>
</tr>
<tr>
<td>Personal and commercial services</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1-00</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Eating and/or drinking</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1-00</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Parking</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1-00</td>
</tr>
<tr>
<td>Entertainment</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1-00</td>
<td>-</td>
</tr>
<tr>
<td>Other</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1-00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>General retail</th>
<th>Transition to (second period)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Financial, real estate, and insurance</td>
<td>0-438</td>
<td>-</td>
<td>-</td>
<td>0-281</td>
<td>0-129</td>
<td>-</td>
<td>0-031</td>
<td>-</td>
<td>0-125</td>
<td>-</td>
</tr>
<tr>
<td>Professional services</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0-028</td>
<td>0-083</td>
<td>-</td>
<td>0-028</td>
<td>-</td>
<td>0-111</td>
<td>-</td>
</tr>
<tr>
<td>Commercial residential</td>
<td>-</td>
<td>0-889</td>
<td>-</td>
<td>0-005</td>
<td>-</td>
<td>0-055</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>General retail</td>
<td>0-400</td>
<td>0-400</td>
<td>-</td>
<td>0-200</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0-400</td>
<td>-</td>
</tr>
<tr>
<td>Personal and commercial services</td>
<td>-</td>
<td>-</td>
<td>0-400</td>
<td>0-200</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1-00</td>
<td>-</td>
</tr>
<tr>
<td>Eating and/or drinking</td>
<td>-</td>
<td>1-00</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Parking</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1-00</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Entertainment</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1-00</td>
</tr>
<tr>
<td>Other</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1-00</td>
</tr>
</tbody>
</table>
DISCRIMINANT ANALYSIS

PURPOSE: A method of producing hybrid variables so as to produce the best possible separation, or discrimination, between various groups. Such discriminant functions are often necessary because of collinearity among independent variables originally used in the analysis.

The method involves two sets of equations: (i) a set relating the group membership to the discriminant functions; and (ii) a set relating the original variables to the discriminant functions.

USES: 1. Testing (and generating) hypotheses, e.g., investigate whether a certain set of related variables (measured on interval or ratio scales) successfully discriminate between groups of observations on a nominal scale.

2. Evaluating a classification, e.g., indicate the number of misclassifications in the dependent variable.

3. Estimating values for other observations, i.e., allocating new observations to an existing classification.
Derivation of a discriminant function, showing: (A) the location of 12 observations, in two groups, on two orthogonal independent variables; (B) the location of members of the two groups, and the group means, on the separate independent variables; (C) location of a discriminant function which achieves maximal separation of the two groups; and (D) the location of members of the two groups, and the group means, on the discriminant function.
A discriminant function separating two groups of observations according to their values on four, related variables.

A discriminant analysis showing the use of two discriminant functions to separate three groups of observations in a three-variable space.
This study investigates predictive models for forecasting residential energy demand. The models are examined in the context of implementation through manipulation of geographic information systems containing land use/cover information. Remotely sensed data is examined as a possible component in this process.
End of Document