NASA CR-166,369

NASA CONTRACTOR REPORT 166369

NASA-CR-166369
19820021800

Relation of Land Use/Land Cover to Resource Demands

Cristopher Clayton

NASA Cooperative Agreement NAG 2-20
March 1981

NASA

NASA CONTRACTOR REPORT 166369

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

N82-29676 #

CHRISTOPHER CLAYTON

ASSISTANT RESEARCHER, UNIVERSITY OF CALIFORNIA, SANTA BARBARA, CALIFORNIA
SOCIAL SCIENTIST, H.D.R. SCIENCES, SANTA BARBARA, CALIFORNIA

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/INDISTRIAL/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.

Digital Codes			First-Order Land Use/Land Cover	Second-Order	Third-Order
1			Urban and built-up land		
	11			Residential	
	12			Commercial and services	
		121			Recreational
	13			Industrial	
	14			Extractive	
	15			Transportation, communications, and utilities	
		151			Utilities
	16			Institutional	
	17			Strip and clustered development	
	18			Mixed urban	
	19			Open and other urban	
		191			Solid-waste dump
		192			Cemetery
2			Agricultural land		
	21			Cropland and pasture	
		211			Nonirrigated cropland
		212			Irrigated cropland
		213			Pasture
	22			Orchards, groves, and other horticultural areas	
	23			Feeding operations	
	24			Other agricultural land	
3			Rangeland		
	31			Grass	
	32			Savannas	
	33			Chaparral (taken as brushland)	
	34			Desert shrub	
4			Forest land		
	41			Deciduous	
		411			Deciduous/intermittent crown
	42			Evergreen (coniferous and other)	
		421			Coniferous/solid crown
		422			Coniferous/intermittent crown
	43			Mixed forest land	
5			Water		
	51			Streams and waterways	
	52			Lakes	
	53			Reservoirs	
	54			Bays and estuaries	
	55			Other water	
6			Nonforested wetland		
	61			Vegetated	
	62			Bare	
7			Barren land		
	71			Salt flats	
	72			Beaches	
	73			Sand other than beaches	
	74			Bare exposed rock	
		741			Hillslopes
	75			Other barren land	
8			Tundra		
	81			Tundra	
9			Permanent snow and icefields		
	91			Permanent snow and icefields	

MINNEAPOLIS[1]	HOUSTON[2]	MILWAUKEE[3]	LOS ANGELES[4]	ORLANDO[5]
Commercial Core Industrial Core Commercial/ Industrial Strip	Commercial/ Industrial/ Transportation	Commerce/ Industry	Commercial/ Industrial/ Institutional	Commercial Industrial/ New Construction
High Density Single Family Res. Low Density Single Family Res. Mixed Single Multiple Family Res.	Residential Residential (New) Mixed Residential	Inner City Wooded Suburbs New Suburbs Other Suburbs	Med./High Density Residential Low Density Residential	Residential Wooded Residential
Urban Open Extractive			Undeveloped Urban Green Space Flood Channels & Extractive	Undeveloped
	Woody Veg. Non Woody Veg.	Trees Grassy Rural	Chapparal Grassland Agricultural	Trees Marsh
	Water	Water	Water	Water

[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

ERTS-1 Satellite Imagery	High Altitude Photography RB-57, 1:120,000	High Altitude Photography RB-57, 1:60,000	Medium Altitude Photography Black-and-White, 1:15,840
Core Residential/Commercial	Individual Structures Residential Areas	Single Family Residential Swimming Pools Apartment Complex Mobile Home Park	Housing Types High Rise Structures Garden Apartments
	Shopping Plaza Commercial Cluster Strip Commercial	Mobile Home Sales Parking Lots with Cars	Pleasure Boat Sales Building Under Construction
	Administrative Buildings Schools University Complex		Institutional Buildings
	Cemetery Golf Course Baseball Diamond	Boat Dock with Small Boats	Power Boat — Wake Park
	Drive-in Theater Marinas		
	Heavy Industry Tank Farm Light Industry	Junk Yard Extracting Industry Fabricating Processing Gas Storage	Power Plant — Coal Piles Overhead Crane Water Pipes Open Storage Area
Excavations	Excavating Industry		
Airports	Airport Terminal Building Aircraft Hangars		
Highways	Highway Interchanges Divided Highways Bridges Rest Areas		
Railroads	R.R. Switching Yards		R.R. Box Cars
Utilities	Power Line Right of Way Secondary Roads Tertiary Roads Port Facilities — Ships		

Source: Gary K. Higgs and M. Sullivan, "A Comparitive Analysis of Remote Sensing Scale/System Attributes for a Multi-Level Land Use Classification System," *Proceedings of the American Society Fall Convention* (Falls Church, Va., 1973), pp. 335-367.

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

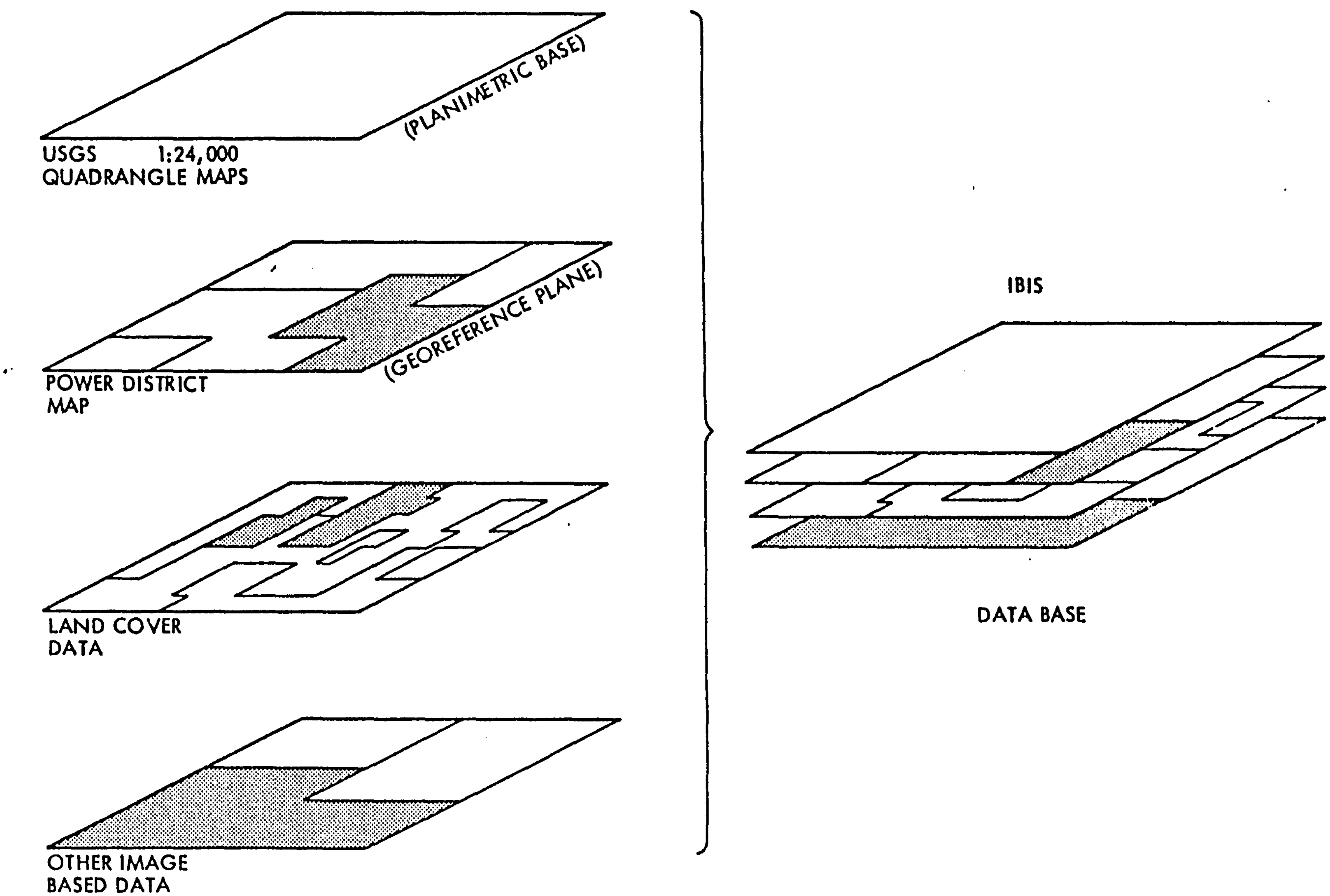
MAP FORMAT - POINT DIMENSION, e.g., ELEVATION,RAINFALL,INTERSECTION

LINE DIMENSION, e.g., WATERCOURSE,RAOD, 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-SAMPLING.
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

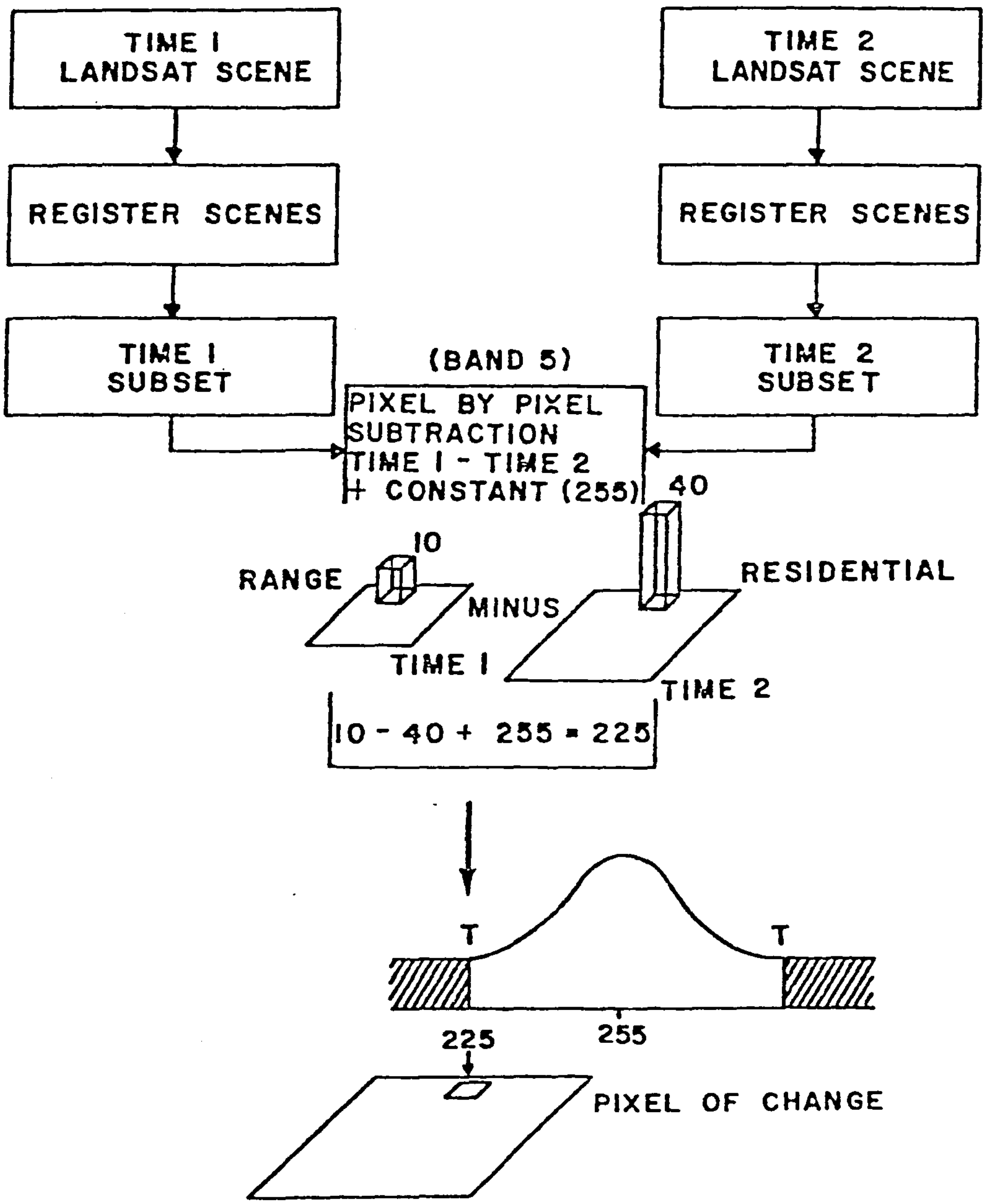
1. IMAGE DIFFERENCING.

   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



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 COMPARION 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.

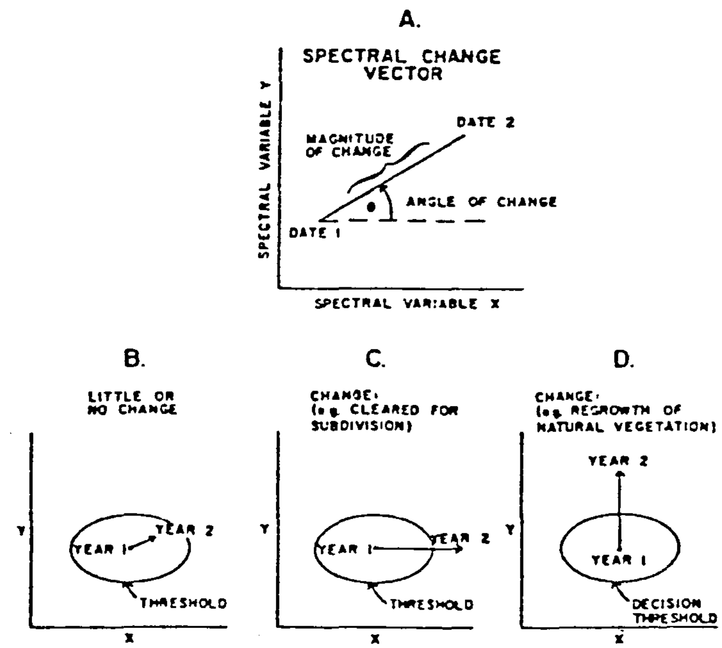
   A. WHEN LAND CHANGES ITS SPECTRAL APPEARANCE MAY CHANGE. PLOT THE VALUE OF TWO SPECTRAL VARIABLES (BANDS) FOR AN AREA BEFORE AND AFTER CHANGE ON A GRAPH

   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
SPECTRAL VARIABLE Y
MAGNITUDE OF CHANGE
DATE 2
ANGLE OF CHANGE
DATE 1
SPECTRAL VARIABLE X
B.
LITTLE OR NO CHANGE
Y
YEAR 1
YEAR 2
THRESHOLD
X
C.
CHANGE: (e.g. CLEARED FOR SUBDIVISION)
Y
YEAR 1
YEAR 2
THRESHOLD
X
D.
CHANGE: (e.g. REGROWTH OF NATURAL VEGETATION)
YEAR 2
Y
YEAR 1
DECISION THRESHOLD
X

LAND USE/LAND COVER PREDICTIVE MODELLING

**** 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 INTERELATE 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 DEPENDES 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.

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

A. EXTRAPOLATION-FILTERING MODEL

$$g_{ij}^{t} = F(g_{i\pm p, j\pm q}^{t})$$

THIS MODEL CAN BE CHARACTERIZED BY A GEOGRAPHICAL QUIZ.

B. DYNAMIC GEOGRAPHICAL

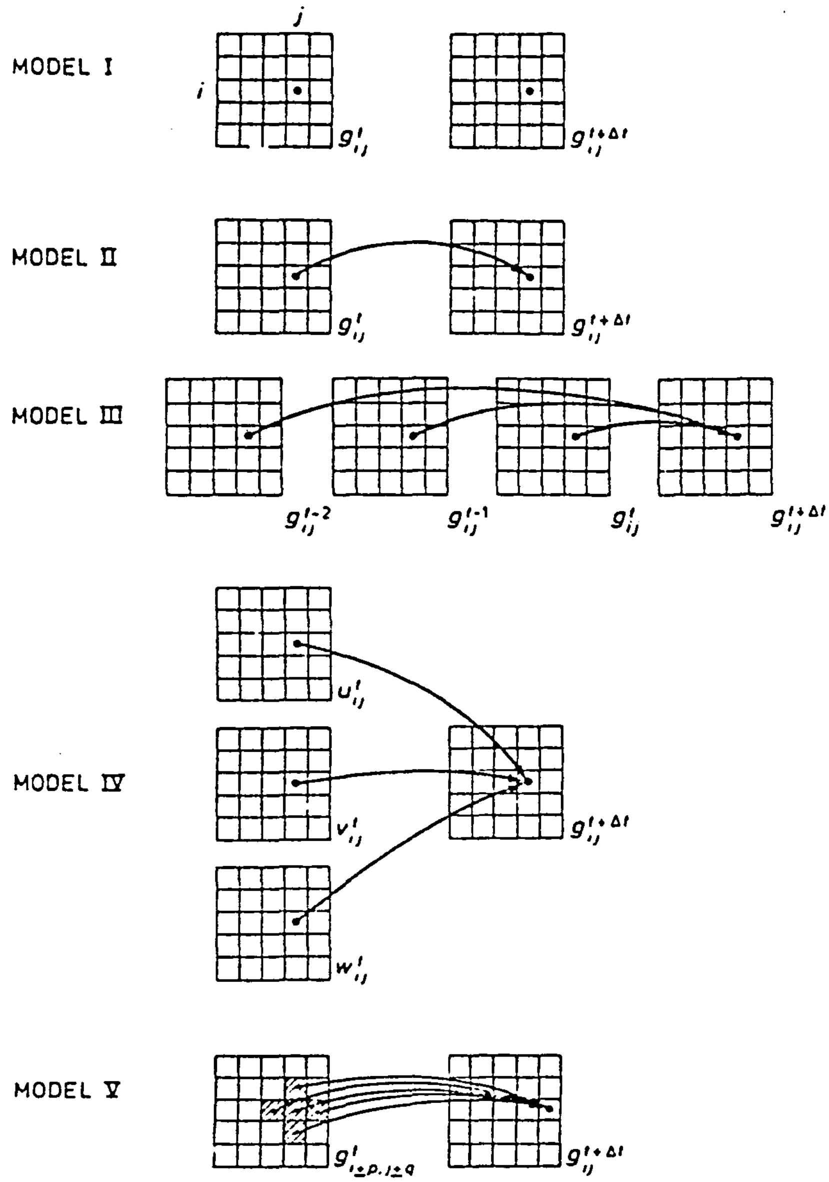
$$g_{ij}^{t+dt} = \dot{F}(g_{ij}^{t}, n_{ij})$$

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 <u>SPATIAL NEIGHBORHOOD STATIONARITY</u>. 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 <u>SPATIAL ISOTROPY</u>, i.e., POSITIONING OF NEIGHBORS DOES NOT COUNT AND <u>SPATIAL STATIONARITY</u>. 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 : RULES ARE PIECE-SPECIFIC BUT APPLY UNIFORMLY AT ANY LOCATION ON THE BOARD.



MODEL I
j
i
g^{t}_{ij}
$g^{t+\Delta t}_{ij}$
MODEL II
g^{t}_{ij}
$g^{t+\Delta t}_{ij}$
MODEL III
g^{t-2}_{ij}
g^{t-1}_{ij}
g^{t}_{ij}
$g^{t+\Delta t}_{ij}$
MODEL IV
u^{t}_{ij}
v^{t}_{ij}
w^{t}_{ij}
$g^{t+\Delta t}_{ij}$
MODEL V
$g^{t}_{i\pm p,j\pm q}$
$g^{t+\Delta t}_{ij}$

A	A	A	A	B	B
A	A	A	B	B	A
A	A		A	A	A
A	B	B	A	A	A
B	B	A	A	A	A
B	B	A	A	A	A

$$\begin{array}{ccccccc} & R & & & & R & \\ R & A & I & \longrightarrow & R & C & I \\ & C & & & & C & \end{array}$$

$$RICRA \longrightarrow C$$

$$(2R, 1I, 1C, A) \longrightarrow C$$

B. OPERATIONAL MODELS INCORPORATING REMOTELY SENSED DATA

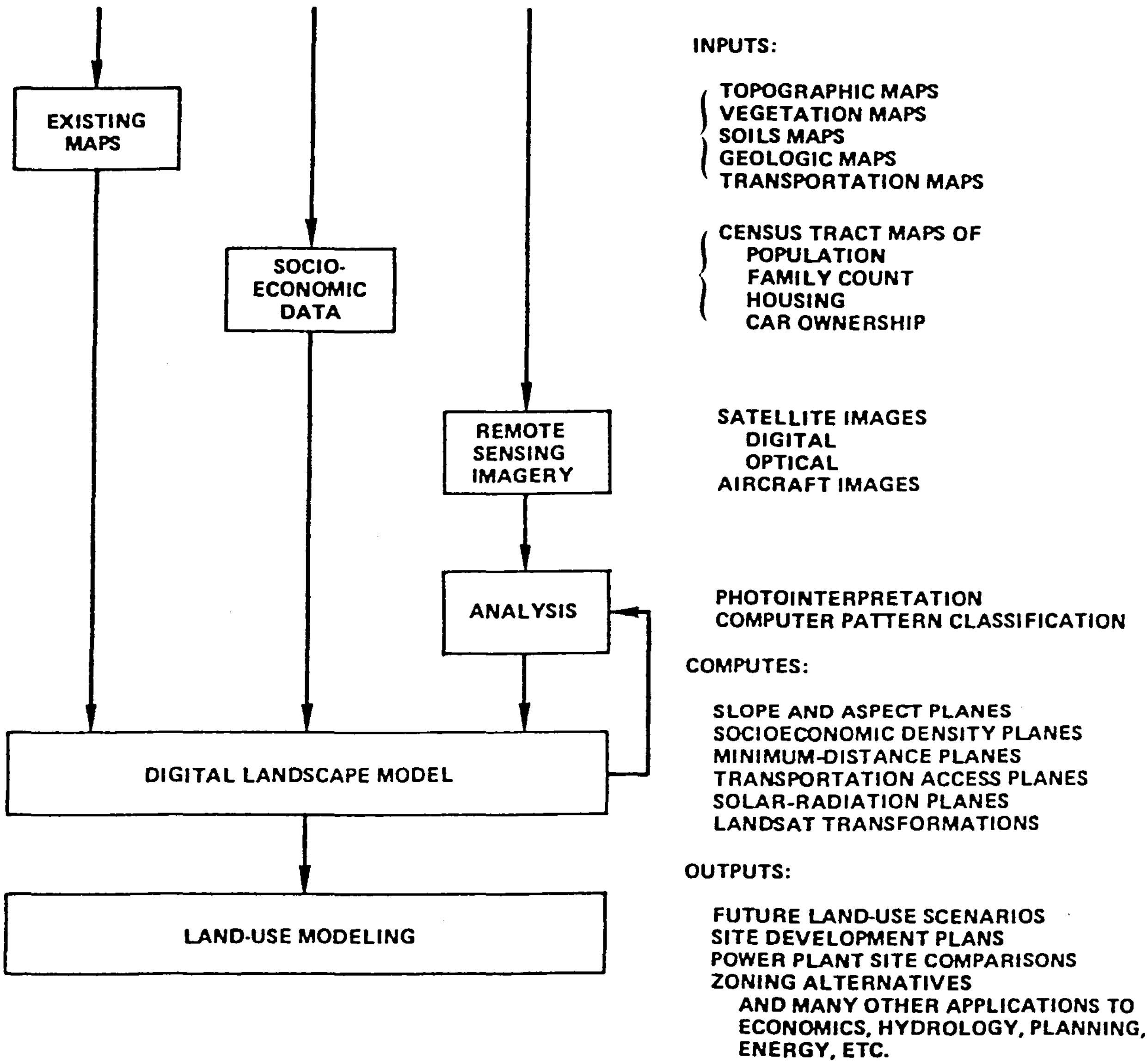
I. LANDSCAPE MODELLING.

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

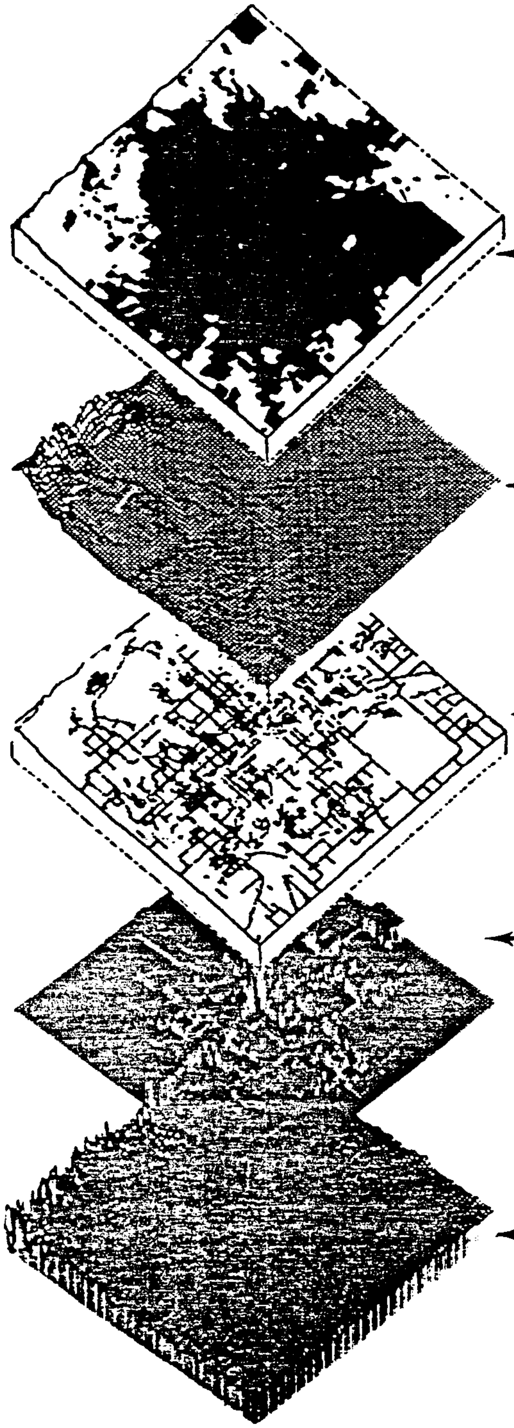
AIM: THE CURRENT THRUST OF LANDSCAPE MODELLING IS THE PROJECTION AND DISPLAY IN A MAP FORM OF THE FUTURE LANDSCAPE WHICH WOULD RESULT FROM THE CONTINUATION OF CURRENT LAND MANAGEMENT PRACTICES OR THE LACK THEREOF.

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



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

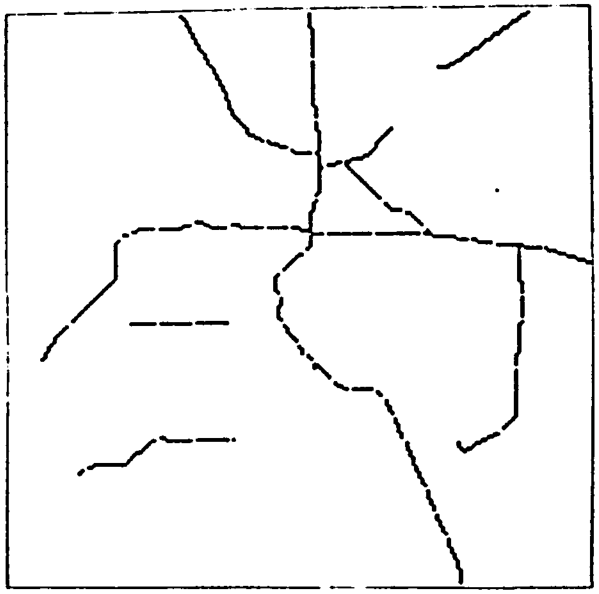
9 PHYSIOGRAPHIC SUBMODEL VARIABLES:
Topographic Elevation
Topographic Slope
Topographic Aspect
USGS Surficial Geology
Solar Insolation for Landsat Imagery
Four Landsat MSS ÷ Insolation Ratios

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

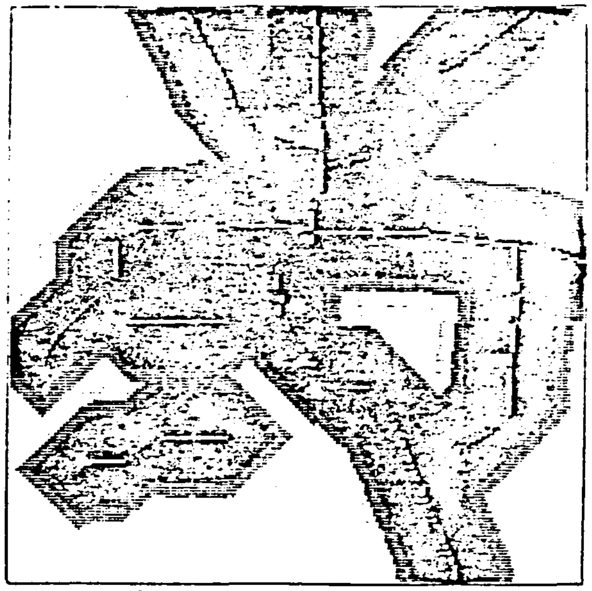
17 SOCIOECONOMIC SUBMODEL VARIABLES:
Four Population/Housing Densities
Per Acre
Five Population/Family/Housing-
Unit Totals
1969 Mean Family Income
Median Housing-Unit Rent/Value
One-/Two-/Three-Car Family Totals
Total Census Tract Acreage
Average Number of Cars Per Family

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

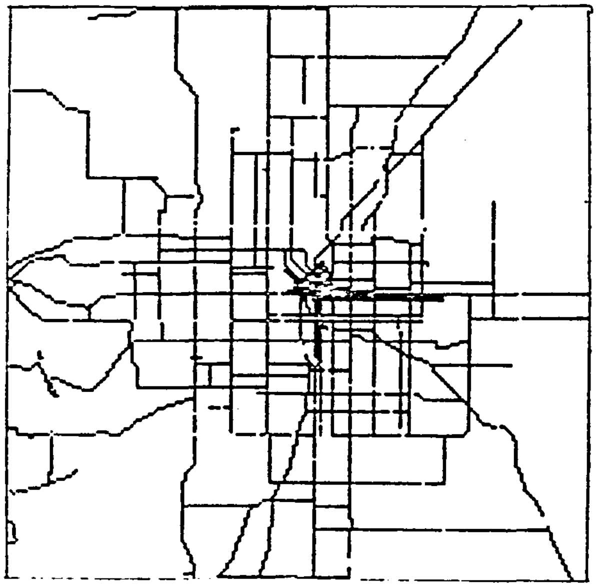
CONCEPTUAL DIAGRAM OF THE LANDSCAPE MODEL OF THE DENVER STUDY AREA.



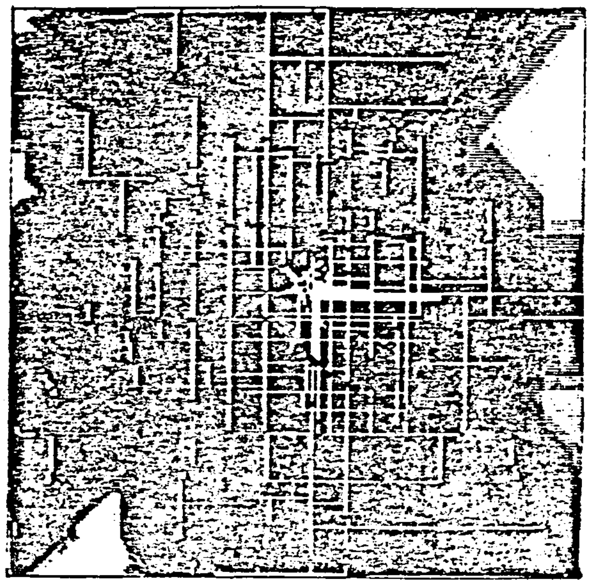
Freeways



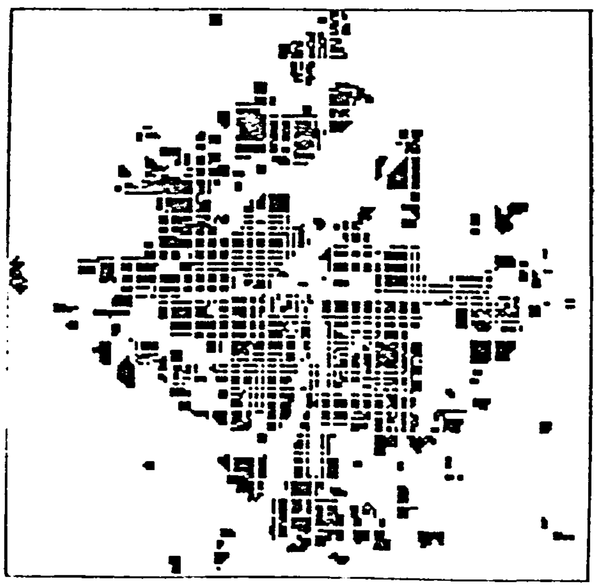
Minimum Distance to Freeways



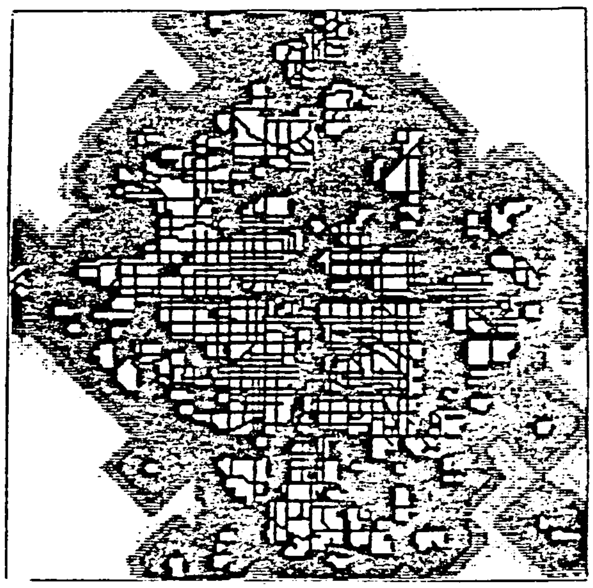
Major Roads



Minimum Distance to Major Roads



Built-Up Urban Areas



Minimum Distance to Built-Up Urban Areas

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.

1963 Land-Use Type	Code→	Converting to 1970 Land Use																					1963 Land-Use Totals
		11	12	13	14	15	16	17	18	19	21	22	23	24	41	51	52	53	55	61	73	75	
Residential	11	6393	11	2			2			12						1							6421
Commercial and services	12	2	1089							6												5	1102
Industrial	13	3	1	882			1																887
Extractive	14	3		5	444						6						5						463
Transportation, communication, and utilities	15					729																	729
Institutional	16	14	2		1		3079			14							15						3125
Strip and clustered development	17							1350															1350
Mixed urban	18							4															4
Open and other urban land	19	239	52	46	35	51	42	39		3175	46					1	6					9	3741
Cropland and pasture	21	394	27	125	139	72	31	262		351	14558			2		4	22	17				5	16009
Orchards and other horticultural areas	22											6											6
Feeding operations	23												2										2
Other agricultural land	24	1			8	13				2	3			5			1						33
Deciduous forest land	41														18								18
Streams and waterways	51	1														95							96
Lakes	52										1						592						593
Reservoirs	53																	158					158
Other water	55																		5				5
Vegetated nonforested wetland	61																			171			171
Sand other than beaches	73			1	9					2											52		64
Other barren land	75						4				10											1873	1887
1970 Land-Use totals		7050	1182	1061	636	865	3159	1655	0	3562	14624	6	2	7	18	101	641	175	5	171	52	1892	

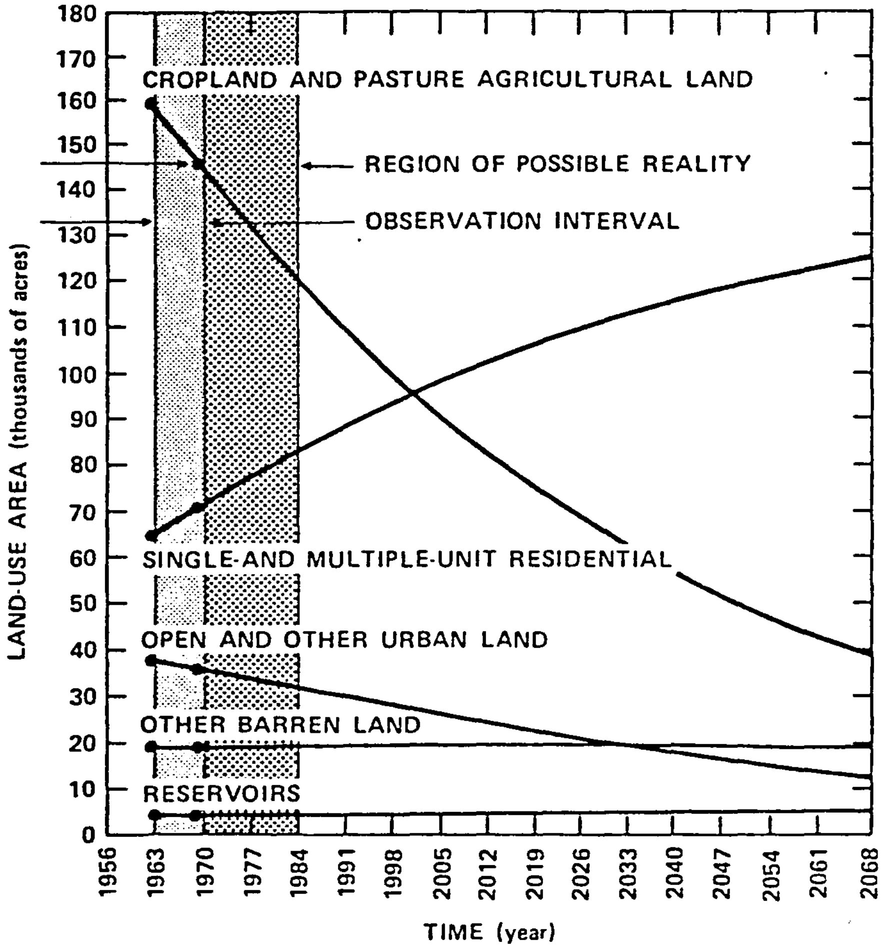
DENVER LAND-USE PROBABILITY TRANSITION MATRIX, 1963 TO 1970. Entries in the matrix denote the fraction of each 1963 land use that converted to another land use in 1970 as computed from table 4. A blank in the matrix denotes that no conversion occurred between the respective land uses during the period 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.

1963 Land-Use Type	Code↓	Converting to 1970 Land Use → 11	12	13	14	15	16	17	18	19	21	22	23	24	41	51	52	53	55	61	73	75
Residential	11	0.996	0.002	–			–			0.002						-						
Commercial and services	12	0.002	0.988							0.005												0.005
Industrial	13	0.003	0.001	0.994			0.001															
Extractive	14	0.006		0.011	0.959						0.013						0.011					
Transportation, communications and utilities	15					1.0																
Institutional	16	0.004	0.001				0.995			0.004							0.005					
Strip and clustered development	17							1.0														
Mixed urban	18							1.0														
Open and other urban land	19	0.064	0.014	0.013	0.009	0.014	0.011	0.010		0.849	0.012			–		–	0.002					0.002
Cropland and pasture	21	0.025	0.002	0.009		0.004	0.002	0.016		0.022	0.909					-	0.001	0.001				-
Orchards and other horticultural areas	22											1.0										
Feeding operations	23												1.0									
Other agricultural land	24	0.030			0.242	0.394				0.061	0.091			0.152			0.030					
Deciduous forest land	41														1.0							
Streams and waterways	51	0.010														0.990						
Lakes	52										0.002						0.998					
Reservoirs	53																	1.0				
Other water	55																		1.0			
Vegetated nonforested wetland	61																			1.0		
Sand other than beaches	73			0.016	0.141					0.031											0.813	
Other barren land	75						0.002				0.005											0.993

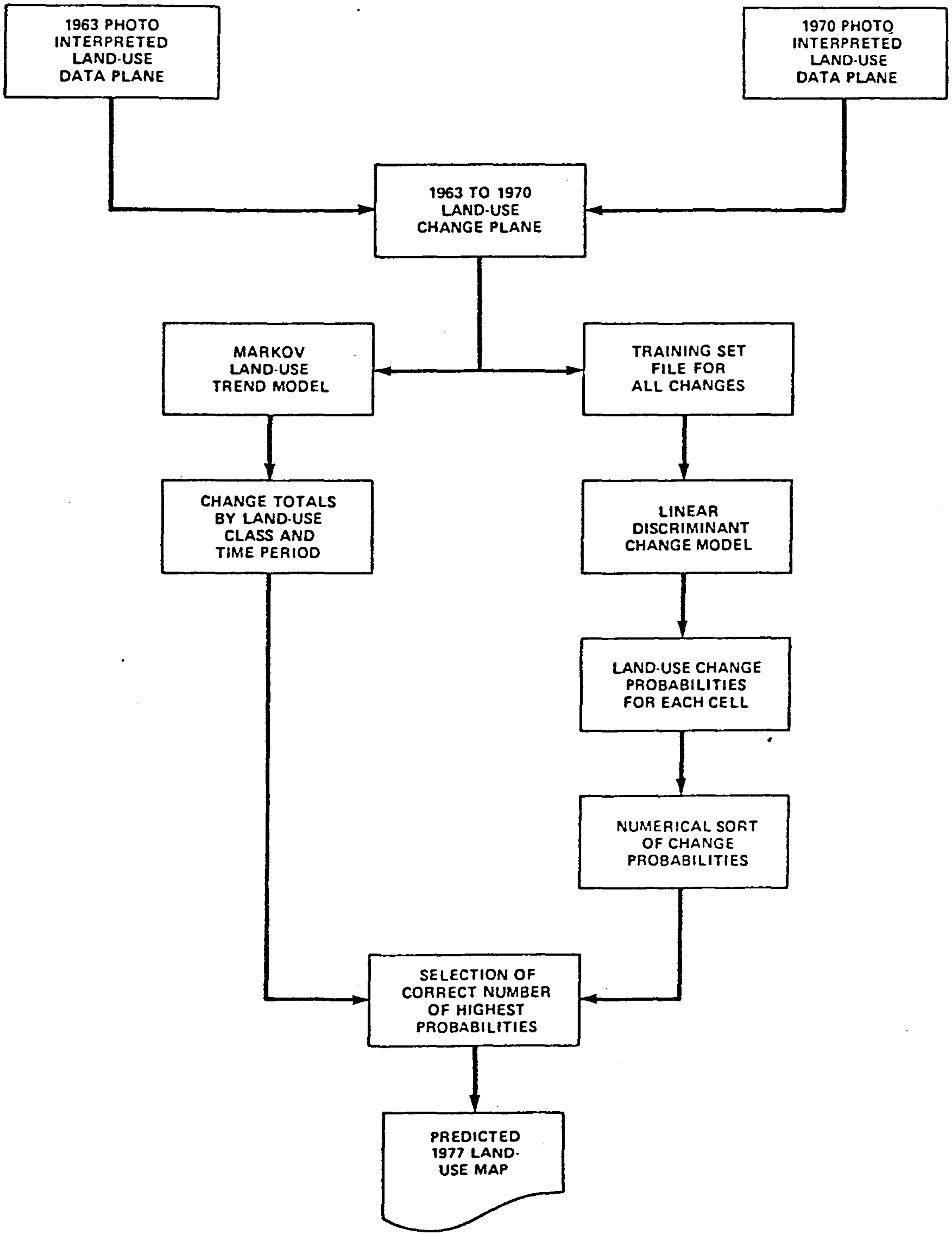
DENVER AGGREGATE LAND-USE PROJECTIONS BY A MARKOV TREND MODEL, 1963 TO 2068. Specific land-use total areas, such as those illustrated in figure 42, are detailed here. Photointerpreted second-order land-use changes between 1963 and 1970 were used to drive this generalized trend model for the 24- by 24-mile 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.

Land-Use Type	Measured Acreages		Projected Acreages															
	1963	1970	1977	1984	1991	1998	2005	2012	2019	2026	2033	2040	2047	2054	2061	2068
Residential	64,210	70,500	76,320	81,700	86,680	91,280	95,530	99,450	103,060	106,400	109,470	112,310	114,920	117,330	119,550	121,600
Commercial and services	11,020	11,820	12,580	13,290	13,960	14,590	15,180	15,730	16,260	16,750	17,210	17,640	18,040	18,430	18,780	19,120
Industrial	8,870	10,610	12,250	13,760	15,170	16,470	17,690	18,810	19,860	20,830	21,730	22,570	23,350	24,070	24,740	25,360
Extractive	4,630	6,360	7,800	9,030	10,090	10,980	11,730	12,350	12,860	13,260	13,580	13,810	13,980	14,080	14,130	14,120
Transportation, communications, and utilities	7,290	8,650	9,820	10,890	11,890	12,810	13,660	14,450	15,190	15,870	16,500	17,090	17,630	18,140	18,610	19,040
Institutional	31,250	31,590	31,880	32,130	32,330	32,500	32,620	32,710	32,770	32,810	32,810	32,790	32,740	32,680	32,600	32,500
Strip and clustered development	13,500	16,550	19,310	21,850	24,190	26,330	28,300	30,110	31,770	33,300	34,710	36,010	37,200	38,300	39,320	40,260
Mixed urban	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Open and other urban	37,410	35,620	33,800	31,980	30,200	28,470	26,810	25,220	23,700	22,270	20,920	19,650	18,460	17,340	16,310	15,340
Cropland and pasture	160,090	146,240	133,600	122,120	111,670	102,150	93,500	85,610	78,440	71,900	65,940	60,510	55,560	51,050	46,940	43,180
Orchards and other horticultural areas	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
Feeding operations	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
Other agricultural land	330	70	30	20	20	20	20	10	10	10	10	10	10	10	10	10
Deciduous forest land	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180
Streams and waterways	960	1,010	1,060	1,100	1,140	1,180	1,210	1,250	1,280	1,300	1,330	1,360	1,380	1,400	1,420	1,440
Lakes	5,930	6,410	6,880	7,340	7,800	8,260	8,700	9,140	9,580	10,000	10,420	10,830	11,240	11,630	12,020	12,400
Reservoirs	1,580	1,750	1,910	2,050	2,180	2,300	2,400	2,500	2,590	2,680	2,750	2,820	2,890	2,950	3,000	3,050
Other water	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
Vegetated nonforested wetland	1,710	1,710	1,710	1,710	1,710	1,710	1,710	1,710	1,710	1,710	1,710	1,710	1,710	1,710	1,710	1,710
Sand other than beaches	640	520	420	340	280	230	180	150	120	100	80	70	50	40	30	30
Other barren land	18,870	18,920	18,960	19,000	19,040	19,070	19,090	19,110	19,130	19,140	19,150	19,160	19,170	19,170	19,170	19,160
Grand Total	368,640	368,640	368,640	368,640	368,640	368,640	368,640	368,640	368,640	368,640	368,640	368,640	368,640	368,640	368,640	368,640

☐ 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, $P = \{p_{i,j}\}$, 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:

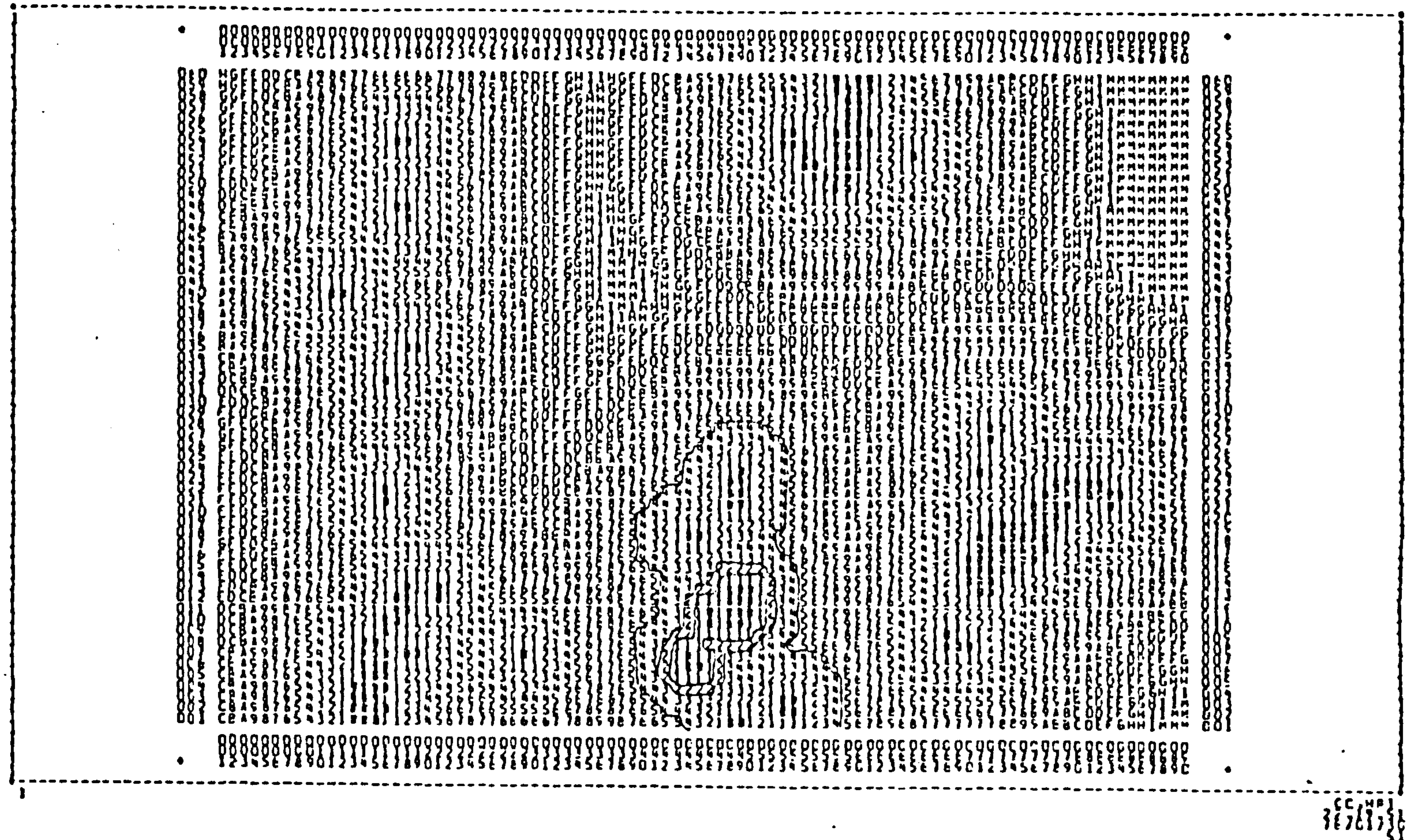
1. BASED ON QUANTIFICATION OF A LAND USE PATTERN
2. OPERATION DEFINITION OF SPATIAL RELATIONSHIPS
3. DERIVATION OF A WEIGHTED INDEX BASED ON FREQUENCIES OF OCCURRENCE FOR EACH DISTANCE FROM ALL OTHER LAND USES
4. IDENTIFICATION OF "TRIGGERING" AND "CONSTRAINING" FACTORS
5. ALLOCATION PROCEDURE OF AGGREGATE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



STATISTICS DATA BASE, INDIANA
HOLCOMB RESEARCH INSTITUTE
BUTLER UNIVERSITY
INDIANAPOLIS, INDIANA
DATA BASE COLLECTED ON A 500 METER BY 500 METER GRID

S E A R C H   F R O M   W A T E R

LEVELS	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
FREQUENCY	0	190	354	346	349	512	351	413	341	332	379	262	154	236	255	181	140	137	101	62

= OF CELLS GREATER THAN HL 163

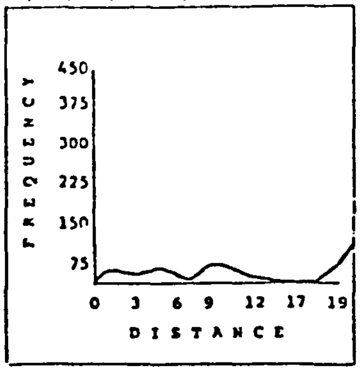
TABLE OF FREQUENCIES COUNTS OF MEDIUM DENSITY HOUSING VERSUS DISTANCES* FROM OTHER LAND USES

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

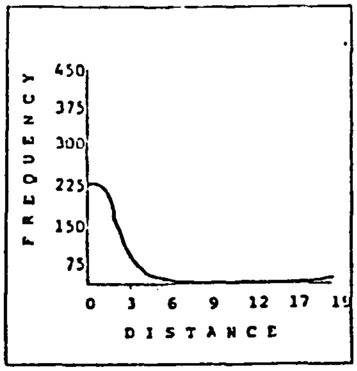
*Distances equal 500 meters.

CK/lmt 2/8/77 revised 11/23/77

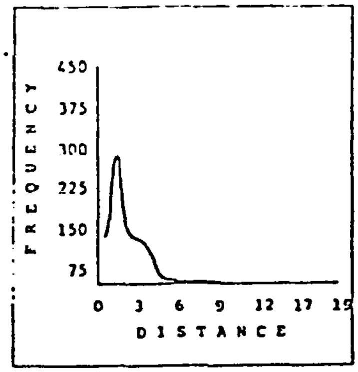
TRANSPORTATION (INTERSTATES)



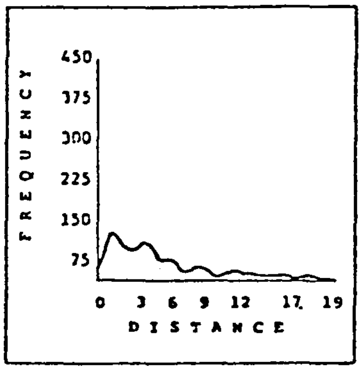
SEWER SERVICE AREAS



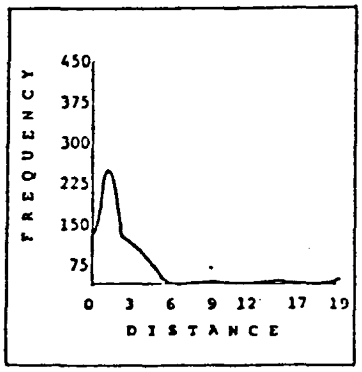
RIVERS



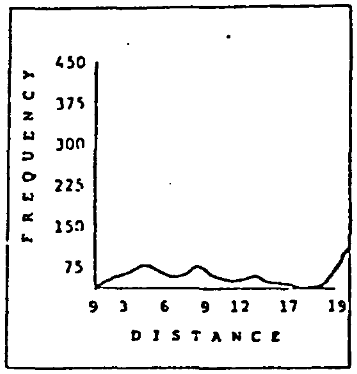
TRANSPORTATION (MINOR)



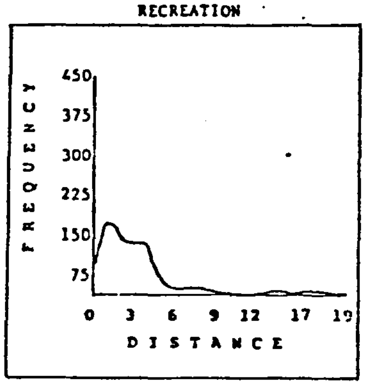
UNCONTROLLED ACCESS



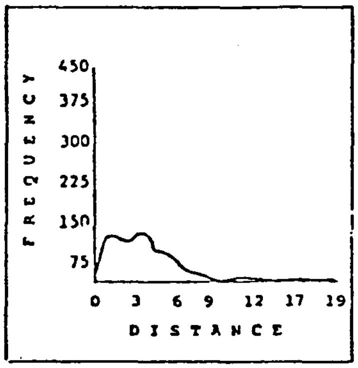
TRANSPORTATION (INTERCHANGES)



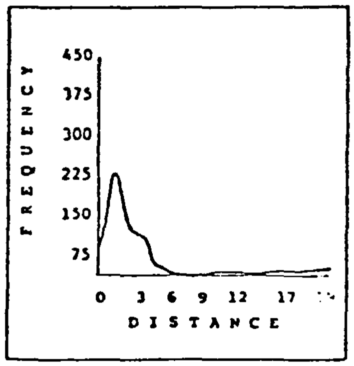
RECREATION



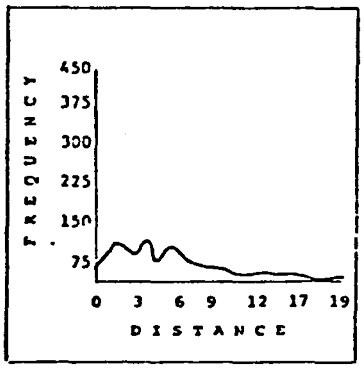
INDUSTRY



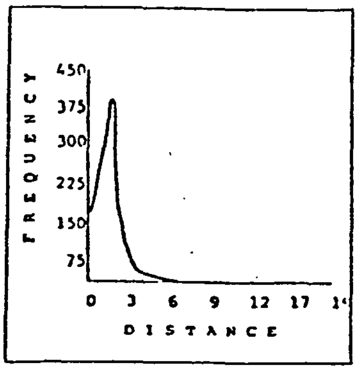
HIGH DENSITY HOUSING



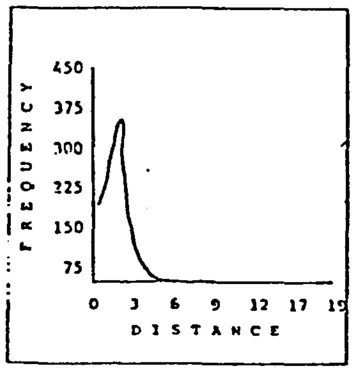
WATER

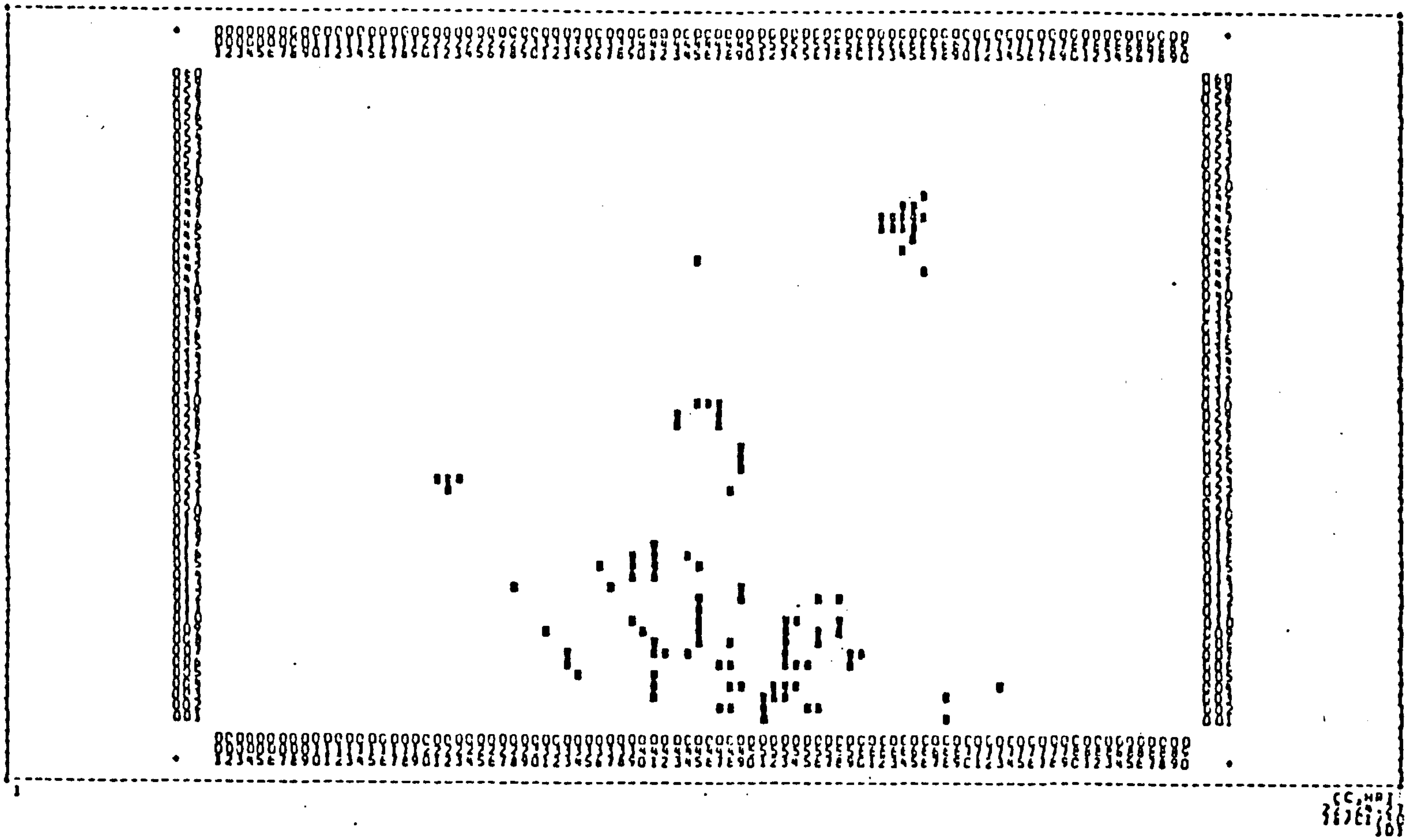


INSTITUTIONS



LOW DENSITY HOUSING



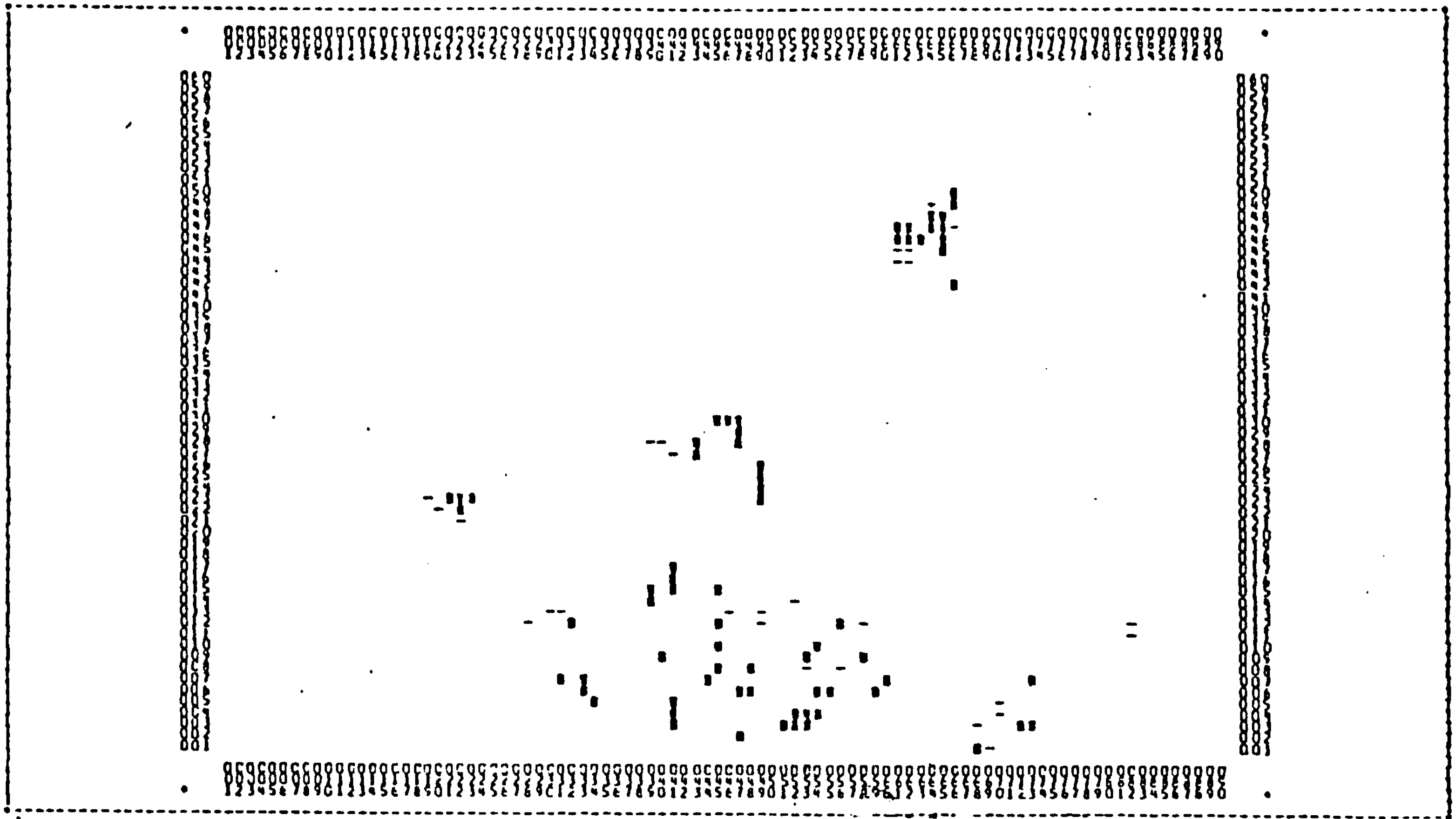


STATISTICS DATA BASE, INDIANA
HOLCOMB RESEARCH INSTITUTE
BUTLER UNIVERSITY
INDIANAPOLIS, INDIANA
DATA BASE COLLECTED ON A 500 METER BY 500 METER GRID

THE 100CELLS WITH THE HIGHEST VALUE
VALUE AND ALSO ON UNDEVELOPED AREAS.

LEVELS 0 1

FREQUENCY 5100 100



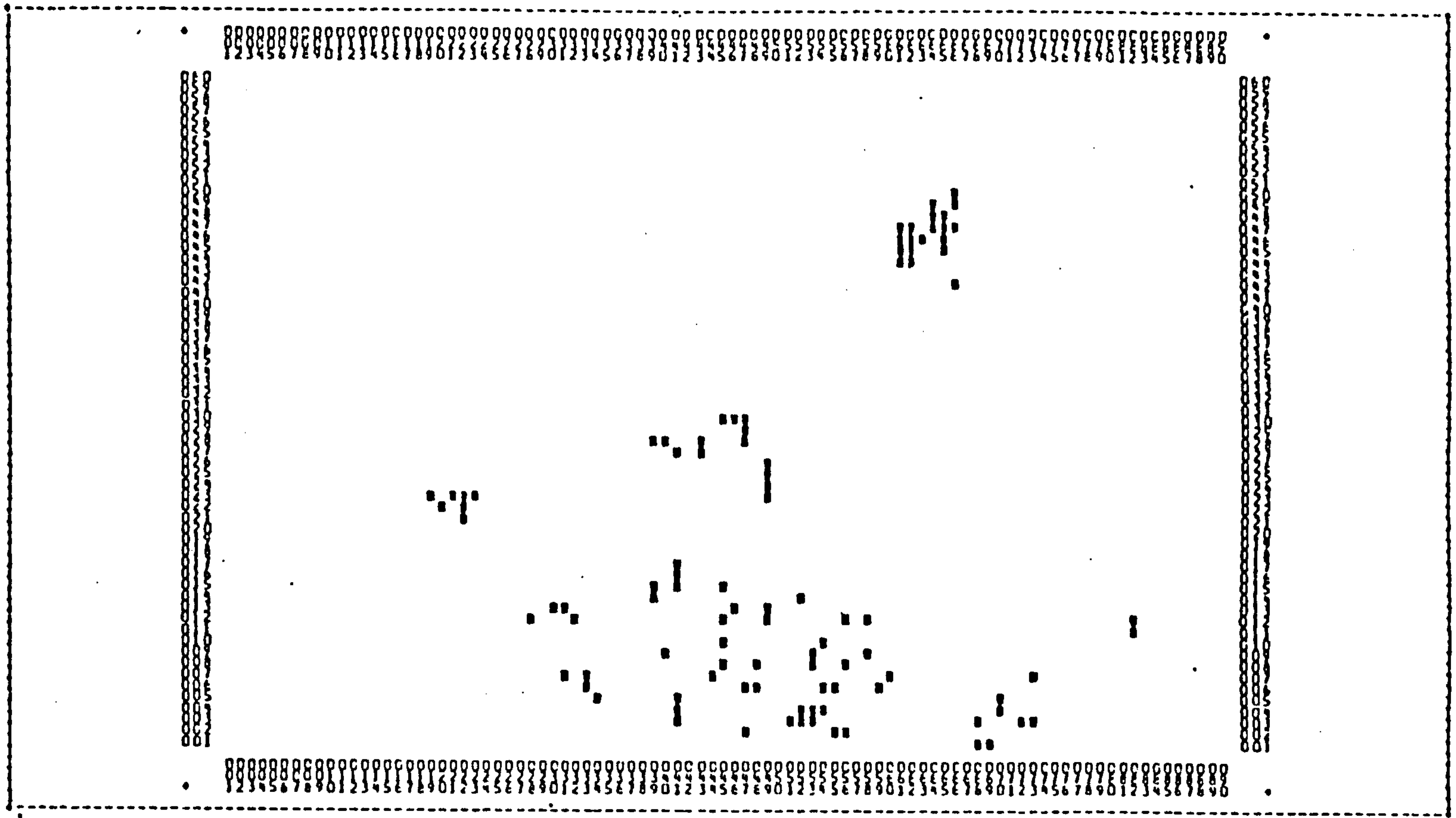
STATISTICS DATA BASE, INDIANA
HOLCOMB RESEARCH INSTITUTE
BUTLER UNIVERSITY
INDIANAPOLIS, INDIANA
DATA BASE COLLECTED ON A 500 METER BY 500 METER GRID

THE CELLS IN THE INDEX THAT OCCUR IN THE
SAME CELLS AS MEDIUM DENSITY HOUSING

LEGEND

1= CELLS IN THE INDEX NOT OCCUPIED BY MEDIUM DENSITY HOUSING
2= CELLS IN THE INDEX OCCUPIED BY MEDIUM DENSITY HOUSING

LEVELS	0	1	2
FREQUENCY	5300	30	10



STATISTICS DATA BASE, INDIANA
HOLCOMB RESEARCH INSTITUTE
BUTLER UNIVERSITY
INDIANAPOLIS, INDIANA
DATA BASE COLLECTED ON A 500 METER BY 500 METER GRID

T H E F R I S T 1 0 0 C E L L S W I T H T H E H I G H E S T V A L U E.

LEVELS	0	1
FREQUENCY	5300	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:

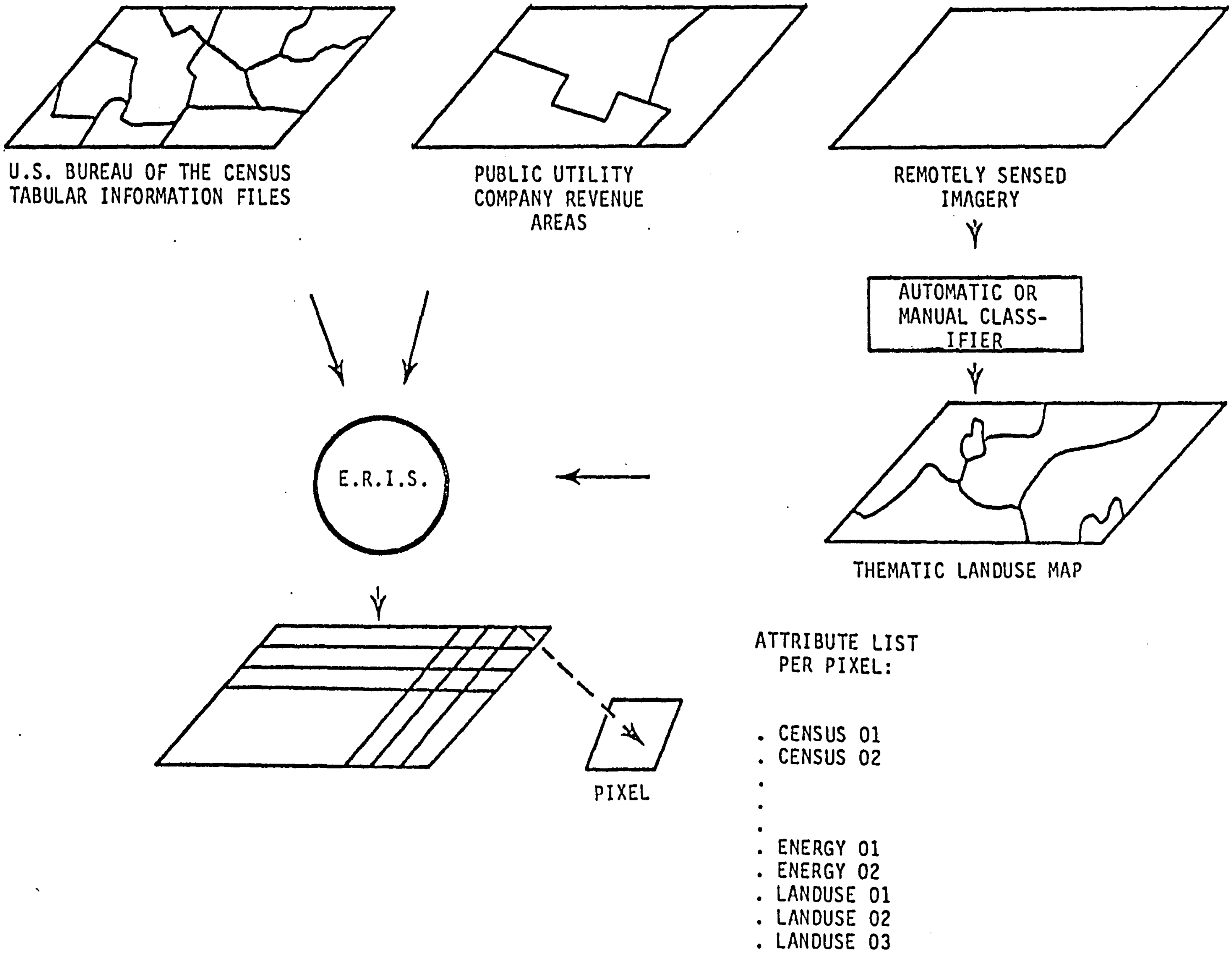
$$P_K = F(P_K^T, P_K^N),$$

WHERE P_K^T IS THE TIME TRANSITON 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.,

$$F(P_K^T, P_K^N) = P_K^T \cdot P_K^N \quad \text{OR}$$

$$F(P_K^T, P_K^N) = W_1 P_K^T + W_2 P_K^N, \text{ WHERE}$$

W_1 AND W_2 ARE APPROPRIATE WEIGHTS.


U.S. BUREAU OF THE CENSUS TABULAR INFORMATION FILES
PUBLIC UTILITY COMPANY REVENUE AREAS
REMOTELY SENSED IMAGERY
AUTOMATIC OR MANUAL CLASS-IFIER
E.R.I.S.
THEMATIC LANDUSE MAP
PIXEL
ATTRIBUTE LIST PER PIXEL:
. CENSUS 01
. CENSUS 02
.
.
.
. ENERGY 01
. ENERGY 02
. LANDUSE 01
. LANDUSE 02
. LANDUSE 03

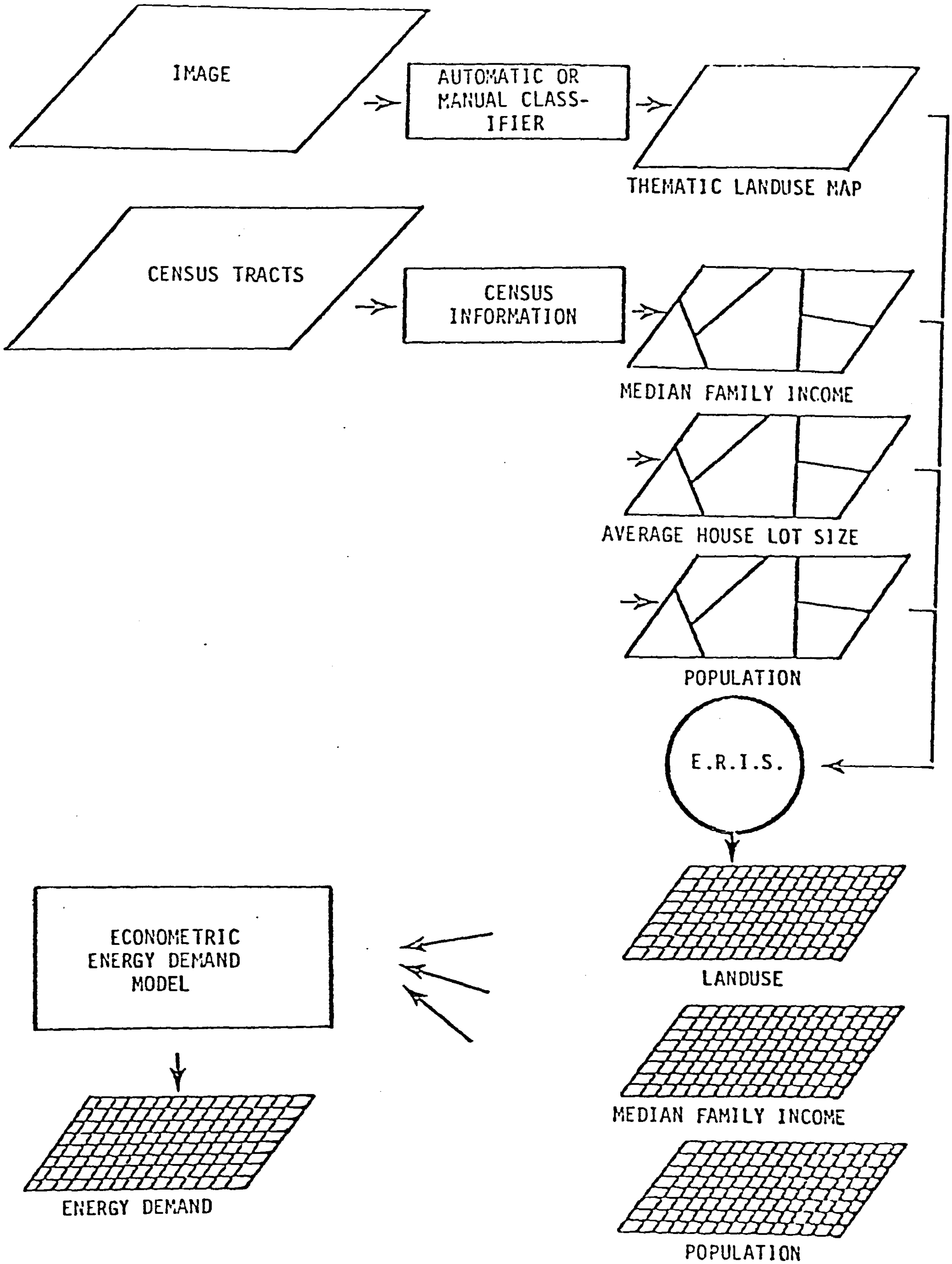
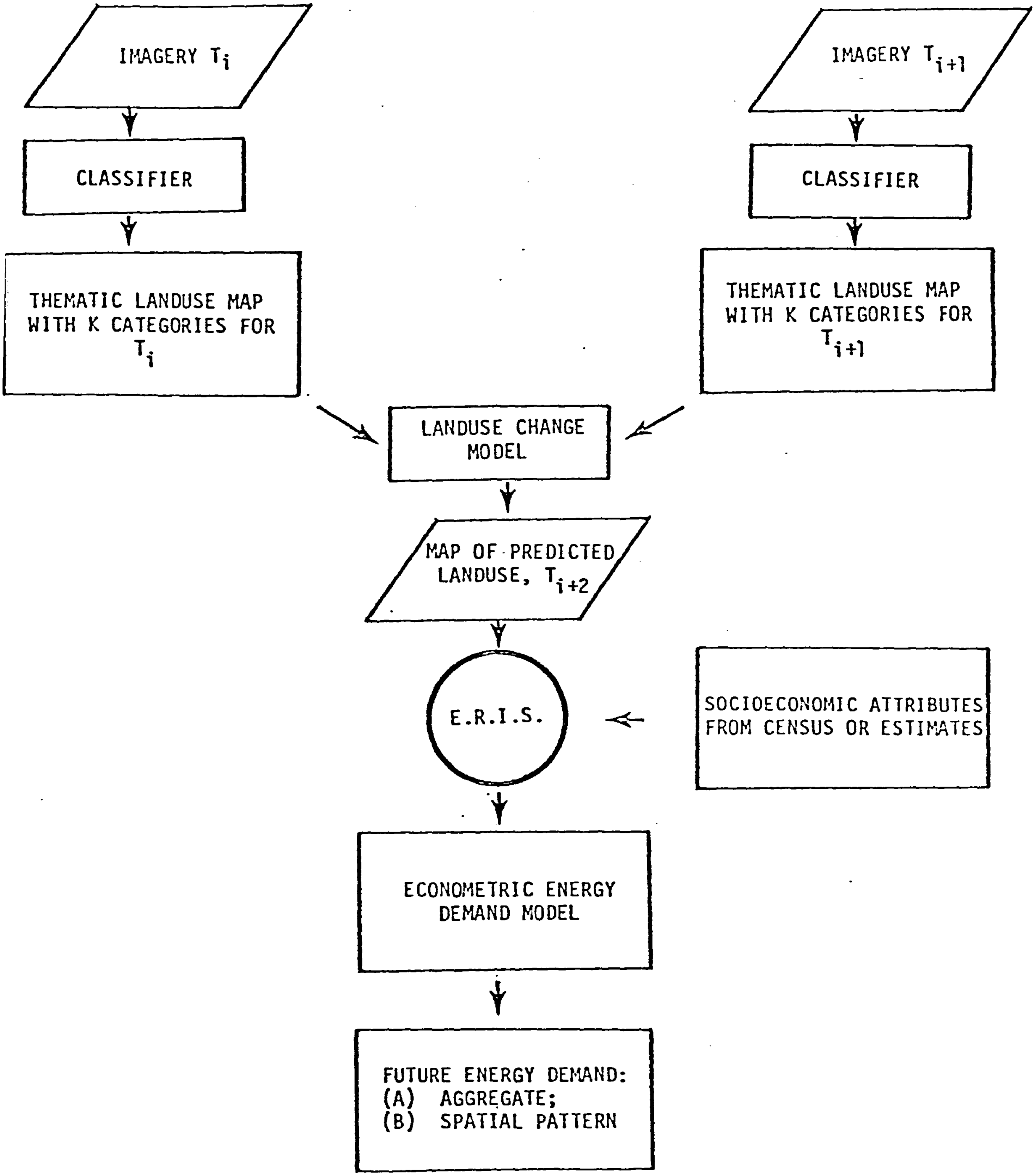


IMAGE
AUTOMATIC OR MANUAL CLASS-IFIER
THEMATIC LANDUSE MAP
CENSUS TRACTS
CENSUS INFORMATION
MEDIAN FAMILY INCOME
AVERAGE HOUSE LOT SIZE
POPULATION
E.R.I.S.
LANDUSE
MEDIAN FAMILY INCOME
POPULATION
ECONOMETRIC ENERGY DEMAND MODEL
ENERGY DEMAND


IMAGERY T_i
CLASSIFIER
THEMATIC LANDUSE MAP WITH K CATEGORIES FOR T_i
IMAGERY T_{i+1}
CLASSIFIER
THEMATIC LANDUSE MAP WITH K CATEGORIES FOR T_{i+1}
LANDUSE CHANGE MODEL
MAP OF PREDICTED LANDUSE, T_{i+2}
E.R.I.S.
SOCIOECONOMIC ATTRIBUTES FROM CENSUS OR ESTIMATES
ECONOMETRIC ENERGY DEMAND MODEL
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 FORCAST 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 VACTOR 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 FORCAST 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. First row, 1947–1951; second row, 1951–1963; third row, 1963–1967; fourth row, 1967–1971.

Transition from	Transition to[a]								
	1	2	3	4	5	6	7	8	9
Financial,	0·798	-	-	0·125	0·056	-	0·014	-	0·007
real estate,	0·724	0·052	0·013	0·089	0·019	0·013	0·038	-	0·051
and insurance	0·747	-	-	0·070	0·014	0·014	0·042	-	0·112
	0·806	-	-	0·015	0·029	0·045	0·059	-	0·045
Professional	0·026	0·615	-	0·218	0·038	-	0·027	-	0·080
services	0·080	0·400	0·120	0·040	0·080	0·040	0·160	-	0·080
	-	0·625	-	0·042	0·208	-	0·125	-	-
	-	1·000	-	-	-	-	-	-	-
Commercial	-	-	0·919	0·054	-	-	0·027	-	-
residential	0·095	-	0·667	-	-	0·048	0·190	-	-
	-	-	0·727	-	-	-	0·181	-	0·091
	-	-	0·682	-	-	-	0·046	-	0·272
General retail	0·029	0·008	-	0·830	0·024	0·016	0·012	-	0·081
	0·033	0·028	0·002	0·539	0·040	0·022	0·191	-	0·144
	0·045	0·003	-	0·719	0·010	0·023	0·069	0·005	0·126
	-	0·003	0·002	0·703	0·014	0·028	0·023	0·016	0·217
Personal	0·030	-	-	0·146	0·732	0·021	-	-	0·098
and commercial	0·055	-	0·004	0·164	0·535	0·008	0·133	-	0·102
services	0·057	0·020	-	0·062	0·647	-	0·095	-	0·119
	-	-	-	0·072	0·619	0·041	0·031	-	0·237
Eating	0·012	-	-	0·060	0·036	0·811	0·019	-	0·062
and/or drinking	0·069	-	0·011	0·042	0·070	0·643	0·168	-	0·049
	0·050	-	-	0·033	0·004	0·767	0·083	-	0·063
	0·009	-	-	0·027	0·009	0·691	0·036	-	0·227
Parking	0·067	-	-	0·022	0·011	0·011	0·845	-	0·044
	0·042	-	0·013	0·042	0·013	0·030	0·795	0·013	0·065
	0·033	-	-	0·033	-	-	0·900	-	0·033
	-	-	-	-	-	-	0·946	-	0·054
Entertainment	-	-	-	-	-	0·042	-	0·958	-
	0·037	-	-	0·111	-	0·037	0·185	0·630	-
	0·154	-	-	-	-	-	-	0·846	-
	-	-	-	-	-	-	0·167	0·666	0·167
Other	0·042	0·004	0·002	0·081	0·065	0·010	0·007	-	0·798
	0·026	0·018	0·018	0·215	0·044	0·062	0·106	-	0·499
	0·036	0·001	-	0·066	0·005	0·009	0·072	-	0·811
	0·003	-	-	0·005	0·003	0·001	-	0·001	0·987

[a] 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}

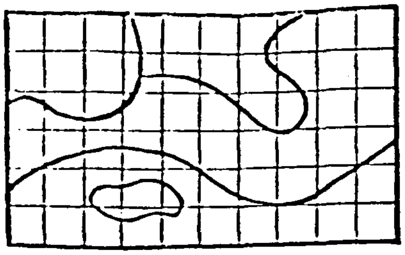


Image T_{i-1}

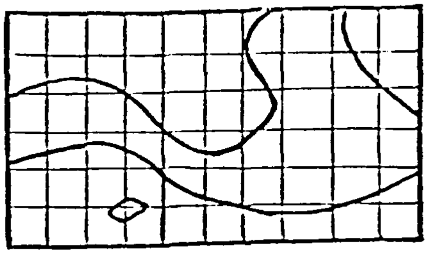
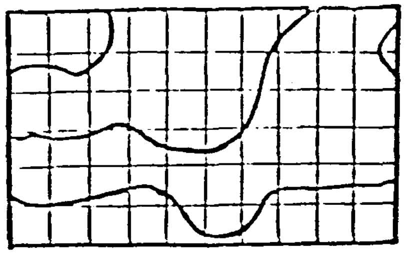


Image T_i



T_{i-1}

$$\begin{array}{c|c|c} & 1\ 2\ 3\ \ldots\ j\ \ldots\ k & \\ \hline 1,2,3,\ldots,i,\ldots,k & \text{Cell Count Matrix} \quad (f_{ij}) & \sum_j f_{ij} \\ \hline & \sum_i f_{ij} & \sum\sum_{ij} f_{ij} \end{array}$$

T_{i-2}

T_{i-1}

$$\begin{array}{c|c|c} & 1\ 2\ 3\ \ldots\ j\ \ldots\ k & \\ \hline 1,2,3,\ldots,i,\ldots,k & \text{Transition Probability Matrix} \quad (P_{ij} = f_{ij} / \sum_j f_{ij}) & \sum_j P_{ij} = 1.0 \end{array}$$

$[P] = T_{i-2}$

$$V_{T_{i-1}} = (Q_1, Q_2, \ldots, Q_i, \ldots, Q_k) =$$

State Vector at T_{i-1}, where $Q_i = \sum_i f_{ij} / \sum\sum_{ij} f_{ij}$

GOODNESS-OF-FIT TEST

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

= 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

Estimated second-order probability transition matrices of commercial activities for downtown Denver. First row, 1947-1951-1963; second row, 1951-1963-1967; third row, 1963-1967-1971. Key as in table 1.

Commercial residential.

Transition to (first period)	Transition to (second period) 1	2	3	4	5	6	7	8	9
Financial,	-	-	-	-	-	-	-	-	-
real estate,	1·00	-	-	-	-	-	-	-	-
and insurance	-	-	-	-	-	-	-	-	-
Professional	-	-	-	-	-	-	-	-	-
services	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-
Commercial	0·051	-	0·795	-	-	-	0·103	-	0·051
residential	-	-	1·00	-	-	-	-	-	-
	-	-	0·882	-	-	-	0·118	-	-
General retail	-	-	-	-	-	-	-	-	1·00
	-	-	-	-	-	-	-	-	-
	-	-	-	1·00	-	-	-	-	-
Personal	-	-	-	-	-	-	-	-	-
and commercial	-	-	-	-	-	-	-	-	-
services	-	-	-	-	-	-	-	-	-
Eating	-	-	-	-	-	-	-	-	-
and/or drinking	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	1·00	-	-	-
Parking	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	1·00	-	-
	-	-	-	-	-	-	1·00	-	-
Entertainment	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	1·00
	-	-	-	-	-	-	-	-	-

General retail.

Transition to (first period)	Transition to (second period) 1	2	3	4	5	6	7	8	9
Financial,	0·438	-	-	0·281	0·129	-	0·031	-	0·125
real estate,	0·750	0·028	-	0·083	-	-	0·028	-	0·111
and insurance	0·889	-	-	0·055	0·055	-	-	-	-
Professional	0·400	0·400	-	-	0·200	-	-	-	-
services	0·400	0·200	-	-	-	-	-	-	0·400
	1·00	-	-	-	-	-	-	-	-
Commercial	-	-	-	-	-	-	-	-	-
residential	-	-	1·00	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-
General retail	0·064	0·010	0·002	0·603	0·043	0·030	0·109	0·002	0·130
	0·052	0·002	0·003	0·702	0·018	0·030	0·085	0·003	0·105
	0·007	0·007	0·004	0·664	0·015	0·019	0·150	0·012	0·122
Personal	-	0·080	-	0·080	0·440	-	0·240	-	0·160
and commercial	0·097	-	0·032	0·205	0·519	-	0·130	-	0·016
services	-	-	-	-	0·200	0·200	0·400	-	0·200
Eating	-	-	-	0·419	-	0·571	-	-	-
and/or drinking	-	-	-	0·225	-	0·626	0·025	-	0·071
	-	-	-	0·444	-	0·467	-	-	0·089
Parking	-	-	-	0·029	-	-	0·914	0·057	-
	-	-	-	0·062	-	-	0·892	-	0·046
	-	-	-	0·088	-	-	0·645	-	0·267
Entertainment	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	1·00	-
	-	-	-	-	-	-	-	-	-
Other	0·073	0·013	-	0·188	0·073	0·061	0·073	-	0·518
	0·101	0·004	-	0·238	0·020	0·009	0·195	-	0·432
	0·004	-	-	0·167	-	0·009	0·238	0·026	0·556

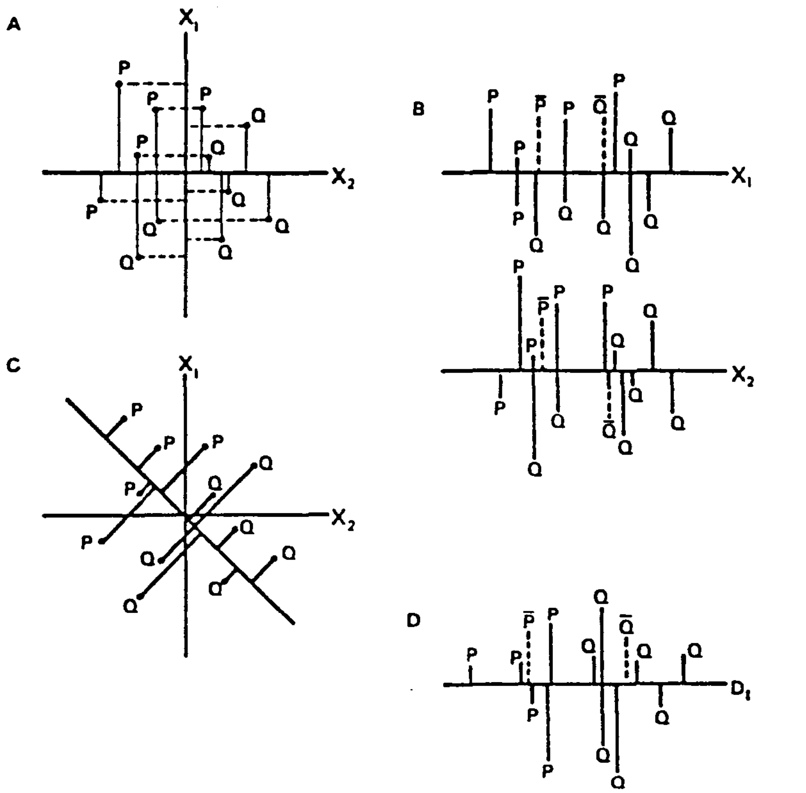
DISCRIMINANT ANALYSIS

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 CO-LLINEARITY AMONG INDEPENDENT VARIABLES ORIGINALLY USED IN THE ANALYSIS.

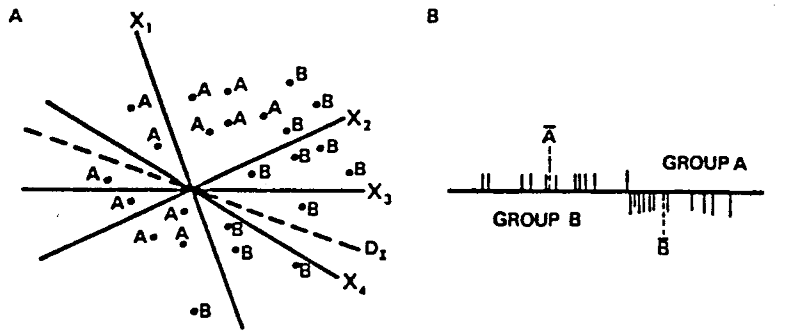
THE METHOD INVOLVES TWO SETS OF EQUATIONS: (i) A SET RELATING THE GROUP MEMBERSHIP TO THE DISCRIMINANT FUNCTIONS; AND (ii) A SET RELATING THE ORIGINAL VARIABLES TO THE DISCRIMINANT FUNCTIONS.

USES:

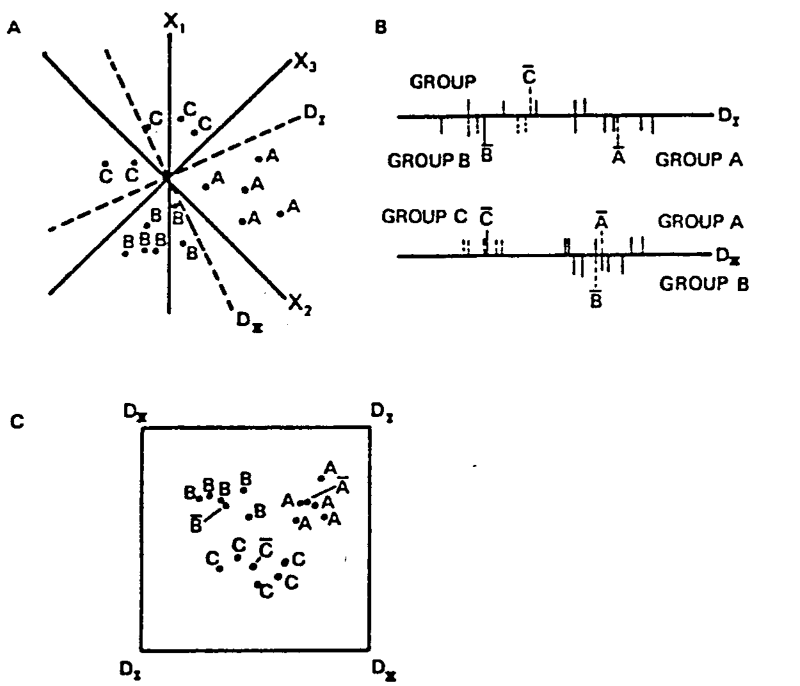
1. TESTING (AND GENERATING) HYPOTHESES, e.g., INVESTIGATE WHETHER A CERTAIN SET OF RELATED VARIABLES (MEASURED ON INTERVAL OR RATIO SCALES) SUCCESSFULLY DISCRIMINATE BETWEEN GROUPS OF OBSERVATIONS ON A NOMINAL SCALE.
2. EVALUATING A CLASSIFICATION, e.g., INDICATE THE NUMBER OF MISCLASSIFICATIONS IN THE 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.

1. Report No. CR 166369	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Relation of Land Use/Land Cover to Resource Demands		5. Report Date March 1981
		6. Performing Organization Code
7. Author(s) Cristopher Clayton		8. Performing Organization Report No.
		10. Work Unit No. T-4334
9. Performing Organization Name and Address Department of Geography University of California Santa Barbara, CA 93106		11. Contract or Grant No. Grant NAG 2-20
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		13. Type of Report and Period Covered Contractor Report
		14. Sponsoring Agency Code

15. Supplementary Notes

Technical Monitor: David Sinnott TE: 415-965-5912
NASA Ames Research Center FTS 448-5912
Moffett Field, CA 94035

16. Abstract

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.

17. Key Words (Suggested by Author(s)) Land Use, Land Cover, Change Detection, Remote Sensing	18. Distribution Statement Unclassified-Unlimited STAR Category 43

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	49	

*For sale by the National Technical Information Service, Springfield, Virginia 22161

End of Document