LUMIS — A LAND USE MANAGEMENT INFORMATION SYSTEM FOR URBAN PLANNING

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ABSTRACT

The Land Use Management Information System (LUMIS) consists of a methodology of compiling land use maps by means of air photo interpretation techniques, digitizing these and other maps into machine-readable form, and numerically overlaying these various maps in two computer software routines to provide land use and natural resource data files referenced to the individual census block. The two computer routines are the Polygon Intersection Overlay System (PIOS) and an interactive graphics APL program. A block referenced file of land use, natural resources, geology, elevation, slope, and fault-line items has been created and supplied to the Los Angeles Department of City Planning for the City's portion of the Santa Monica Mountains. In addition, the interactive system contains one hundred and seventy-three socio-economic data items created by merging the Third Count U.S. Census Bureau tapes and the Los Angeles County Secured Assessor File. This data can be graphically displayed for each and every block, block group, or tract for six test tracts in Woodland Hills, California. Other benefits of LUMIS are the knowledge of air photo availability, flight pattern coverage and frequencies, and private photogrammetry companies flying Southern California, as well as a formal Delphi study of relevant land use informational needs in the Santa Monicas.

INTRODUCTION

The Santa Monica Mountains of Los Angeles are a natural buffer between the developing Beverly Hills — Bel Air communities on the south and the San Fernando Valley on the north. They act as recreational open spaces to eight million people in the Los Angeles Basin. The City of Los Angeles traditionally proposes land uses by assessing and mapping socio-economic variables including population, housing, and parcel-level land use. Since the Santa Monicas encompass large areas of natural features as yet undeveloped, the idea of applying remote sensing to an existing geographic information system was born.

USER ADVISORY COMMITTEE AND TECHNICAL SUBCOMMITTEE

In order to make a thorough assessment of land use informational needs in the Santa Monica Mountains, a committee of prominent political officials actively involved in land use planning in Southern California was organized. This User Advisory Committee has been informed of every developing aspect of the LUMIS program. In addition, these officials have designated at least one, and in some cases three, members of their working staff to work directly with the LUMIS staff in formulating land use informational needs in the Santa Monicas. This working group is designated the Technical Subcommittee. The User Advisory Committee and the Technical Subcommittee agencies represented are the Jet Propulsion Laboratory, the Los Angeles Department of City Planning, the Southern California Association of Governments, the Community Analysis Bureau, the City Administrative Office, the Regional Planning Commission, the California State Office of Planning and Research, the State Department of Transportation, the State Water Resources Control Board, State Parks and Recreation, State Mines and Geology, Department of Water Resources, Cal Poly (Pomona), UCLA, and UC Riverside.

The first User Advisory meeting was convened on June 12, 1974, at the Jet Propulsion Laboratory. This meeting was well attended and resulted in a large number of responses in the ensuing Delphi study.

LUMIS NEWSLETTER

For purposes of informing the User Advisory Committee and selected land use planning officials of LUMIS developments, a monthly newsletter was initiated in May, 1974. An original list of approximately 225 officials was compiled for the Newsletter distribution. It was decided to add names to the list only for those respondents who requested such in writing; i.e., to let knowledge of the LUMIS Newsletter availability spread by "word of mouth" or by the official on the original list circulating the Newsletter among his staff. It was also decided to let normal attrition take its course; i.e., if an addressee on the list moved without informing the LUMIS staff in writing of his new address and a Newsletter addressed to him was returned, he was removed from the list. From May, 1974, to May, 1975, the LUMIS Newsletter distribution list grew from 225 to over 500 people. In addition to land use planning officials, the list includes virtually all land use remote sensing specialists, land use data base management analysts, and photogrammetrists in the United States, and many outside of the country.

The Newsletters were considered a valuable contribution to the LUMIS task for the following three reasons:

1. They allowed monthly dissemination of LUMIS developments to a wide range of potential future users of this or a similar system. This dissemination has prompted several planning agencies to take action to obtain LUMIS software from the City of Los Angeles. The Newsletters also illustrate the evolving plans for LUMIS; the problems, changes in concepts, and personnel contacts are clearly stated.
2. The Newsletters prompted scores of letters from planners and researchers developing similar systems. These letters contributed to an overall knowledge of land use information systems state-of-the-art by LUMIS staff and permitted them to redesign LUMIS software in more optimal ways than previously conceived.
3. The Newsletters comprised the best documentation of the LUMIS task, thus allowing a final report to be more easily written.

DELPHI LAND USE NEEDS STUDY

The Delphi land use needs study for the Santa Monica Mountains was carried out in three phases. The first phase identified 164 possible relevant land use types to consider incorporating into the LUMIS inventory. The second phase consisted of an importance ranking of these 164 items by the Advisory Committees. The third phase ranked these items again with the members having knowledge of the scores obtained on the second phase. The third phase reduced from 164 to 74 the land use data items considered in LUMIS (ref. 1).

In this Delphi study, members of the Advisory Committees were queried successively over several months in a procedure characterized by (ref. 2) anonymity of respondent, and involving interactive feedback between the LUMIS staff and the Committees to obtain a convergent consensus of relevant data items to be collected for the Mountains. The reader interested in more details of the technique employed in the LUMIS task is advised to consult reference 1.

Table 1 summarizes the main land use category ranking scores. The table shows the number of Advisory Committee members voting at three levels of importance for various broad level land use categories in the Santa Monica Mountains. It should be remarked that each of the three importance levels were broken into three sublevels, and each of the generalized land use categories were broken into from three to twenty subcategories, so that Table 1 represents averages across both dimensions of the matrix. However, the voting ran fairly consistent across both the subcategories and the levels allowing the major groupings in Table 1. An interesting aspect of this study revealed in Table 1 is the convergence of this final polling relative to earlier phases of the study.

It should be pointed out that although the LUMIS task takes in the City's portion of the Santa Monicas, the study area also includes a full ten percent of the entire San Fernando Valley, and portions of Hollywood, West Los Angeles, Westwood, Bel Air, Brentwood, Santa Monica, and Pacific Palisades. Thus, the first nine land use categories in Table 1 (from Residential through Public Facilities) taken from the Standard Land Use Code were included in this inventory. The remaining categories were selected by the LUMIS Advisory Committees as part of the Delphi process. In order to effectively plan developmental and conservational elements in the Santa Monicas, it was considered important to include the overlapping communities between the Mountains and the heavily urbanized regions of the City.

Rather surprising to the LUMIS staff is the relative unimportance placed by the Advisory Committees on trade and service facilities. This may stem from past exclusionary zoning of these facilities in the Mountains. The lack of importance placed on manufacturing, agriculture, and mining likely stems from the almost complete absence of these land uses in the study area.

In the natural resource categories the lack of relevance associated with physiography, wild life, and aesthetics probably stems from the nebulosity associated with the definition of some of the items in these categories. Apparently there is also a lack of appreciation for the potential fire hazard associated with dry chaparral stands and other vegetation in the Mountains. It is also interesting that one Advisory Committee member who voted on the first nine cultural items elected not to vote at all on the physical resources.

AERIAL PHOTOGRAPHS

As requirements for land use types and data accuracies were being obtained by the Delphi study, a simultaneous search and interview procedure was conducted among various photogrammetric companies and engineering agencies to evaluate the quality, geographic coverage patterns, and frequencies of coverage for all of the Los Angeles Basin including the Santa Monicas. The results of this search are presented in ref. 3. Surprisingly, all of Los Angeles County is flown at scales of from 1:12,000 to 1:48,000 by various companies every year. The interpretation of Santa Monica Mountain photography for the years 1970, 1972, and 1974 was performed by Cornell University.

Reference 3 listed a table (Appendix III) indicating nine agencies possessing aerial photos for southern California. The photo variables included film format, scale, resolution, vignetting, exposure, form (positives, negatives, transparencies, prints), camera orientation (vertical or oblique), camera type, filters used, date and time, altitude, coverage (flight lines), overlap for stereo coverage, photogrammetric controls, indexing, geographical area covered, and cost of photos. Appendix IV of reference 3 listed eighteen agencies and companies and their land use activities involving air photos. Appendix V of reference 3 revealed the pattern and frequency of air photo coverage of various geographical regions of southern California and which photogrammetric companies are most likely to fly those areas in the future.

From the results of reference 3, the largest users of aerial photography in Southern California, i.e., Caltrans, the Community Analysis Bureau, Regional Planning, the County Engineer, Water Resources, UC Riverside, and VTN, Associates, all employ a great variety of cameras and film types depending upon the applications of each agency type. Black and white film tends to be used for larger scale, general reconnaissance or planning purposes with color infrared employed for smaller scale, environmental quality investigations; 9" × 9" format film still prevails. The RC cameras are the most favored. Most agencies are flexible in providing positive and negative prints or transparencies. Profit-making photogrammetric companies usually supply only positive prints or transparencies.

Most agencies fly only their areas of jurisdiction — for general planning they tend to minimize overlap for stereo purposes and ignore photogrammetric ground control. Thus with thirty percent or less of both side and end lap, precise orthophotos are available for only 20 percent of the coverage area. In contrast, photogrammetric companies flying for private developers and engineers requiring accurate map products will provide 50 to 60 percent overlap with ground-surveyed control points. Photos generally cost from $7 to $12 for small quantities — the price can drop to as low as $1 each for large batches (several hundred).

Although the uses of air photos depend to a great extent on the agency's area of interest and concern, reference 3 reveals the growing application of remote sensing in land use planning, environmental impact reporting, and transportation studies. Two very active civil engineering consulting companies, Dames and Moore and DMJM, are using air photos for environmental impact monitoring and resource analysis. CUNY (City University of New York) is attempting to link various data bases via remote sensing; a similar attempt to define census tracts from LANDSAT imagery by James Wray of the U.S. Geological Survey has met with partial success.

In terms of frequency, aerial photography covering the entire Southern California area has been taken by two or more firms. This coverage includes Los Angeles and Orange counties as well as Ventura County, San Diego and San Bernardino counties on a yearly basis since 1967. According to the management of most of the firms represented in this report, this trend will continue for many years to come.

AIR PHOTO INTERPRETATION

Land use maps were drawn for a 14-tract pilot area in the northwest corner of the Santa Monica Mountain project area from the three sets of photography employed in the project; i.e., sets for 1970, 1972, and 1974. The air photo interpretation and map compilation were performed early in the task to understand the magnitudes of relief displacement errors on the aerial photos. The 14-tract pilot area comprises very rugged terrain, with elevations ranging from 800 to 1500 feet. Even with the relatively small scale (1:48,000) photography used for the 1970 and 1972 land use maps, relief displacements of several hundred feet exist in the more rugged terrain of the Woodland Hills area of the City.

The aerial photos used in the LUMIS project were previously flown for general planning purposes by several Los Angeles City agencies. Since the coverage was not designed for photogrammetric control, only about ten percent sidelap and overlap exist for the stereo coverage of the photos. For this reason an orthophoto for the entire mountain range could not accurately be constructed since the center sixty percent of the area on each photo cannot be viewed stereoscopically. However, the overlap and endlap were sufficient to construct a photomosaic from the 1972 photos. This mosaic was available to the Cornell University interpretation team and was used by them to physically displace each land use boundary from its apparent geographic position on the individual photo to its true geographic position as evidenced on the mosaic. The photomosaics (two duplicate positives were made from the 1972 imagery) were constructed to rigid specifications and checked by the LUMIS staff by overlaying the final photomosaic transparent negative over the corresponding U.S. Geological Survey 7-1/2-minute quadrangle maps of the same area.

Since the photomosaic was not yet available when the first land use maps of the Woodland Hills pilot area were made, a simple and cheap method was devised to allow for relief displacement. This method will work for elevation ranges of one-thousand feet on a 1:36,000 to 1:48,000 scale 9-inch aerial photograph. In this method, one chooses several points (seven of these control points were used for the pilot area) which can be identified on both an air photo stereo pair and the U.S.G.S. quad map. These points are generally small street intersections and well defined building corners, all points at elevations covering the range of elevations encountered on the photo. These control points were carefully and precisely punched with a fine needle point while observing the pair of conjugate points with a pocket stereoscope. The State Plane Coordinates (SPC's, California, Zone 7) of the control points were then calculated in the following manner. Please see figure 1.

The control point in the quad map was bracketed by 2-1/2-minute latitude and longitude grid tics. It is suggested that the SPC tics on the topo map margins not be used in determining the control point SPC's for two reasons: (1) there is an insufficient number of these tics to establish a dependable grid on the topo map, especially when considering that (2) the SPC grid will not be linear on the topo map projection.

The SPC's for the 2-1/2-minute intersection tics were obtained from the U.S. Coast and Geodetic Survey Plane Coordinate Intersection Tables (2-1/2-minute), SP-327, a copy of which can be obtained from the Superintendent of Documents. Thus the SPC's of the bounding lat-long tic marks were known and were designated (X_1, Y_1), (X_2, Y_2), (X_3, Y_3), and (X_4, Y_4) for the southwest, southeast, northwest, and northeast tics respectively. See Figure 2. Since the SPC's form a curvilinear coordinate system on the topo map, a 4-way linear interpretation for the X and Y coordinates of control point 1 was performed.

The grid tics around the control point were connected with a straight edge and a hard lead (4H) pencil. A perpendicular north-south line was constructed through the control point to the bottom and top grid lines. Since the scale of the topo map is 1:24,000, or 1" = 2000', the 20 scale of an engineer's scale (not architect's) was used to measure the units of x_1, x_2, y_1, y_2. Then the four solutions for each of the X and Y coordinates of the control point were calculated by:

$$
\begin{aligned}
X &= X_1 + 1000x_1 + \frac{y_1}{y_1 + y_2}(X_3 - X_1) \\
X &= X_3 + 1000x_1 - \frac{y_2}{y_1 + y_2}(X_3 - X_1) \\
X &= X_2 - 1000x_2 + \frac{y_1}{y_1 + y_2}(X_4 - X_2) \\
X &= X_4 - 1000x_2 - \frac{y_2}{y_1 + y_2}(X_4 - X_2) \\
Y &= Y_1 + 1000y_1 - \frac{x_1}{x_1 + x_2}(Y_1 - Y_2) \\
Y &= Y_2 + 1000y_1 + \frac{x_2}{x_1 + x_2}(Y_1 - Y_2) \\
Y &= Y_3 - 1000y_2 - \frac{x_1}{x_1 + x_2}(Y_3 - Y_4) \\
Y &= Y_4 - 1000y_2 + \frac{x_2}{x_1 + x_2}(Y_3 - Y_4)
\end{aligned}
\qquad (1)
$$

The four X and Y solutions shown above always agreed to within 3 to 30 feet of each other. An example of the calculation for the SPC's of a land use control point is exhibited as Figure 3.

The SPC's of all seven control points were thus calculated. Choosing one point near the center of the photo and another with approximately the same elevation near the edge, the scale in this direction was determined by measuring the distance between the points in inches and dividing by the true ground distance obtained from the SPC coordinates calculated above. This scale was used as the "base" scale for the ensuing land use map. The land use map was then geographically "tied down" in the following manner.

Using the base scale and the SPC's of the control points, these points were plotted on a non-shrinkable, mylar base sheet. The air photo was placed under the mylar sheet and oriented until the two control points which were used to determine the scale coincided between the photo and mylar sheet. The other five photo and mylar control points will not generally coincide since the photo has a varying scale dependent on elevational changes. The photo control points were then marked on the mylar base. The distance and direction from the initially plotted control point (the map position) using the base scale and the imaged position (just marked on the mylar from the underlying photo) is the distance and direction which the mylar should be displaced when tracing the land use boundaries in this region of the photo. By thus partitioning the air photo into regions of fairly constant scale, reliable land use maps with positional accuracies not exceeding 80 feet were compiled of Woodland Hills. By this method, the Planning Department can perform the same type of map compilation for other areas limited in geographical extent and elevation variation without the expenditure of funds for a photomosaic.

The Woodland Hills land use maps were constructed in this manner — sliding the transparent tracing sheet over the air photos to adjust for relief displacement and tracing the polygon boundaries of different land uses utilizing the principles of air photo interpretation and classifying the interpreted land uses from the Delphi-selected land use data items described under "Delphi Land Use Needs Study." Sixteen polygons were ground truthed by car as they could not be positively identified from the air photos alone. The most difficult land use discriminations to interpret from the photos alone were the distinctions between large food stores and banks and between small day care centers and private church schools. Riding stables were also difficult to interpret from the photos alone as they are generally concealed by crown cover in the Woodland Hills region of the city.

The penciled land use mylar polygon maps for all of the Santa Monica Mountains were then inked on a second overlay. In the case of the pilot area maps in Woodland Hills, the mylar inked maps were photographically reproduced onto two matt finishes per map. One matt was used for polygon identification and digitizing. The second matt was colored according to seven broad land use categories. The colored land use maps of Woodland Hills for the years 1970, 1972, and 1974 are illustrated in figures 4 through 6, respectively. For the rest of the Santa Monicas outside of the pilot area interpreted by Cornell University, the one available inked land use map per area was digitized directly.

It is interesting to analyze the land use changes in Woodland Hills during the years 1970 to 1974 utilizing figures 4 through 6 as the Los Angeles City Planning Department is presently doing. Pierce College is the large dark island in the sea of dark farmland in the northeastern corner of the figures (pt. 3). The rapidly disappearing farmland signifies the foreseeable end of agriculture as a resource in the City of Los Angeles. Note the threat to agriculture and open space in the top central portion of the maps — the encroaching light shopping centers and banking institutions (SW of pt.2). The entire large dark graded area in this region, near Topanga Canyon Boulevard in 1972 (figure 5), has been completely built over in 1974 (figure 6). However, the multi-family units (white) are staying fairly constant except for some building in the central region near Topanga Canyon Boulevard. The activity encouraging shopping center developments is the large increase in single family residences, a trend quite dissimilar to other regions of the San Fernando Valley, where the ratio of condominium starts to single family housing starts is higher and continuing to grow (in 1975). The large increase in single family units is manifested by the dwindling dark open spaces in the southern, mountainous areas of Woodland Hills near the large, dark island (the Woodland Hills Country Club, pt. 6) in the sea of gray. Note that the large triangular dark graded area at the southern border of the pilot area in 1972 has been completely covered by single family residences in 1974. Also note the dark terracing at the south-eastern border of the area in 1974 revealing the probable direction of new single family housing construction in the near future.

The following section illustrates the computerized procedure whereby the qualitative analysis performed above can be numerically described in terms of acreage and acres of change per year to allow the Los Angeles City Planning Department to apply the information contained in maps such as figures 4 through 6 for land use policy decisions.

POLYGON INTERSECTION OVERLAY SYSTEM

The main objective of the LUMIS Task was to develop a system consistent with the Los Angeles City's line printer mapping capability of their IBM 370/165. However, during the summer of 1974 it became apparent that system incompatibility would be a problem. Batch processing for development of the system at JPL was to be done on a UNIVAC 1108. Thus, conversion software had to be established to insure the transferability of JPL developed LUMIS products to the City's computer operations.

The second and far more basic problem regarding computer system compatibility is the conceptual difference between ordinal and nominal data systems (ref. 4). Ordinal systems are "number referencing," i.e., data or information is referenced to a geographical system. Thus, natural resources such as forests, rivers, cropland, and geologic formations are mapped with selected identifiers (total area, boundary, centroid) referenced to a selected geographic coordinate system. Nominal systems are "name referencing," i.e., data or information is referenced to a name designating system. Number of elderly persons over 62 years of age, total land improvement value, and percent families with unmarried female heads of household are data items referenced to a name; e.g., a block, tract, or councilmanic district (ref. 5).

The distinction between these two types of systems appears obvious; yet very few remote sensing specialists and information systems developers seem to have grasped this distinction. This misunderstanding by the remote sensing profession is manifested by the desire to digitize all areal units and relate census and other similarly referenced data to ordinal data via coordinate overlays. This approach, while valid, ignores all the DIME file technology developed by the U.S. Census Bureau for the purpose of aggregating nominally referenced individual data items to polygons of census geography. The planner, similarly, aggregates line scanner pixels to a name unit in order to give the area of alluvial fan in a district. Both points of view reflect the lack of appreciation for the importance of various means of data referencing. The "Ordinal" man thinks of geographic coordinates and the "Nominal" man thinks of place names. The "Ordinal" man thinks that nominal data can be easily interpolated, extrapolated, or aggregated to some polygon other than the orginally referenced polygons. Although there are spatial population projection models, to employ them over geographic space destroys the concept of an information system, which should be designed from observation, not theory (ref. 6). The "Ordinal" man has yet to understand that "Nominal" man is interested in place names; socio-economic data such as people and land values move geographically too fast for "Ordinal" man — his geographic system is stagnant with respect to people.

If a Councilmanic District boundary moves 20 blocks westward in one year, the Councilman is more concerned with the change in the number and characteristics of his constituents than the precise geographic location at any instant of time. An argument can be made that he should be concerned, since the coordinates involved in precisely describing the boundary may have impact on information applicable to engineering activities in the area. This fundamental understanding between the engineering ordinal and the planner's nominal data systems has been of great benefit to the LUMIS staff.

The LUMIS approach to the ordinal-nominal systems incompatibilities is outlined in Figure 7. Basically, it involves the spatial definition of census areal units; i.e., the block, block group, and tract in terms of the California Zone 7 State Plane Coordinate System. These, in turn, are used as the map and land use geographic reference units. Flexibility is provided in the interactive graphics mode described in the next section by allowing both an ordinal presentation of the land use or physical resource as a polygon boundary and a nominal presentation of population and housing near the centroid of a name designator (tract 1340.01, block 302, of figure 7). The LUMIS computer subsystems have a provision for converting the ordinal polygon boundaries to nominal block acreages by means of polygon overlay software. Since LUMIS is a block level system, i.e., the census block is the smallest aggregate unit, the distinction between ordinal and nominal systems is made since there is no method by which the nominal socio-economic data can be geographically distributed within the block. The desire of

"Ordinal" man to force his system must be addressed by parcel level identifiers (ref. 7). Census blocks are irregularly shaped, hence geographical overlaying of land use and other map polygons over census blocks requires digitization of both census polygons and polygons drawn as overlays from maps and aerial photo sources. The use of census blocks as the land use geographic reference unit has the advantages of the utility of existing Metropolitan Map Series, the existence of digitized block nodes in many SMSA's[1] of the United States, and the topological chaining of digitized street segments into blocks, block groups, and tracts by means of the U.S. Census Bureau DIME (Dual Independent Map Encoding) file edit software. An additional advantage is gained in urban areas since census blocks are usually defined by street boundaries and are hence easily recognized on aerial photos (as opposed to artificially defined Universal Transverse Mercator or State Plane Coordinate grid cells). The street pattern and contained land uses are thus visually preserved even in the presence of photo tilt and relief displacement so that gross overlay errors from non-orthographically corrected photos are easily detectable.

The chief disadvantage of census blocks is the low accuracy of boundary location — usually the width of a secondary street (approximately 80 feet). Census block boundaries are generally defined no better than the width of a street and in some instances run along an arroyo or river where the boundaries are even more poorly defined. It should be remarked, however, that land use boundaries are generally no better defined by remote sensing or any other means since, for example, the precise line between family residential areas and wooded lots is difficult to perceive and define. Unless very precise definitions for land use boundary designators are set (which is generally not the case), in remote sensing the definition is the sharp discontinuity between spectral signatures or interpreted patterns and tones, which may be completely unrelated to land use. It is suggested that the definitional clarity of census block and land use polygon boundaries are quite compatible.

The census blocks become the major polygons in the overlay technique employed in LUMIS. Eight other digitized map type polygons, or map models, become the minor polygons. Major polygons are census blocks which, after processing with the polygon overlay software, contain the information overlaid from the minor polygon. These minor polygons are created from land use and natural resource maps (which in turn are created from air photo processing), slope maps (in turn created from elevation maps), elevation maps, geology maps, landslide and fault maps, soil maps, and air pollution indices.

The polygon overlay software is the PIOS (Polygon Intersection Overlay System). PIOS was originally developed for the San Diego Comprehensive Planning Organization (CPO)[2] by Environmental Systems Research Institute (ESRI) of Redlands, California (ref. 8). The system was designed and implemented in 1971 under a contract from CPO to ESRI to digitize soils polygons of San Diego County and then quantify soils type within Traffic Analysis Zones (TAZ), statistical areas used for planning purposes by CPO. PIOS numerically overlays any general set of geographically referenced polygons, two members of the set at a time, and produces a residual polygon of the intersecting polygons' common boundary and the area of intersection. This residual polygon can be overlaid with a third polygon, and so forth, each overlay producing a residual polygon of common intersection. This overlay system is conceptually similar to a "cookie cutter".

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[1] Standard Metropolitan Statistical Area. The advantage of digitized block nodes is questionable. LUMIS staff found serious errors in ten percent of several hundred previously digitized nodes in the Santa Monica Mountains. We therefore discarded this file and redigitized all these block nodes for our own use.

[2] The LUMIS staff acknowledges Mr. Lee P. Johnston and Terry de Berry of the CPO for their help in acquiring PIOS.

Overlay processing is the most severe demand imposed upon any polygon information system. It requires massive computation of polygon records while searching the files. The overlay capability of PIOS includes several features that minimize this computer processing (ref. 9):

1. Each polygon record carries extremity coordinates that define the extreme X and Y coordinates for that polygon. This eliminates a great deal of initial file scanning.

2. All polygons are complete and not related to a map window. This means that polygons appearing on separate maps are connected along the borders. This has the effect of removing all of the source map borders and irrelevant boundaries.

3. A unique quadrature procedure for strip analysis of polygons is employed which has proven to be faster than the conventional point-in-polygon methods.

The PIOS software has been modified at the Jet Propulsion Laboratory to provide a data file of acres of land use and other map variables referenced to the individual census block. The final overlay analysis uses this file and converts it temporarily into a work file usable by the polygon overlay program. This work file is composed of an arbitrary map windowing system. The windowing technique allows for various rectangular areas to be sorted out of the data file permitting computational analysis or graphics display of any given area. The rectangular area resembles, in many ways, the border of a map. It essentially is a technique for selecting a designated area from a continuous geographic data file. In this way any geographic area can be windowed and pulled off the file for subsequent analysis according to the coordinate rectangle specified. It should be noted that the original map information was digitized from a rigid map windowing system being composed of land use maps, MMS maps, geology maps, and others.

Having windowed the final master file into a temporary work file, the polygon overlay program accesses this work file for the purpose of aggregating and summarizing the areas (by average) of the subordinate polygons by homogeneous types (land use, geology, others) into each dominant polygon type (census block).

Considerable analysis has been done on various techniques for the polygon overlay analysis (ref. 9). The most basic of these techniques involves the point-in-polygon technique. Using a polygon data base, this type of algorithm calculates the location of single points relative to polygons. A point may lie inside, outside, or on the line of a given polygon. Because polygons are defined by chains of points surrounding each polygon it is a simple step to organize the point-in-polygon technique so that it can do polygon overlay analysis.

A second method involves the generation of a grid cell technique with a variable grid cell size for varying sizes of polygons. If a correct amount of computer storage is allocated, this technique allows the user to specify varying degrees of inaccuracy and a grid cell size can be selected for each dominant polygon. Each dominant polygon and the associated polygons that are overlayed are assigned a cell size dependent on total polygon size and its perimeter length. If the polygon is made up of a 0.01 inch grid then the accuracy is at the same level as the thickness of the lines on the input maps. However, land use polygons can be quite large (i.e., 100 square inches) and a perimeter description can involve as many as 2,000 vertex points. For this size of polygon to fit into a reasonable core space, it would be necessary to choose a cell size an order of magnitude larger than 0.01 inch. This large grid size introduces unacceptable inaccuracies.

The San Diego CPO grid cell program that was written, however, is substantially faster than the point in polygon routines and if the polygon sizes are reasonably small (2 - 3 square inches) the algorithm is quite useful (ref. 9).

The third technique investigated proved quite successful and is used in PIOS. It involves a hybrid of the standard point-in-polygon routine. This technique is an efficient polygon stripping technique that subdivides data for subsequent point-in-polygon calculations.

The general logic of this stripping technique is not unique, but it does provide for a substantial increase in efficiency. Briefly the technique involves reading in a major polygon and partitioning it into a predetermined number of strips. The number of strips is determined by the tradeoff between efficiency gained in the processing and the core storage requirements necessary to run the program. It should be noted that as the complexity of polygons increase the efficiency gained by increasing the number of strips also increases. The coordinates of the polygon are stored in an array such that it is possible to maintain points to each set of side points that make up each strip. New points are generated at strip boundaries so that each strip is wholly contained.

Since the point-in-polygon technique uses directed line segments in the positive x-direction of slope zero, each point of interest will appear in one, and only one, strip and the directed line segment will not cross over onto another strip. Therefore, to determine if a point is in or out of the polygon, only a single strip and not the entire polygon needs to be considered. This amounts to considerable reduced machine costs (see figure 8).

After the major polygon (census block) has been stripped a minor polygon (land use, for example) is read in to compute the intersection points, if any. Each point in the minor polygon is tested for being in or out of the major polygon. This information is kept in a memory table. After the special case of locating the first point has been considered, four possible actions are taken by the program when considering the remaining points. They are as follows:

Please refer to figure 8. Let the subscript 1 indicate the first (or previous) point and 2 the next point of the same polygon. Let I indicate a minor polygon point inside the major polygon and O a minor polygon point outside the major polygon. Let B_i be a set of arbitrary points on the major polygon boundary with, in this example, B_1 and B_3 being major-minor polygon boundary intersections.[3] The four possible conditions and the actions taken are tabulated below:

First Minor Point Condition	Example	Second Minor Point Condition	Example	Action Taken
IN	I_1	IN	I_2	Add point to the line segment defining the new polygon being calculated.
IN	I_1	OUT	O_2	Find intersection (B_1). Determine direction on major polygon. Follow major polygon until it goes out of minor polygon (B_1 - B_2 - B_3).
OUT	O_1	IN	I_2	Find intersection (B_3). Determine direction on major polygon. Follow major polygon until it goes out of minor polygon (B_3 - B_2 - B_1).
OUT	O_1	OUT	O_2	Throw away point O_1. Do not consider segment as part of polygon.

[3] B_1 and B_3 are actually calculated by PIOS since the equations of the straight line segments joining adjacent points on both major and minor polygons are formed from the digitized coordinates of these points.

After selecting one of these actions, a new polygon is developed and subsequently computed for area.

Having sorted all of the acreages of each minor polygon type by census blocks, this preliminary listing of polygon sizes is summarized into a final file containing the integration of map types within specified census blocks.

INTERACTIVE GRAPHICS TERMINAL

In addition to the polygon overlay software, a secondary objective of the LUMIS task was to demonstrate the potential of interactive computer graphics to the City to illustrate the value of an advanced LUMIS operating system. An interactive system with computer graphics capability was initiated on a short term lease with two vendors — one supplying the terminal and the other supplying APL software support.[4] This lease was decided upon since the City, should it choose to support a similar graphics system, would most probably follow a similar mode of terminal support initially. The lease period for the terminal in the LUMIS Task expired at the end of December, 1974. A successful demonstration was given to the Planning Department staff prior to its expiration. That demonstration has resulted in the Planning Department considering the establishment of a similar system.

In the meantime JPL has established the APL language on the Caltech PDP-10. Since JPL has many computer terminals, further interactive terminal development will now be performed on the PDP-10. There was thus a definite need to make all LUMIS software easily transferable, an original objective of the task, since the polygon overlay system was developed at JPL on a UNIVAC 1108 and was transferred to the City IBM 370, and the interactive system was transferred from a local vendor to the PDP-10 and finally will be transferred back to the local vendor's computer or the City's IBM 370.

The interactive graphics system basically takes the same input as PIOS; i.e., digitized block boundaries and map polygons. Whereas PIOS overlays various digitized polygons and creates a residual polygon of common intersection to relate map information to an individual census block, the graphics routines display the digitized polygons (the ordinal data) in map form and the socio-economic data (the nominal data) at the polygon centroids. (Refer to figure 7.) To date (June 1975) the interactive graphics system encompasses strictly one hundred and seventy-three socio-economic data items regarding population, housing, and land use for six census tracts (approximately two hundred blocks) in Woodland Hills, California. The socio-economic data items were obtained by merging the Third Count U.S. Census tapes and the Los Angeles County Secured Assessor File for these six tracts. A similar merged file for the remaining seventy-eight tracts in the Santa Monica Mountains has been supplied to JPL by the Los Angeles Planning Department. This data has not yet been inputted to the interactive software, nor has additional development of this system been performed as the City has not yet committed itself to supporting terminal development.

The six digitized tracts contained in the interactive system are located in the western tip of the pilot area (please see figures 4 through 6), west of the line formed by extending Shoup Avenue south to the Los Angeles City Limits. The six tracts consist of three north of the Ventura Freeway (1351.01, 1372.01, and 1372.02) and three south of the Freeway (1374.02, 1374.01, and 1375.02). The three tracts north of the freeway are representative of some of the more congested residential and commercial areas of the City of Los Angeles and the three tracts south of the freeway are some of the most rapidly changing tracts in the city from the standpoint of transition from open space to single family units. The transition has been aptly discussed under the subsection "Air Photo Interpretation".

[4] Tektronix, Inc., and Proprietary Computer Systems, Inc., respectively.

Figures 9 through 11 are polaroid shots taken of the interactive terminal with a demonstration set of census blocks displayed. Since the basic units are digitized census blocks, they represent true-to-scale street maps of two different block groups in Woodland Hills. Since they also reveal block aggregates of algebraically-combined socio-economic data, these figures illustrate an interesting merger of an ordinal and nominal data system. The variables are significant in themselves.

Figure 9 reveals the percentages by block of persons 62 years of age or older to the total population of that block. The block group shown is 300 in census tract 1375.02. The relatively lower percents of elderly in the more expensive, winding blocks in the center and east side of the tract conform to the common image of the San Fernando Valley's youthful population. Note that in many blocks City data has been censored to LUMIS staff. The user-provided algebraic expression to access this data and combine it into a planning variable is illustrated at the top of the terminal.

Figure 10 is an interesting example of how temporal trends can be detected using combinations of data. Although land use data from remote sensing imagery has not yet been added to the system, the land use maps prepared from this imagery were available. Using this map and previous displays of single family and multi-family units, LUMIS staff knew that this block group (100) of census tract 1375.02 is composed strictly of single family units except at the north along the Ventura freeway. Since the Assessor File contains 1974 data and the Housing Census contains 1970 data, a look at the change in single family units can be obtained by selecting the right variables from each file. In the user-supplied expression at the top of the terminal, SFD is the single family units from the 1974 Assessor File and OCC + VACANT is the sum of the 1970 total occupied units and vacant units for sale. Note the increase of 27 and 29 housing units in the southerly mountains of this block group. The 1970, 1972, and 1974 aerial photography reveals the clearing and terracing associated with preconstruction of these homes, as pointed out in the subsection "Air Photo Interpretation".

Figure 11 is the same block group as Figure 10, indicating the total improvement value for each block divided by the number of parcels on which improvement took place in 1974. The ratio is a measure of the average improvement value per lot. Note the high two and one-half million dollar improvement (a commercial development) near the freeway. Also note that the block with censored data in Figure 11 is one of the same blocks censored in Figure 10.

The LUMIS interactive graphics package encompasses a user oriented, English language mode for communication with the APL routines necessary to graphically display the ordinal data and to call the PL/1 programs which manage and access the data files.

CONCLUSIONS

Delphi study. - The Delphi Study was a tremendous benefit to LUMIS staff in reducing the number of land use data items from 164 to approximately 74. It eliminated the need to acquire land use information concerning manufacturing, trade, and services which would have necessitated data sources other than aerial photography and City files. By eliminating most subcategories of climate and all of physiography, wild life, and aesthetics, items which were difficult to define - let alone interpret - were avoided. Vegetation is retained in the inventory since this land use is critical in zoning and fire insurance. The remainder of the retained items are relevant to planning in the Santa Monicas and are fairly easily interpretable from aerial photography.

The Delphi study was probably more important in the personal interaction the study provided between LUMIS staff and the leading land use planners in agencies throughout the Los Angeles basin. These relationships have permitted LUMIS staff to become involved in other land use planning activities unrelated to the Santa Monica Mountains, thus providing future potential applications for LUMIS.

Interactive computer graphics terminal. - The LUMIS system (utilizing PIOS) has been set up on the City's computer and allows the data to be used by the City Planning Department in its normal mode of operation. Implementation of the interactive graphics system would allow a more efficient mode of operation to be developed. Many planning examples similar to figures 9 through 11 were demonstrated to the Los Angeles Planning Director and staff. It was pointed out that to have at hand 173 data items for the approximate 200 blocks on line in the terminal would require several volumes of computer printout. To have at hand data for the entire Santa Monica Mountains would require a library of computer listings in table form. The LUMIS terminal provides a scaled street map and links the City's data to it almost instantaneously. The current software encompasses English language user statements and a self-instructing mode to assist the user in displaying tables and maps of selected areas. In summary, the Director of Planning has agreed that the interactive terminal development of the LUMIS task could be a vital tool in planning and zoning in the Santa Monica Mountains, and a proposal has been initiated for the City to support interactive terminals.

The method of digitizing census units in the LUMIS project has been done on a street segment basis to facilitate block, group, and tract chaining. This method is compatible with U.S. Census Bureau DIME-file editing and was done to allow rapid retrieval of any census areal unit in the hierarchy of units. Thus, the LUMIS methodology has direct transferability to all urban agencies building files and information systems based on DIME files. For areas which do not have accurately digitized block nodes, the LUMIS scheme of digitization is certainly appropriate.

The interactive terminal development to date satisfies Los Angeles City planners in their need to spatially relate urban variables. This satisfaction is due to the capability of the system to overlay dynamic socio-economic variables at an instant of time and geographic blocks into which the variables were originally aggregated. This is a first step toward more effective land use management through integration of differently referenced information — ordinal, and nominal. The LUMIS staff clearly recognizes that much further work needs to be done in this integration research of different data referencing systems.

Integrated approach. - As well as the integration of information systems and data referencing units, the LUMIS staff recognized that the integration of various disciplines and institutions would be necessary to effectively implement a land use information system. Much of the information system developmental research was performed by JPL engineers at City Hall, whereas City planners were involved in LUMIS systems concepts from the start of the project. The Natural Resources Laboratory at Cornell University, with a staff of twenty-seven photo interpreters and resource managers, was retained for the important evaluation and processing of aerial photography. The very important Advisory Committees provided the direction and guidance to the LUMIS staff to insure that the project was truly a multifaceted solution to a real land needs problem, not an academic exercise to create a land use gaming tool.

ACKNOWLEDGMENTS

The LUMIS staff would like to take the opportunity to thank the many people who have helped to make this project a meaningful entry of remote sensing and interactive information systems into city government. The LUMIS Advisory Committees have been very helpful in maintaining a realistic approach to a very serious land use problem in the Santa Monica Mountains. Particularly, the time spent in discussing land use problems in Los Angeles by Mr. Jene McKnight of the Los Angeles Regional Planning Commission and Mr. Thomas Sisson of the City Administrative Office is acknowledged. The continuing interest and support of Mr. Calvin Hamilton, the Director of the Los Angeles Planning Department, has created growing awareness and interest at City Hall for the LUMIS project. We are deeply indebted to Mr. Lee Johnston and Terry de Berry of the San Diego Comprehensive Planning Organization for supplying us with the basic PIOS software. Finally, to the many planners, environmentalists, conservationists, politicians, and social activists we have passed in Planning Commission hearings, our thanks for reminding us that land use analysis is a study of people and why they come and go.

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TABLE 1. RESULTS OF DELPHI SANTA MONICA MOUNTAINS LAND USE NEEDS

Evaluation	Land Use/Resource							
No. of Persons Voting	Residential	Manufacturing	Transportation, Utilities	Trade	Services	Cultural, Recreation	Agriculture, Mining	Underdeveloped
Very Important	8	3	9	6	4	9	7	9
Important	3	8	2	4	6	2	3	1
Not Important	0	0	0	1	1	0	1	1
Total No. of Persons Voting	11	11	11	11	11	11	11	11

TABLE 1. RESULTS OF DELPHI SANTA MONICA MOUNTAINS LAND USE NEEDS (contd)

Evaluation	Land Use/Resource									
No. of Persons Voting	Public Facilities	Climate	Geology	Physiography	Hydrology	Pedology	Vegetation	Wild Life	Aesthetics	Special Districts
Very Important	8	8	8	7	8	8	7	5	7	8
Important	2	1	1	2	1	1	2	3	1	1
Not Important	1	1	1	1	1	1	1	2	2	1
Total No. of Persons Voting	11	10	10	10	10	10	10	10	10	10

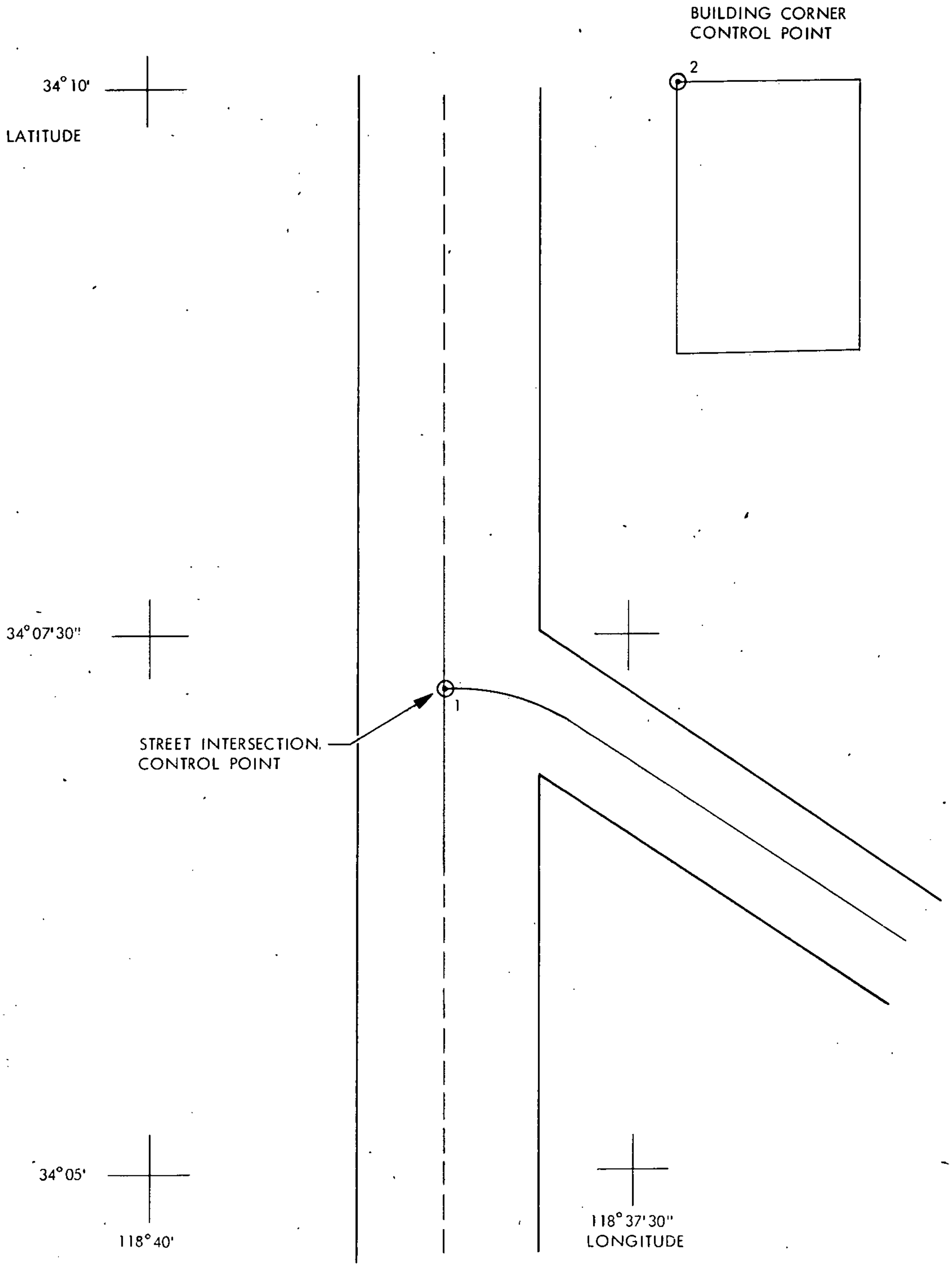

Figure 1. Geographic Position Determination of Control Points

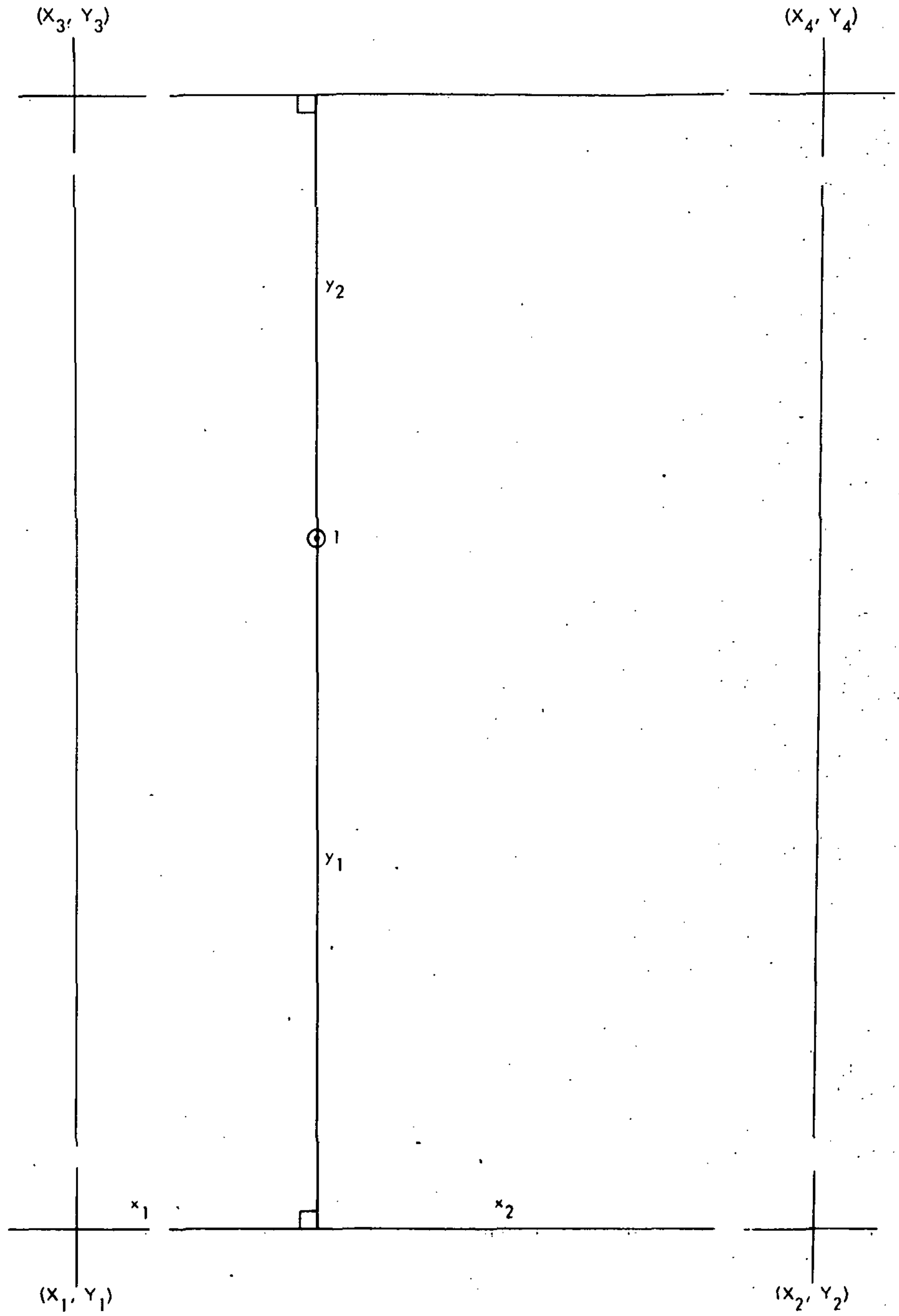

Figure 2. Geographic Position Determination of Control Point 1

LUMIS PROJECT TEST SITE

WOODLAND HILLS

LAND USE MAP 17001

REFERENCE POINT 1: INTERSECTION OF MULHOLLAND DRIVE AND NORTHBOUND FEEDER OFF VENTURA FREEWAY

ELEVATION: 900 FEET

	GRID TICS			
	SW 1	SE 2	NW 3	NE 4
LATITUDE	34° 07' 30"	34° 07' 30"	34° 10'	34° 10'
LONGITUDE	118° 40'	118° 37' 30"	118° 40'	118° 37' 30"
X	4085806.8	4098417.5	4085856.4	4098460.8
Y	4158058.9	4158020.2	4173221.8	4173183.2

$x_1 = 8.91$	$X_3 - X_1 = 49$	$Y_1 - Y_2 = 39$
$x_2 = 3.68$	$X_4 - X_2 = 43$	$Y_3 - Y_4 = 39$
$y_1 = 13.22$	$y_2/\Sigma y = 0.8732$	$x_1/\Sigma x = 0.7077$
$y_2 = 1.92$	$y_2/\Sigma y = 0.1268$	$x_2/\Sigma x = 0.2923$

	X	Y
	4094760	4171251
	4094760	4171251
	4094776	4171274
	4094776	4171274
AVERAGE:	4094768	4171262

Figure 3. SPC Calculation for Land Use Control Point

Figure 4. 1970 Woodland Hills Land Use Map

Figure 5. 1972 Woodland Hills Land Use Map

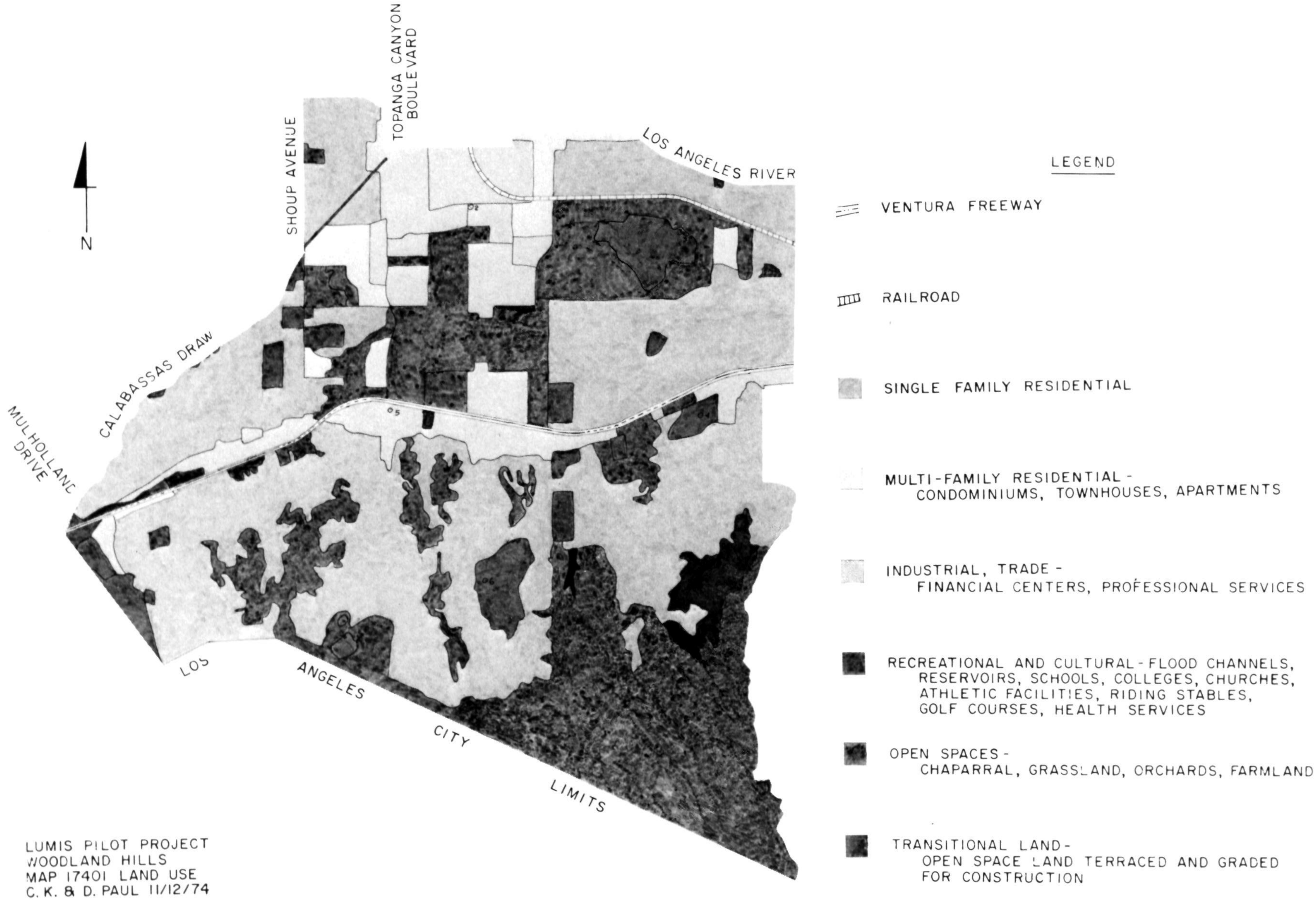

Figure 6. 1974 Woodland Hills Land Use Map

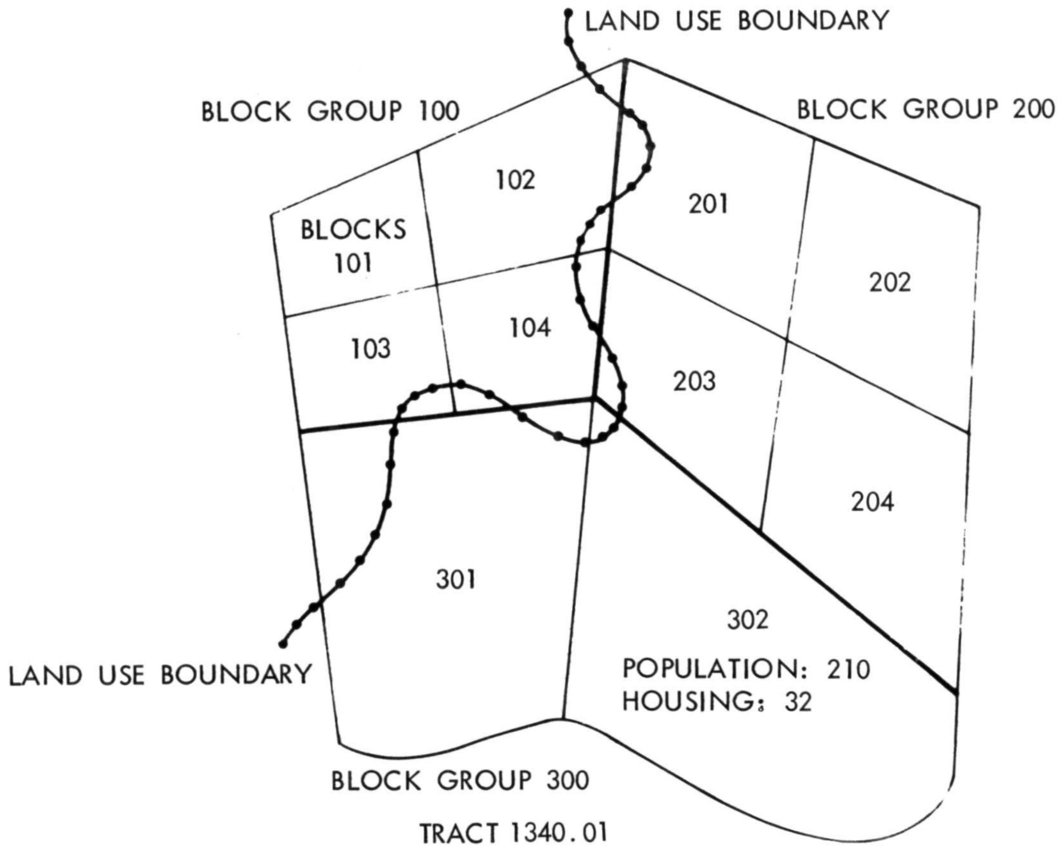

Figure 7. Ordinal-Nominal Systems Integration

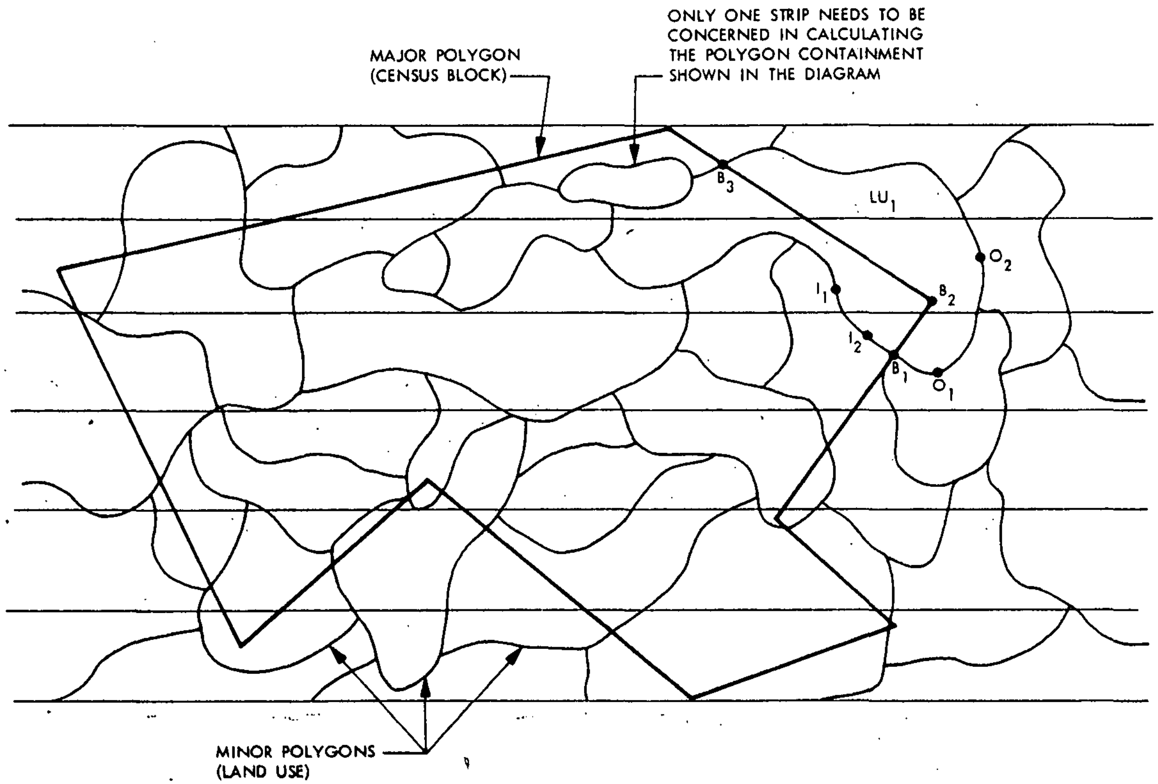

Figure 8. PIOS Stripping Method

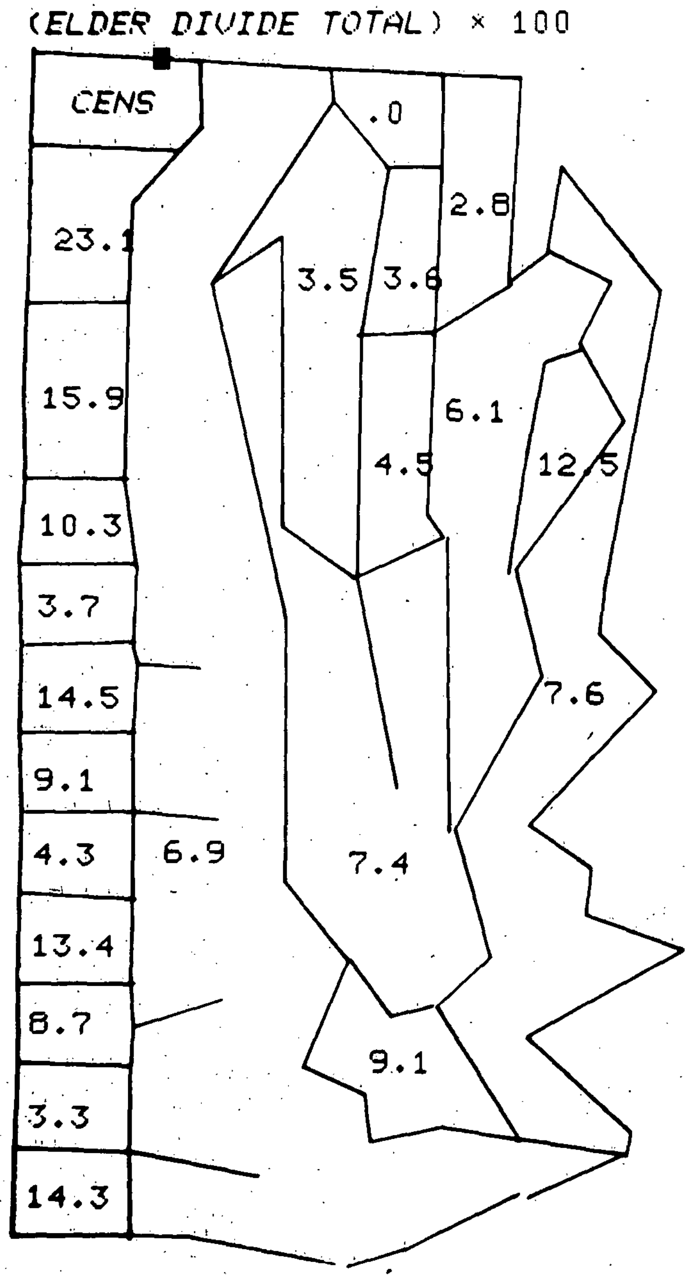

Figure 9. Percent Population Over Sixty-two in Age
Block Group 300, Census Tract 1375.02
Los Angeles - Long Beach SMSA

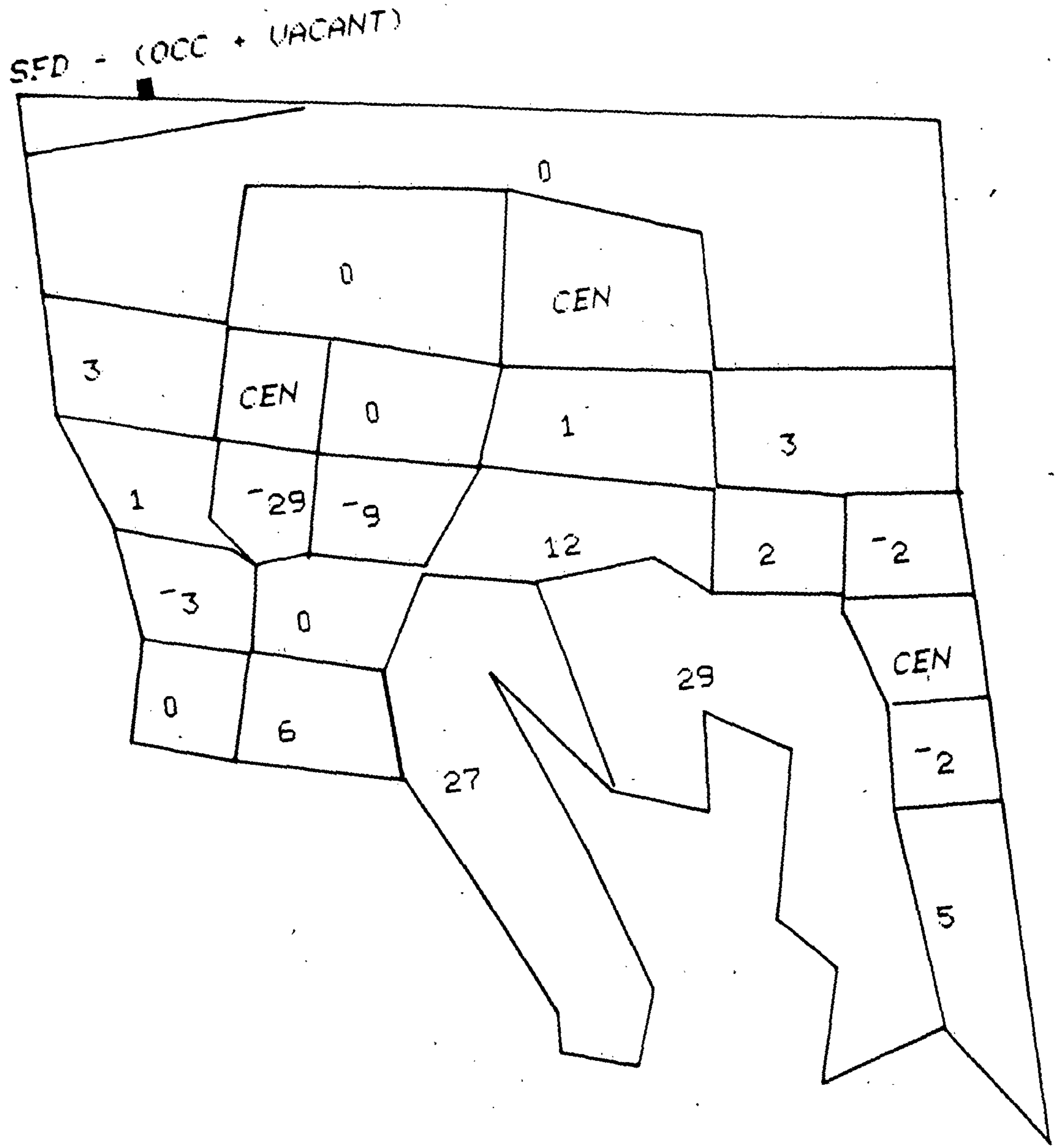

Figure 10. 1970-1974 Change in Single Family Dwelling Units Block Group 100, Census Tract 1375.02 Los Angeles - Long Beach SMSA

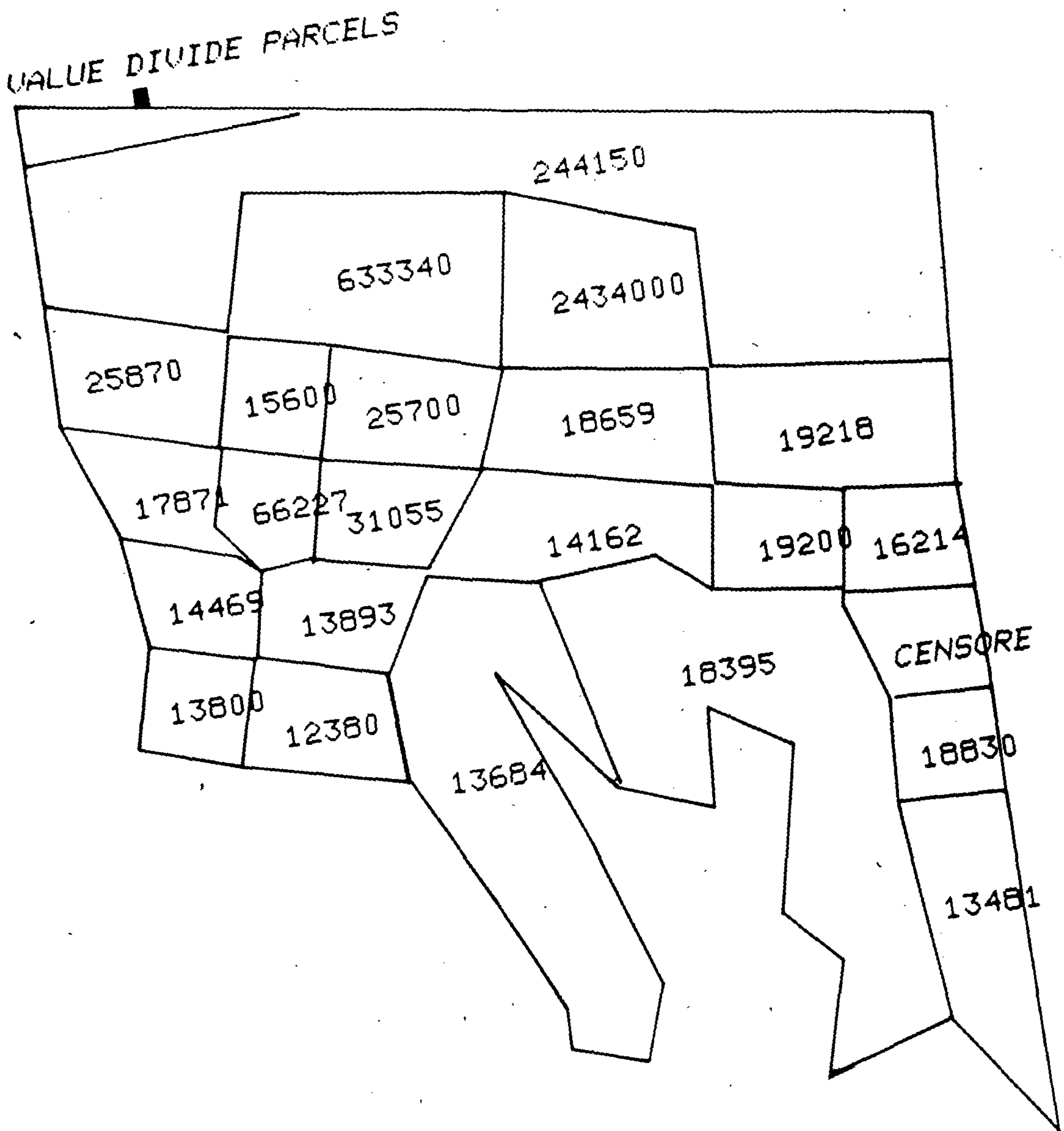

Figure 11. Average 1974 Improvement Value Block Group 100, Census Tract 1375.02 Los Angeles - Long Beach SMSA