SAND99-0535C

GIS-Based Population Model Applied to Nevada Transportation Routes

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ABSTRACT

Recently, a model based on geographic information system (GIS) processing of U.S. Census Block data has made high-resolution population analysis for transportation risk analysis technically and economically feasible. Population density bordering each kilometer of a route may be tabulated with specific route sections falling into each of three categories (Rural, Suburban or Urban) identified for separate risk analysis. In addition to the improvement in resolution of Urban areas along a route, the model provides a statistically-based correction to population densities in Rural and Suburban areas where Census Block dimensions may greatly exceed the 800-meter scale of interest.

A semi-automated application of the GIS model to a subset of routes in Nevada (related to the Yucca Mountain project) are presented, and the results compared to previous models including a model based on published Census and other data. These comparisons demonstrate that meaningful improvement in accuracy and specificity of transportation risk analyses is dependent on correspondingly accurate and geographically-specific population density data.

INTRODUCTION

The calculation of incident-free transportation risks for radioactive materials (RAM) shipments with the RADTRAN code [1] requires input data describing the population density within some distance (usually ½ mile or 800m) of the route centerline. In early releases of RADTRAN, national average values for three zones (Rural = 6/km^2, Suburban = 719/km^2, Urban = 3861/km^2) were employed in calculating aggregate risks for entire routes. In response to demands for "route-specific" risk analyses, geographically correlated data were made available with the addition to the HIGHWAY [2] and INTERLINE [3] routing codes, produced by Oak Ridge National Laboratory, of a population model based on U.S. Census Tracts. These codes supplied distance-weighted average population densities in three ranges (Rural: 0 – 66, Suburban: 67 – 1670, Urban: >1670/km^2) for an entire route or portions of it delimited by highway intersections.

As public concern focused more intensely on the transportation aspects of actions involving RAM, the need for increasingly localized analyses of potential doses to the public, particularly in highly populated areas, demanded improved population data. The advent of GIS systems has made possible detailed analysis of large amounts of geographically-correlated data such as U.S. Census Block-level population data. In order to capitalize on the inherent capabilities of commercial GIS programs for transportation risk analysis needs, Sandia National Laboratories

(SNL) developed software tools (scripts) to supplement the standard GIS capabilities. These tools automate tabulation of population data along entire routes (hundreds to thousands of kilometers long, kilometer-by-kilometer if desired), for incident-free dose estimation with RADTRAN. Preliminary studies revealed that even U.S. Census Blocks in Rural and Suburban areas can be large compared to the 800-meter scale normally used for RADTRAN input. An earlier study, which compared population density within 800 meters of the route centerline (based on residence locations) to average block density, yielded a distribution of correction factors. This distribution can be randomly sampled and the sampled ratios multiplied by the average population densities tabulated through use of the automated GIS tools [4]. The application of this distribution and these tools to sample routes in Nevada are presented in the following to illustrate their utility.

ROUTE DESCRIPTIONS AND DATA

Potential shipment of spent nuclear fuel (SNF) to the proposed nuclear waste repository at Yucca Mountain, NV, has drawn intense scrutiny for over 10 years. Initial dose estimates for potential routes to this site were based on the original RADTRAN aggregate model employing nominal Rural, Suburban and Urban population densities as described earlier [5]. Subsequently, an effort to derive localized estimates of the population densities near these routes [6] was based on:

1. 1980 U.S. Census data – Population of places larger than 1000 persons, areas of places greater than 2500 persons, population totals by county and urbanized areas.
2. ZIP Code Summaries – Population of places less than 1000 persons.
3. Map Atlas – Areas of places less than 2500 persons.

The truck routes considered in this latter study, which was performed by SAIC, were:

1. Interstate 15 Southbound, 270 km
2. Interstate 15 Northbound, 208 km
3. US 93 Northbound, 188 km
4. Interstate 80 Eastbound
5. US 95 Southbound
6. State Route 373 Northbound

(These routes begin at the state line and end at the proposed Yucca Mountain site.)

In the present comparison, the three routes that pass through Las Vegas (Routes 1 – 3) were used because they traverse areas with appreciable suburban and urban representation. These routes are depicted in Figure 1; Route 3 was modified slightly to use a portion of I15 rather than US95 (between US93 and Las Vegas) in accordance with HIGHWAY routing for SNF shipments, which is based on DOT guidelines. The population data from the sources discussed above are given in Table I; the GIS-based values also are given, with and without correction for large Census Blocks.

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Table I – Population Data for Three Routes, Five Methods

Route	Rural		Suburban		Urban	
	Route Fraction	Pop. Den. Pers/km^2	Route Fraction	Pop. Den. Pers/km^2	Route Fraction	Pop. Den. Pers/km^2
I15 Northbound						
Aggregate	0.82	6	0.17	719	0.01	3861
SAIC Study†	0.78	3.6	0.02	353	0.20	1200
HIGHWAY	0.90	1.8	0.09	450	0.01	2415
GIS Uncorr'd.	0.85	2.1	0.14	580	0.01	1967
GIS Corrected	0.84	3.2	0.11	557	0.05	3402
I15 Southbound						
Aggregate	0.82	6	0.17	719	0.017	3861
SAIC Study†	0.84	3.7	0.02	317	0.14	1200
HIGHWAY	0.91	1.6	0.07	700	0.02	2310
GIS Uncorr'd.	0.91	1.6	0.08	693	0.01	2486
GIS Corrected	0.89	2.4	0.08	579	0.03	3677
US93 Northbound						
Aggregate	0.82	6	0.17	719	0.01	3861
SAIC Study†	0.69	3.6	0.08	134	0.23	1200
HIGHWAY	0.85	2.8	0.13	414	0.02	2172
GIS Uncorr'd.	0.83	3.7	0.16	520	0.01	1967
GIS Corrected	0.81	4.5	0.15	439	0.04	3402

† Distance-weighted average population densities were computed from the SAIC tables [6].

DISCUSSION

Examination of Table I clearly indicates that the Rural fractions and population densities are the least affected by the method of data estimation or collection. The Aggregate method results in the largest population density estimates for all three zones and for all three routes; it is, therefore, the most conservative. Also, the SAIC study is the most divergent; it clearly underestimates the Rural fraction and overestimates the Suburban and Urban fractions for all three routes.

All of the Urban fractions are in good agreement between the three routes but the values produced by the SAIC study are substantially larger. However, the SAIC population densities are the lowest, partially compensating for the overestimate of Urban distance. The overestimate of Urban route fractions appears to have been largely at the expense of the Suburban route fraction when compared to the other methods.

The relative contributions to total population doses are depicted in Table II, which lists the products of route fractions and population densities from Table I. As already noted, the Urban contribution was overestimated for all three routes by the SAIC study compared to all of the other methods, including the GIS Corrected values. These results also indicate that the Suburban contributions were overestimated by the Aggregate method. It should be noted, however, that an evaluation (part of a study in progress) of several hundred routes distributed over a large fraction

Table II – Relative Dose Contributions for Three Routes, Five Methods (Route Fraction x Population Density)

Route	Rural Route Fraction	Suburban Route Fraction	Urban Route Fraction
I15 Northbound			
Aggregate	4.92	122	38.6
SAIC Study	2.81	7.06	240
HIGHWAY	1.62	40.5	24.2
GIS Uncorr'd.	1.78	81.2	19.7
GIS Corrected	2.69	61.3	170
I15 Southbound			
Aggregate	4.92	122	38.6
SAIC Study	3.11	6.34	168
HIGHWAY	1.46	49.0	46.2
GIS Uncorr'd.	1.46	55.4	24.9
GIS Corrected	2.14	46.3	110
US93 Northbound			
Aggregate	4.92	122	38.6
SAIC Study	2.48	10.7	276
HIGHWAY	2.38	53.8	43.4
GIS Uncorr'd.	3.07	83.2	19.7
GIS Corrected	3.64	65.8	136

of the U.S. agrees, to within uncertainties, with the Suburban fraction of 0.17. Finally, the GIS Corrected results suggest that population densities obtained from the HIGHWAY code are low by as much as a factor of two; this is not surprising since the HIGHWAY population data are based on U.S. Census Tracts which provide a lower level of resolution than the Block data.

An illustration of the resolution of population concentrations achievable with GIS-based population modeling and the effect of the statistical correction for blocks that are large compared to 800m is presented in Figures 2a and 2b. The two figures present a portion of the I15 Southbound route within the Las Vegas metropolitan area; the segments overlaid on the highway and Census block maps depict rectangles (nominal 1 km by 1.6 km) that select the Census blocks used to calculate the population density for each kilometer. The individual route segments (1 km along the route) are shaded according to whether the population density associated with that segment is Rural (lightest), Suburban (gray) or Urban (black). In Figure 2a the values are not corrected for large block sizes and in Figure 2b the random correction factors have been applied to route segments for which the total area of blocks selected is greater than 3.2 km^2 (twice the area of the intersecting rectangle). As expected, there are more Urban route segments in Figure 2b.

CONCLUSIONS

It has long been recognized that national average data are likely to be inaccurate when applied to isolated portions of a route [1]; that recognition is confirmed in this study. This study also highlights the inaccuracy associated with using data describing metropolitan areas in their entirety, as was done in the SAIC study, to describe a limited portion of that metropolitan area along an isolated segment of a route. Computing systems and geographic data bases, which have become widely available in recent years, make detailed population analyses possible and economically feasible, and free analysts from reliance on these former methods. High population-density areas typically cover a small fraction of a route. When risks associated with such areas are to be estimated and contrasted with risks for an entire route of several hundred kilometers, it is essential that the data on which such calculations and comparisons are based be of commensurate (highest) quality. This update of studies that preceded the availability of GIS systems and databases demonstrates the improvement now obtainable in the accuracy of an indispensable input to transportation risk analyses.

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* Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract DE- AC04-94AL85000.

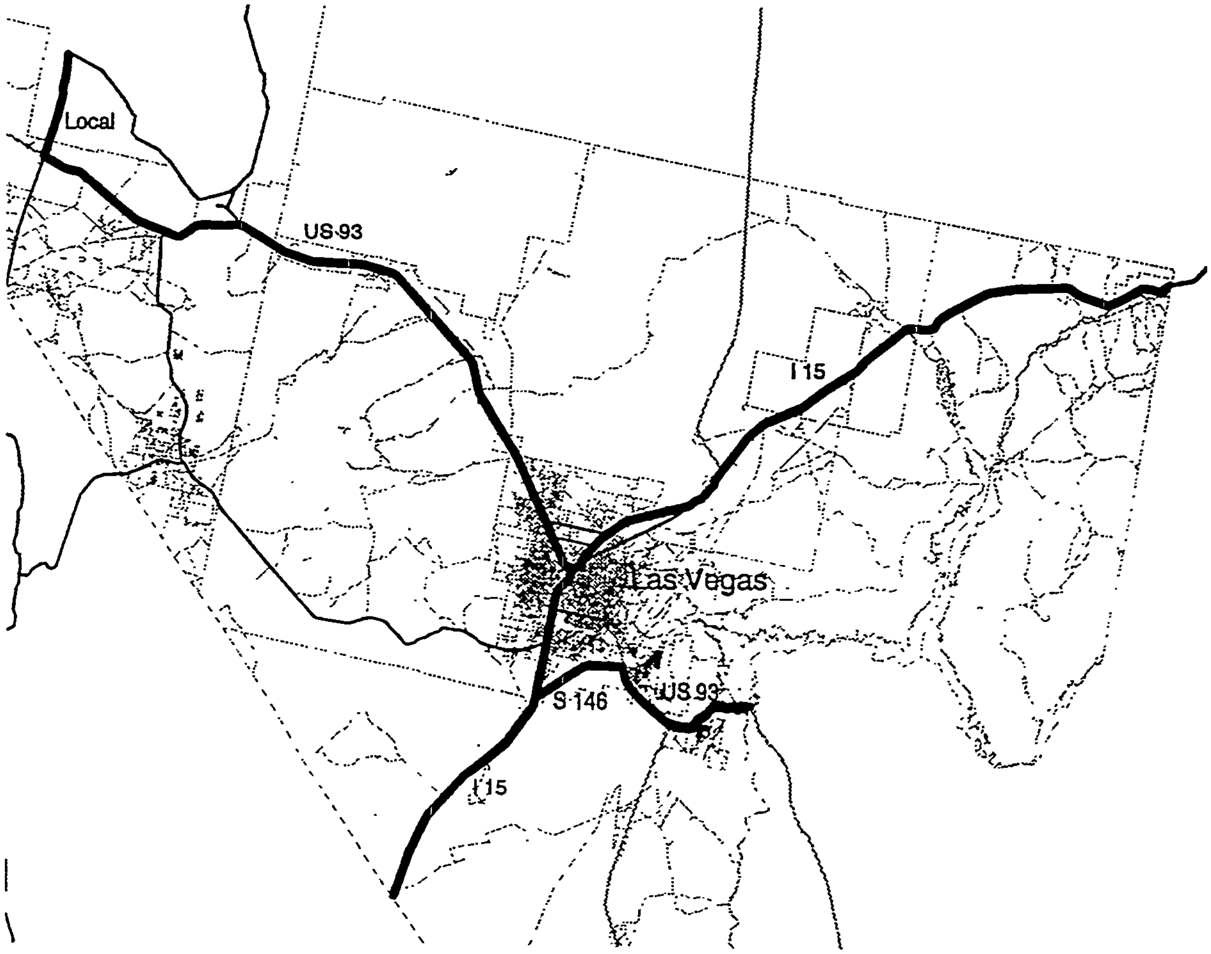

Figure 1 – Map of Three Routes Analyzed

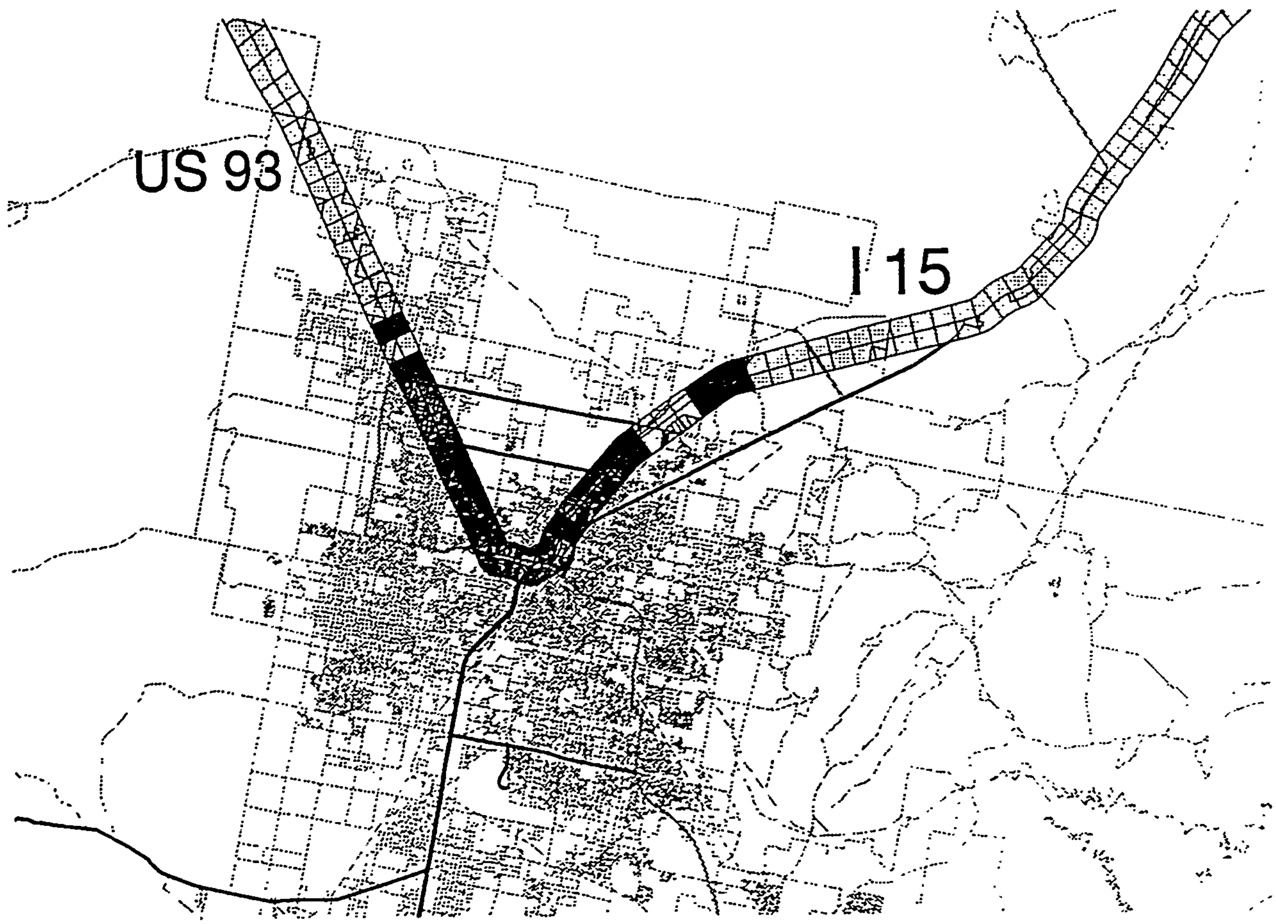

Figure 2a – Map of Population-Density Zones on Route through Las Vegas (Uncorrected)

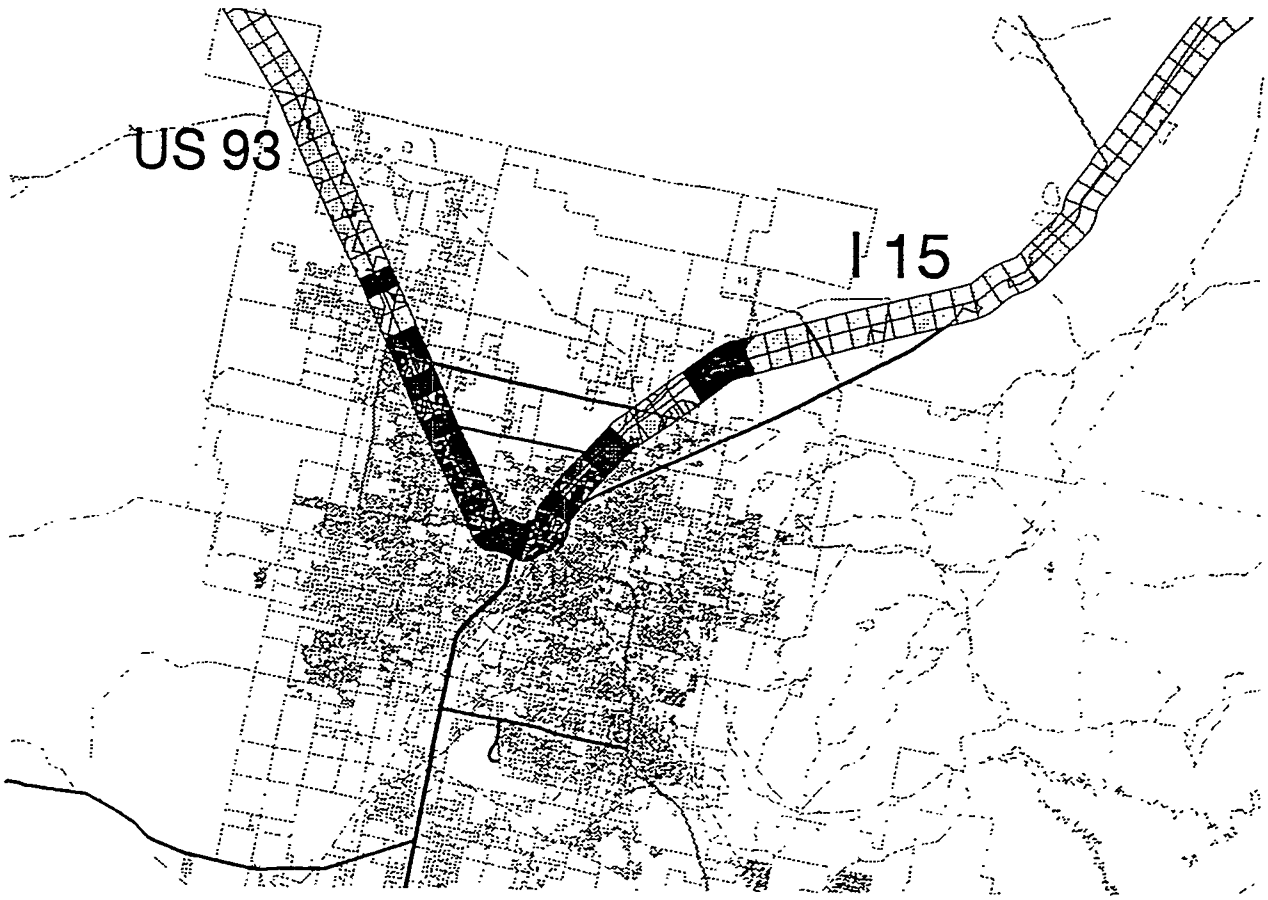

Figure 2b – Map of Population-Density Zones on Route through Las Vegas (Corrected)