Quantitative Methods

for

Environmental Justice Assessment

of

Transportation

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Environmental Justice for Transportation

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Abstract
Application of Executive Order 12898 to risk assessment of highway or rail transport of hazardous materials has proven difficult; in general, the location and conditions affecting the propagation of a plume of hazardous material released in a potential accident are unknown. Therefore, analyses have only been possible in geographically broad or approximate manner. The advent of geographic information systems and development of software enhancements at Sandia National Laboratories have made kilometer-by-kilometer analysis of populations tallied by U.S. Census blocks along entire routes practicable. Tabulations of total, or racially/ethnically distinct populations close to a route, its alternatives, or the broader surrounding area, can then be compared and differences evaluated statistically. This article presents methods of comparing populations and their racial/ethnic compositions using simple tabulations, histograms and Chi Squared tests [2] for statistical significance of differences found. Two examples of these methods are presented: comparison of two routes and comparison of a route with its surroundings.

Key Words: Environmental Justice, Hazardous Material, Transportation, Relative Risks, Chi Square

Introduction

Executive Order 12898 requires that:

> "To the greatest extent practicable and permitted by law, and consistent with the principles set forth in the report on the National Performance Review, each Federal agency shall make achieving environmental justice part of its mission by identifying and addressing, as appropriate, disproportionately high and adverse human health or environmental effects of its programs, policies, and activities on minority populations and lowincome populations in the United States and its territories and possessions, the District of Columbia, the Commonwealth of Puerto Rico, and the Commonwealth of the Mariana Islands."

For highway or rail transportation of hazardous materials, there is a distinction relative to issues connected with locating facilities at fixed sites: the highways or railways are in place and cannot be relocated. Therefore, all alternatives (except the no-action alternative) are between existing routes (predominantly on interstate highways or mainline railways), and total avoidance of impacts on minorities or low-income population is generally impossible. Estimation of the potential radiological risks associated with highway transport of radioactive materials (RAM) with the RADTRAN computer code [1] requires input data describing the densities of populations within some distance (usually 0.8 km) of all portions of a candidate route ("proximate" populations). Until recently, data distinguishing minority and non-minority populations near hundreds (or even thousands) of kilometers of potential routes were not available with adequate spatial resolution within acceptable cost.

With the advent of commercial geographic information systems (GISs) and databases describing highways, U.S. Census blocks and other information that is geographically distributed, it became feasible to determine and tabulate population characteristics along transportation routes with 1-kilometer resolution and to tabulate any population category included in the block data. A means of gathering the necessary population data along potential transportation routes, based on a commercial GIS and developed at Sandia National Laboratories (SNL), was used in this study. It automatically compiles data on all block-population categories for routes hundreds of kilometers in length (on a kilometer-by-kilometer basis, if desired) in a few hours. A Census block is included in the collection of population data along a route if it lies wholly or partially within a predefined distance from the centerline of the route. In the present examples, the distance is 0.8 km (0.5 mile). This process defines a 'bandwidth' around the route(s) to be analyzed. Compilations of such data for two or more alternative routes may then be compared to each other or to the regions surrounding the routes.

The examples given in this paper use 1990 Census block population data. For many actual applications, the 1990 census data would be inadequate without an update or other augmentation. The examples given here are intended to be illustrative only. For studies of smaller scope, such as the first illustrative example below, local databases that are compatible with a particular GIS in use would be preferred if more current and if available. Such current and detailed data are not uniformly available for all locations across the U.S. in GIS-compatible formats. However, it should be noted that the suitability of a database is primarily dependent on the time-scale of changes (in route locations or population distributions to be compared) relative to time elapsed since compilation of the database.

Statistical Evaluation

In the absence of regulatory guidelines for assessing environmental justice issues related to transportation, we have developed a quantitative method based on the Chi Squared (χ^2) test for goodness of fit [2] of two distributions and on the new GIS-enabled capability to generate distributions characterizing population data related to transportation routes.

Population data compiled for any route and its alternates may be used to construct histograms of numbers of census blocks versus values of a population characteristic of concern – for example, ratios of minority to total population for each route. Since all U.S. Census block-data categories of population are available in the GIS database, each category can be investigated separately, if desired. The histograms can be integrated (summed) and normalized to create cumulative distributions of number of census blocks versus values of the chosen population characteristic. Similar cumulative distributions can be constructed for surrounding counties or other appropriate environs for comparison with the immediate vicinity of the route. The χ^2 test of distributions characterizing population near a route and an alternate, or region(s) through which the route passes, affords a more definitive comparison than averages and standard deviations of the population characteristics being compared (e.g., a T test). This enhanced comparison is analogous to the difference in comparing the spectra of two light sources instead of their intensities; unusual features of the population along a route, compared to another population, are more likely to be discovered by a comparison of distributions than by a comparison of averages and standard deviations.

Sample Applications

Two sample analyses are presented to illustrate the comparisons possible with the methods described above. In the first, two alternative routes through a congested area ("Silicon Valley") are compared. The second is illustrative of a route without immediate alternatives. In this case, the proximate population (i.e., the population within a specified bandwidth of the route) is compared to the population in the counties traversed by the route.

Comparison of Two Routes

Two possible routes through a mixed industrial and residential area south of San Francisco, CA, in Santa Clara County were characterized and compared. The two routes (Interstate 280 and US101) are shown in Figure 1 together with the highlighted U.S. Census blocks included in the analysis (proximate populations). The racial/ethnic characteristics, as they are tabulated in the census block data, of these populations are summarized in Table I (Note that the "white" population *fraction* is higher for I280). For each route, the ratio of minority (total minus white) to total population was computed for all census blocks lying wholly or partially within a 1.6-km (1 mile) bandwidth for each 1-kilometer segment of the route. Figures 2 and 3 present a histogram overlaid with a cumulative distribution of these ratios for each of the two routes, and Figure 4 offers a direct comparison of the two cumulative distributions.

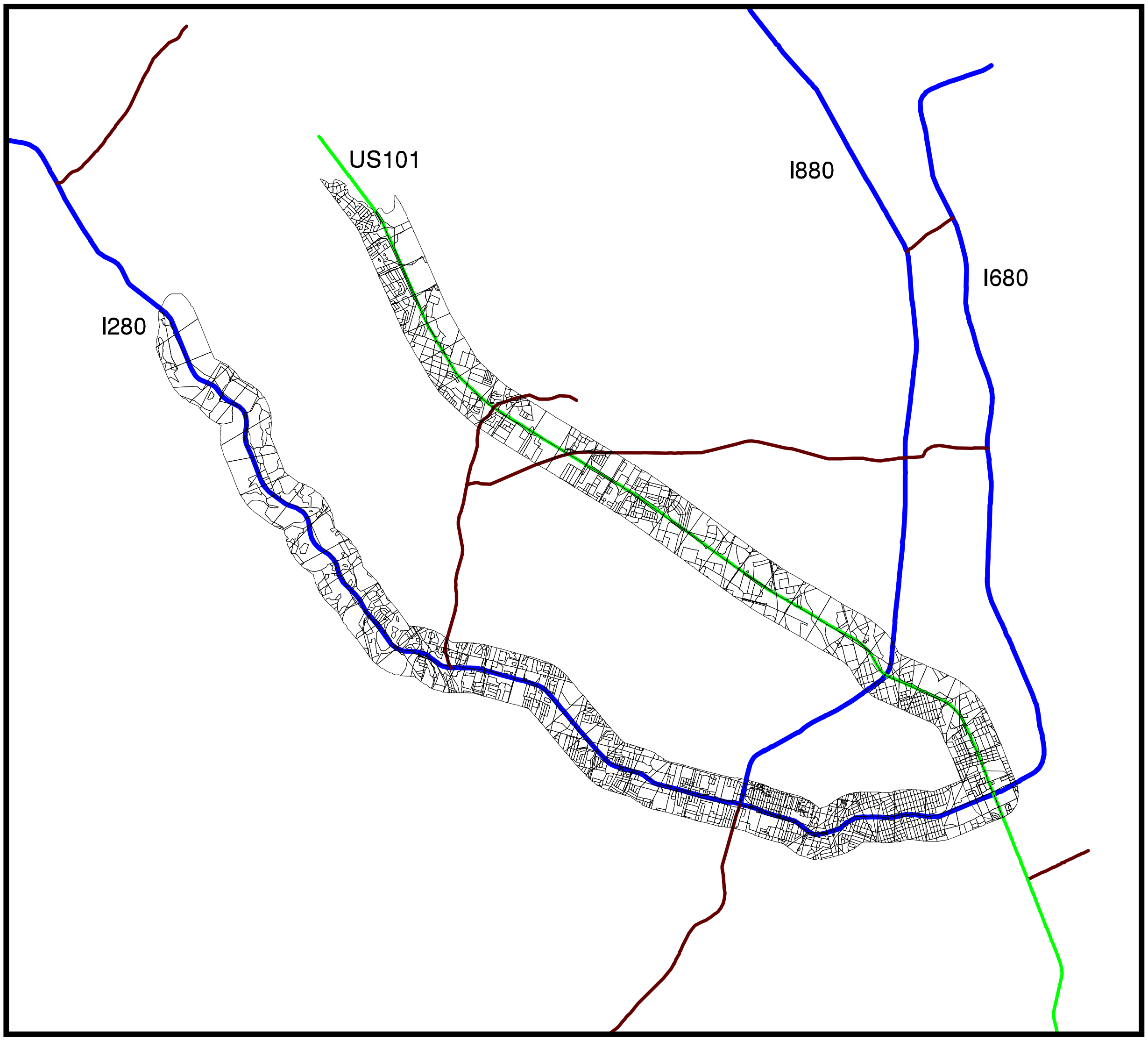

Figure 1 – Map of Analyzed Portions of I280 and US101 in Santa Clara County, CA

Table I – Comparison of US101 and I280 Proximate Populations

	TOTALPOP	WHITE	BLACK	AMERIND	ASIAN	OTHER	HISPANIC
I280	195464	130843	7011	1162	30937	25511	50789
Fraction of Total	1.00	0.67	0.04	0.01	0.16	0.13	0.26
US101	131252	77251	5852	890	25390	21869	42947
Fraction of Total	1.00	0.59	0.04	0.01	0.19	0.17	0.33

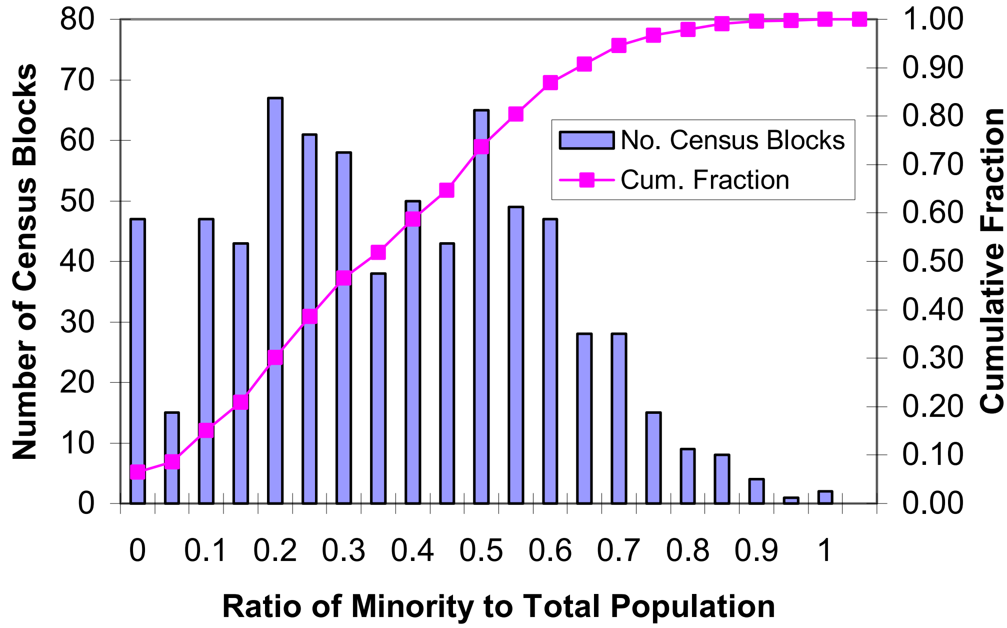

Figure 2 – Histogram and Cumulative Distribution of Minority-to-Total Ratios for the US101 Proximate Population

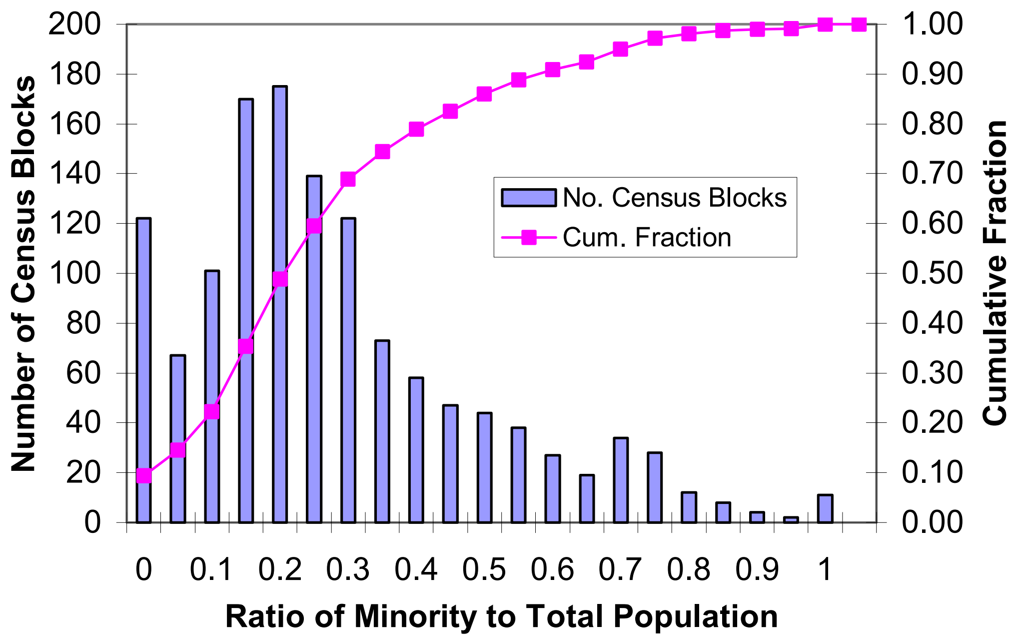

Figure 3 – Histogram and Cumulative Distribution of Minority-to-Total Ratios for the I280 Proximate Population

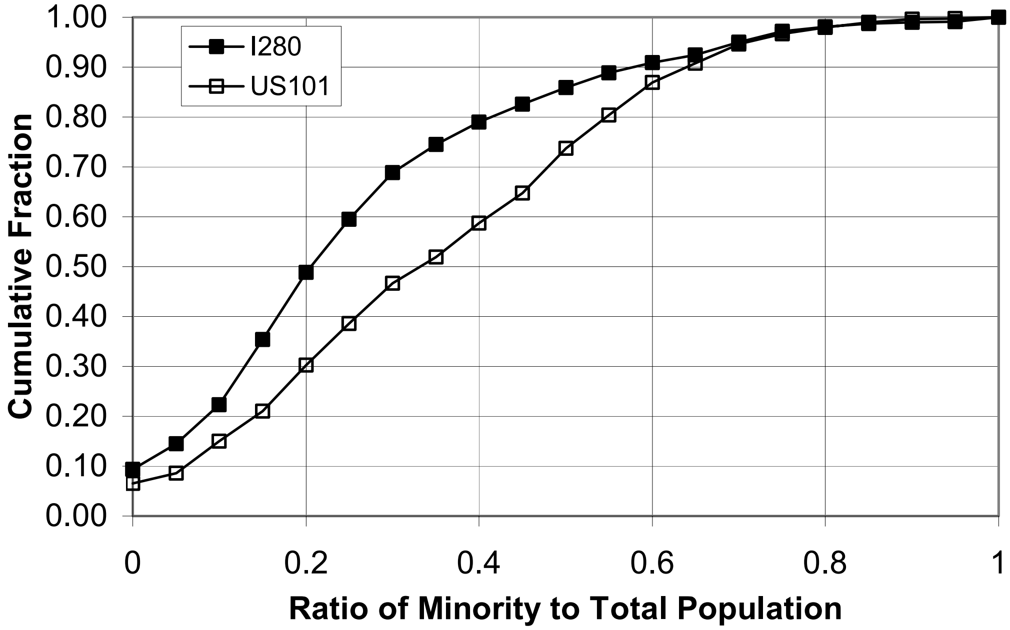

Figure 4 – Comparison of Cumulative Distributions for US101 and I280 Populations

The histograms graphically display the variations in proportion of minorities for each route. The cumulative distributions because of their integral nature, do not depict the differences as clearly but yield a less cluttered side-by-side comparison.

The statistical significance of the apparent differences in minority proportions of the two populations along these two routes may be determined by means of a χ^2 evaluation of the goodness of fit between the two cumulative distributions in Figure 4. Calculation of χ^2 for these distributions is summarized in Table II, which includes the intervals of ratio values, numbers of census blocks, and χ^2 values. The numbers of census blocks for I280 were scaled to have the same total as US101 in order to facilitate evaluation of shapes apart from differences in magnitude).

For 18 degrees of freedom (*df*), the value of χ^2 for a significance level of 5% obtained from Table A.VII.2c in Meyer [2] is 28.9. Since the calculated value of 293.3 is much larger, the two distributions clearly describe populations of distinct minority proportion. The differences in distribution of racial/ethnic group in Table I were also found to be statistically significant by a χ^2 test: computed value was 5382 and the tabulated value for 5 *df* and a significance level of 5% was 11.1.

Table II – Chi-Squared Calculation for Distributions in Figure 4

Intervals	US101	I280	Scaled I280	Chi Sq.
= 0	47	122	68	6.48
>0 - .05	15	67	37	13.36
>.05 - .1	47	101	56	1.53
>.1 - .15	43	170	95	28.25
>.15 - .2	67	175	98	9.55
>.2 - .25	61	139	77	3.50
>.25 - .3	58	122	68	1.47
>.3 - .35	38	73	41	0.18
>.35 - .4	50	58	32	9.67
>.4 - .45	43	47	26	10.79
>.45 - .5	65	44	25	66.83
>.5 - .55	49	38	21	36.56
>.55 - .6	47	27	15	67.86
>.6 - .65	28	19	11	28.63
>.65 - .7	28	34	19	4.33
>.7 - .75	15	28	16	0.02
>.75 - .8	9	12	7	0.80
>.8 - .85	8	8	4	2.81
>.85	7	17	9	0.65
Totals	725	1301	724	293.27

Comparison of a Route and Surroundings

Part of a standard, hypothetical truck route for spent nuclear fuel (SNF) was analyzed. It consists of the entire length of I70 in the state of Missouri (over 400 km) and lies between St. Louis and Kansas City, Missouri. This route, which includes short suburban by-passes (also interstate highways) around the central city areas at each end, is shown in Figure 5. Summary information for each race/ethnic group was tabulated for each of the 3734 U.S. Census blocks that lie wholly or partially within 0.8 km of the route centerline (proximate population). These data were compared to data for the 10 counties traversed by the route. Table III presents these two sets of data for a simple, numerical comparison.

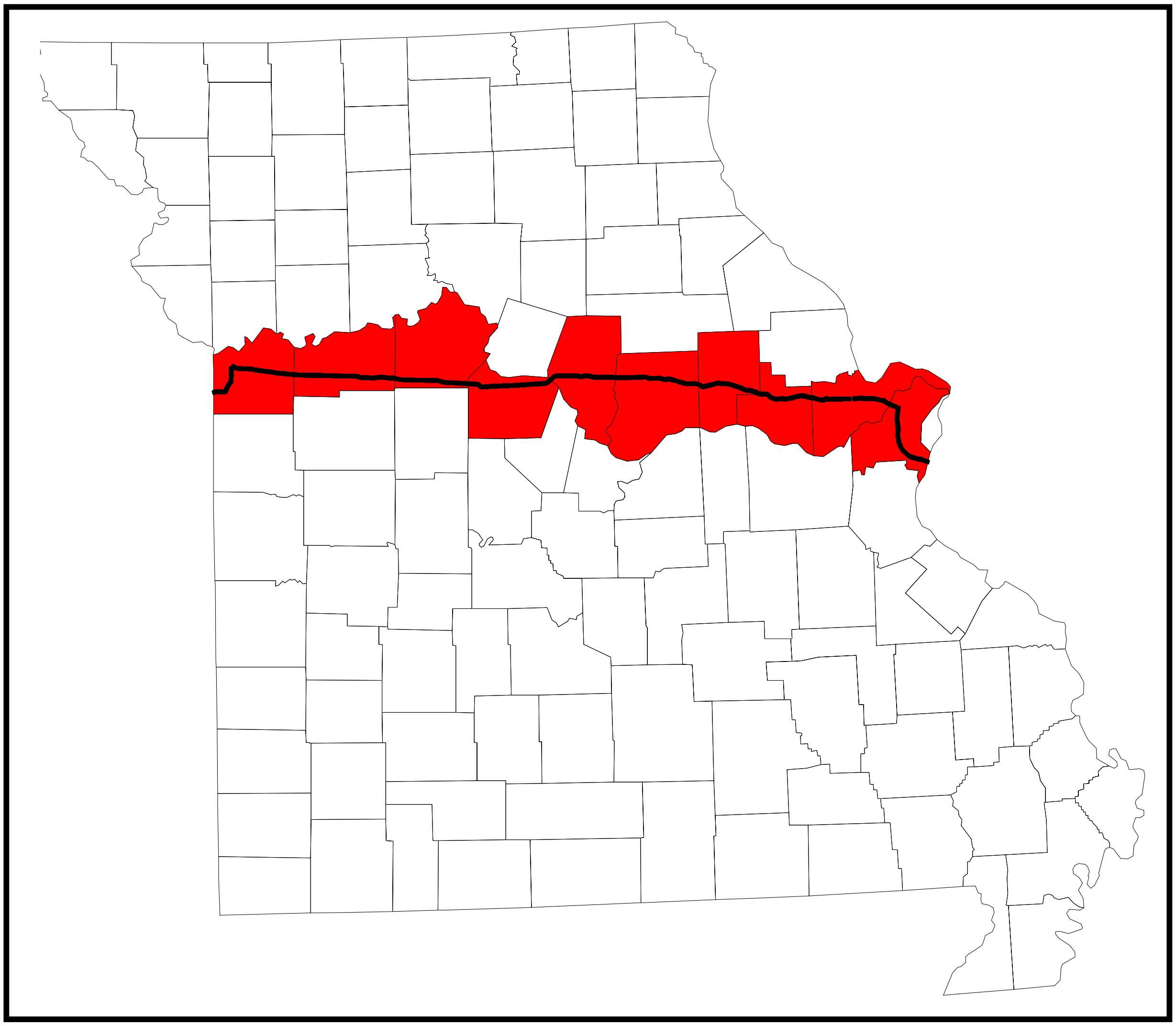

Figure 5 – Map of Test Route and Intersected Counties Across Missouri

Table III – Comparison of County and Proximate Population by Race/Ethnic Group

No. of Blocks	COUNTY	Total Pop.	White	Black	Amer. Indian	Asian	Other	Hispanic
Counties Intersected by the Route								
11696	189-St.Louis	993529	836232	139318	1477	14167	2335	9811
3654	183-St.Charles	212907	205424	4963	528	1431	561	2308
946	219-Warren	19534	18903	513	46	33	39	152
1378	139-Montgomery	11355	11015	289	12	20	19	45
1865	027-Callaway	32809	30937	1579	104	120	69	171
2531	019-Boone	112379	100055	8377	394	3129	424	1226
1003	053-Cooper	14835	13557	1147	55	47	29	96
1651	195-Saline	23523	21974	1352	45	61	91	208
2043	107-Lafayette	31107	29976	880	106	69	76	219
11696	095-Jackson	633232	478849	135649	3032	6446	9256	18890
	Total =	2085210	1746922	294067	5799	25523	12899	33126
	Fraction of Total =	1.0000	0.8378	0.1410	0.0028	0.0122	0.0062	0.0159
Summary of 3734 Blocks within 0.8 km of the Route								
	Total =	231000	213111	12866	587	3503	933	3046
	Fraction of Total =	1.0000	0.9226	0.0557	0.0025	0.0152	0.0040	0.0132
	Average Pop./Block =	61.86	57.07	3.45	0.16	0.94	0.25	0.82
	Std. Dev. of Pop./Block =	142.83	132.36	19.84	0.69	5.08	1.08	2.73
	Std. Dev. as Frac. of Total =	0.0006	0.0006	0.0015	0.0012	0.0014	0.0012	0.0009

As in the previous example, Figures 6 and 7 present histograms and cumulative distributions of the ratios of minority-to-total population calculated for all census blocks identified for each 1-kilometer segment of the entire route, and for all census blocks in the 10 Missouri counties traversed by the route. The two cumulative distributions are superimposed in Figure 8 for easy comparison; note that the county population appears to be more heavily weighted toward large minority fractions. To determine whether this difference in distributions is statistically significant, the χ^2 value was calculated. The intervals of ratio values used, the corresponding numbers of census blocks, and the χ^2 values are listed in Table IV. The numbers of census blocks for "County" were scaled to have the same total as the proximate values in order to facilitate evaluation of shapes apart from differences in magnitude. For 12 *df*, the value of χ^2 for a significance level of 5% is 21.0. Since the calculated value of 270.9 is, again, much larger, the two distributions describe distinct populations. Calculation of χ^2 for the racial/ethnic distributions in Table III yields a value of 32525 (dominated by the difference in black populations) and the tabulated value for a significance level of 5% is 11.1; clearly the distributions are distinct.

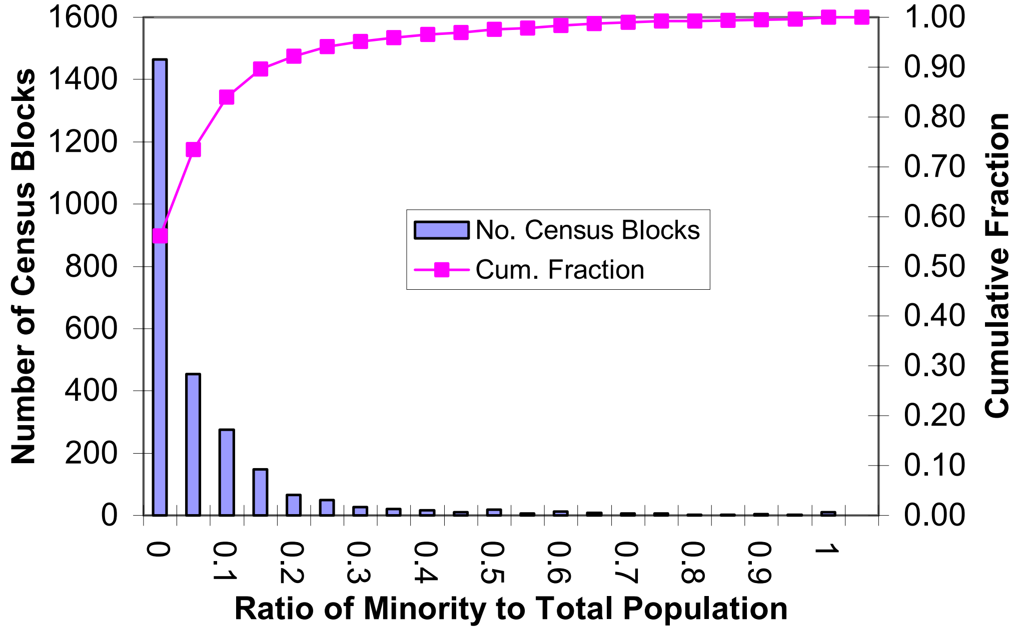

Figure 6 – Histogram and Cumulative Distribution of Minority-to-Total Ratios for the Route Proximate Population

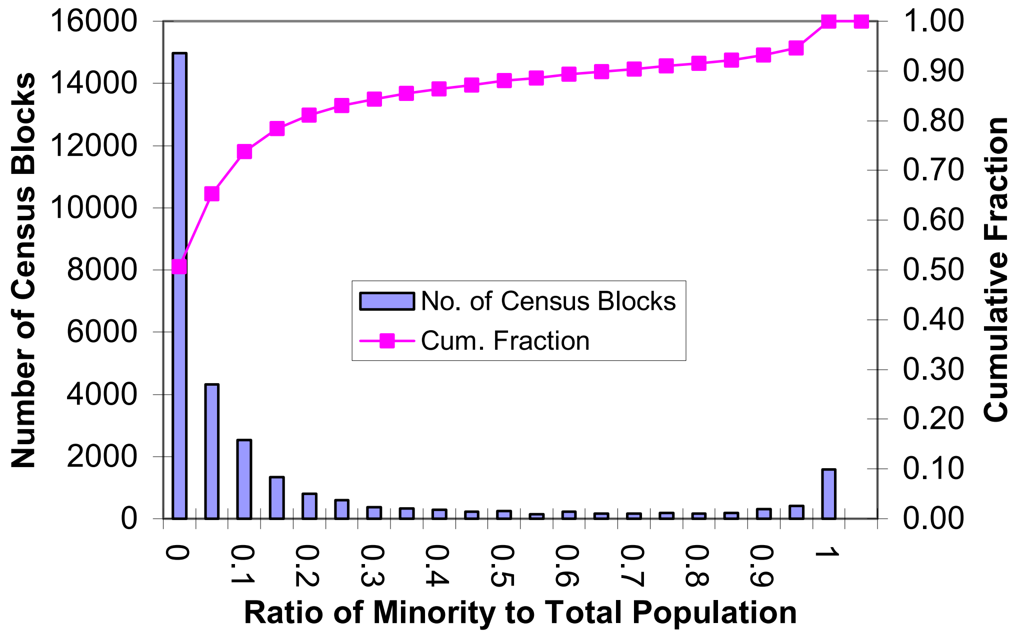

Figure 7 – Histogram and Cumulative Distribution of Minority-to-Total Ratios for the Route County Populations

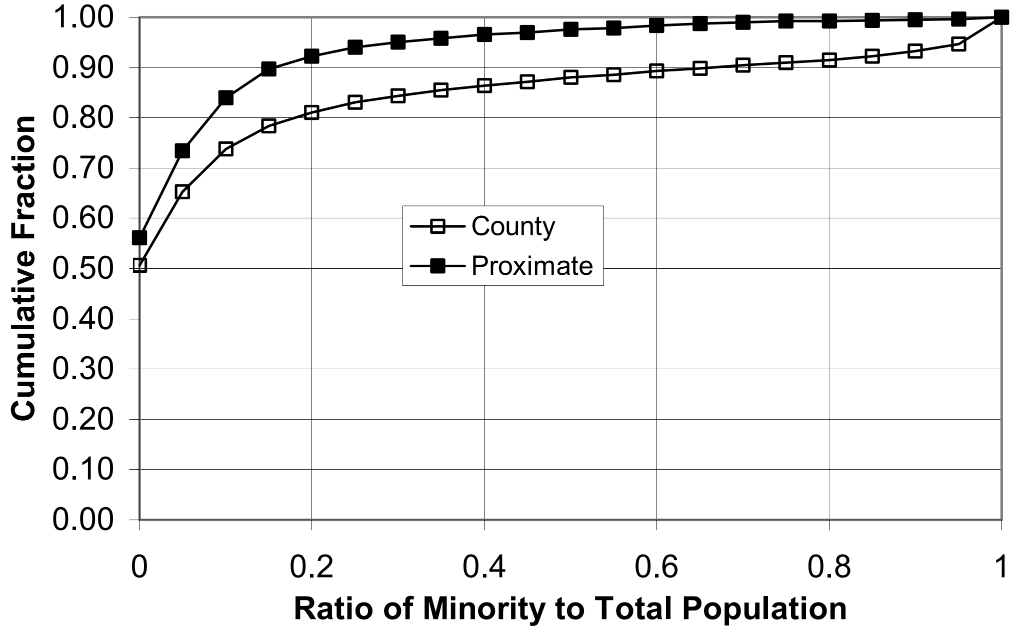

Figure 8 – Comparison of Cumulative Distributions for Route Proximate and County Populations

Table IV – Chi-Squared Calculation for Distributions in Figure 8

Intervals	Proximate	County	Scaled County	Chi Sq.
= 0	1465	14982	1322	15.47
>0.00 - 0.05	453	4329	382	13.20
>0.05 - 0.1	275	2531	223	11.95
>0.10 - 0.15	148	1344	119	7.29
>0.15 - 0.2	66	805	71	0.36
>0.20 - 0.25	49	588	52	0.16
>0.25 - 0.30	27	375	33	1.12
>0.30 - 0.35	20	334	29	3.04
>0.35 - 0.45	27	503	44	6.81
>0.45 - 0.55	25	405	36	3.23
>0.55 - 0.65	22	390	34	4.48
>0.65 - 0.80	15	500	44	19.22
>0.80	19	2504	221	184.58
Totals	2611	29590	2611	270.91

Conclusions

In the first example, Table I yields a mixed assessment of which route potentially imposes the smallest minority impact: I280 has the *smaller fraction* of minorities (1.0 – 0.67 = 0.33 versus 1.0 – 0.59 = 0.41) but a *larger number* of minorities (195464 – 130843 = 64621 persons versus 131252 – 77251 = 54001 persons). However, the concern in addressing environmental justice (EO 12898) is "disproportionately high" impacts on minorities, which suggests the fractional comparison is preferable.

Figures 2-4 graphically indicate that a relatively greater fraction of minority persons will be impacted by use of US101 than I280, that is, the numbers of census blocks with larger minority fractions are greater in Figure 2 and the cumulative distribution for US101 does not rise to 1.0 as quickly in Figure 4. However, the χ^2 test results are definitive and would remain the most reliable metric even in situations where the results were not so graphically clear-cut.

In the second example (Table III), impacts to minority groups do *not* appear to be disproportionate; this is evident from the larger "White" fraction for the proximate population than for the county population. The single group which would appear to bear disproportionate impacts is the Asian population which constitutes 1.52% of the proximate population compared to 1.22% of the county population. If it were desirable to investigate impacts to such sub-groups of the total minority population, similar data could be tabulated, using the GIS, on a county-by-county basis rather than limiting analysis to the aggregated data shown in Table II.

For this case, comparison of total numbers of persons is obviously inappropriate since the total population (or any of its racial/ethnic components) of a county is very unlikely to be less than that of a narrow strip along an interstate highway. Here, as in the previous example, however, the χ^2 test will reliably indicate whether significant differences in proportional representation of minority populations are present, even when they are not graphically evident.

While specific cases may lead to some disagreement regarding what constitutes "disproportionate" impact, we conclude that for transportation scenarios, comparison of two alternative routes (on a fractional or total numbers basis) is appropriate and fully achievable with the tools demonstrated by the first example. For situations in which an immediate alternative route is not available, the second example demonstrates that a similarly instructive analysis is possible with these same tools. Either approach offers graphical and quantitative comparisons of the differences in potential impacts on minorities from shipments of hazardous materials along existing transportation routes.

References

1. Neuhauser, K. S., and Kanipe, F. L., "RADTRAN 4 - Vol. 3: User Guide," SAND89-2370, Sandia National Laboratories, Albuquerque, NM (1992).
2. Meyer, Stuart L., Data Analysis for Scientists and Engineers, John Wiley & Sons (1975).