Using Simulation to Estimate Vehicle Emissions in Response to Urban Sprawl within Geauga County, Ohio

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Abstract. Urban sprawl often leads to rapid expansion and haphazard developments of low density residential land uses that are spatially disjoined. Populations occupying these new developments are expected to contribute to increased traffic volumes and vehicle emissions through increased home-work journeys. Computer simulation is one of few feasible approaches to model projected trends of local communities to understand how they evolve and better plan their future courses. The VERTUS model was developed as a planning tool to estimate vehicle emissions in response to urban sprawl. The model is specific towards estimating vehicle emissions at the local and highway levels during the home-work journey. The model was applied to Geauga County, Ohio to estimate how an increase in housing over a 20-year period from 2000-2020 will influence vehicle emissions generated. Results indicate that emissions are currently highest in the western part of the county where the greatest number of households is located. This geographic distribution remains when emissions are estimated for growth in housing. While additional housing translates to more vehicle emissions, this research found that differences exist among the county's individual municipalities in terms of emissions generated. In several instances, municipalities with a smaller growth in housing generate a greater amount of emissions than a municipality with a larger growth in housing. These differences result from variations in the commuting characteristics of each municipality's residents and provide insight into how household travel patterns relate to vehicle emissions.

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INTRODUCTION

Computer simulation has become an effective tool for urban planners to manage urban growth at the local community level. This is significant as the landscape in the United States has come under considerable alteration through the rapid expansion of housing developments into rural and suburban areas along city edges (Ewing, 1994; Sutton, 2003; Wolman et al., 2005). Throughout the years, this movement has grown into the phenomenon termed urban sprawl. Urban sprawl is typically characterized as an undesirable form of development. Open green space, critical nature areas and, in many cases, prime farm lands are being overrun by housing and pavement for additional roads. Many are located in areas that are the least accessible from the built-up urbanized areas. This increases geographic separation over space between the location of housing developments and work locations. The population therefore travels greater distances to work, shopping and recreation, among others, to overcome this spatial division. Longer travel distances translate to increasing vehicle emissions that negatively impact the environment. The spatial dimension of "dirty-air" primarily being an urban problem may now extend to suburban and rural areas. Growth-induced air pollution is an important and critical issue. However, the extent of the problem is relatively unknown as household travel patterns have been discussed and related to land-use patterns in urban growth literature, but have not been extended to how they affect vehicle emissions (Frank et al., 2000).

As a result, the Vehicle Emissions Related to Urban Sprawl (VERTUS) model was developed for estimating vehicle emissions in response to urban growth. The model addresses the shortcomings of urban growth models that solely focus on land use effects, Urban Growth Simulator (UGS) (Lee, 2003), WhatIf? (Klosterman, 2001), and UrbanSim (Waddell, 2002); and models that estimate emissions for a given area but not resulting from urban growth, MOBILE (US Environmental Protection Agency [EPA], 2003), Mobile Emission Assessment System for Urban and Regional Evaluation (MOBILE) (Bachman et al., 2000), and ONROAD (Yu, 1998). Given a level of urban growth, VERTUS estimates the amount of vehicle emissions generated as the population travels from new housing developments to their place of work. Emphasis is placed solely on home-work journeys as most of the population participates in this trip purpose on a daily basis. VERTUS' design was implemented within the UGS to offer users a simulation tool that quantifies the environmental impact on land use and air quality resulting from urban sprawl. This paper first provides a brief overview of the design and functionality of VERTUS and its incorporation into UGS as a planning tool for estimating vehicle emissions. Second, it demonstrates the applicability of the model and its methodological design for this purpose through a case study of residential growth in Geauga County, Ohio at the municipality (township and village) level. Results from this analysis provide insight into the relationship between urban growth, household travel patterns, and vehicle emissions.

MATERIALS AND METHODS

VERTUS' design is based on the premise that given locations of new housing, the amount of vehicle emissions generated during the population's home-work journey can be estimated. Emphasis is solely placed on home-work journeys as most of the population participates in this trip purpose on a daily basis. VERTUS is stand-alone simulation engine that can run independent of other urban growth models. For the purpose of this research, it was coupled with UGS to link together the components of urban sprawl, trip generation, and vehicle emissions to estimate emissions at the municipality level.

Urban Sprawl Model

UGS was developed as an impact assessment tool for urban sprawl within a 15-county region in northeast Ohio but can be applied nationally at several geographic levels: township, village, city, county, or community level (Lee et al., 2002). With the simulator, users enter a projected amount of residential, commercial, or industrial developments with the average lot size in acres. Users can further define locations of new developments as either along

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a road frontage or away from the road in clusters. Users also have the option to incorporate any or all growth management strategies: open space management, avoiding development on environmentally critical areas, avoiding development of farmlands, and limiting developments in a pre-set growth boundary. With user inputs defined, the simulator develops cells until the projected growth for each community is accommodated.

When simulation is complete, UGS displays a map showing locations of newly developed areas (Fig. 1). Users can also view statistics indicating how much agricultural and critical nature area is lost and the amount of nutrients loaded into the soil resulting from additional development. It should be noted that the algorithms within UGS are such that the simulated housing locations will vary with each simulation even if the housing inputs are the same for each. However, results are consistent as the simulator places new developments in areas with current or proposed water- and sewer-service. Users can also export locations of simulated housing development as a polygon shapefile, the Geographic Information System (GIS) data format readable by most GIS software packages. This capability is essentially the first step of VERTUS where users export the locations of simulated housing developments to serve as the initial starting points for home-work journeys.

Trip Generation Model

The trip generation model establishes the variables required to model home-to-work journey travel, including:

- number of workers
- number of non-commuters
- number of home-work journeys
- locations of employment centers
- percentage of workers that travel to each employment center

The US Census 2000 Transportation Planning Package (CTPP) data-set were utilized to model these components. CTPP are special tabulations from the decennial census designed for transportation planners that contains information by place of residence, place of work, and flows between home and work. It is the only Census product that summarizes data by place of work and provides information on the travel flow between home and work. Because the data are based on the decennial census, the data are reliable and accurately reflect the characteristics of the surveyed population. Additionally, CTPP data have been used in other studies (Wang, 2000; Boyce and Bar-Gera, 2003; Cho et al., 2001; Gottlieb and Lentnek, 2001). With these data, algorithms were developed that calculate home-work journey variables depending on the municipality being simulated. Estimating the number of workers for newly developed areas is a function of the number of housing units input into UGS. VERTUS multiplies the number of new housing units and the number of workers per household for that particular municipality to estimate the number workers. The model next calculates how many of these workers participate in the

Figure 1. UGS interface representing Parkman Township, Geauga County, Ohio -- Locations of new housing are circled.

home-work journey as some are non-commuters; work at home, walk or ride their bike, and carpool to work (CTPP categories). CTPP data also provide the commuting patterns of home-work journeys; where home-work journeys travel for work and what percentage travels to each work location. Last, to model home-work journey travel, locations of employment were established for each county of work at the Traffic Analysis Zone (TAZ) level. Using a methodology developed by Giuliano and Small (1991 and 1999), employment density and total employment threshold values were determined for the region of study. TAZs within each county that met the threshold values are considered employment centers. In using this methodology, a single TAZ or multiple TAZs may be identified as prospective employment centers. However, to streamline the modeling process and reduce user input, VERTUS establishes one employment center per county by calculating the geographic center where multiple exist.

Vehicle Emissions Model

In estimating vehicle emissions emitted during the home-work journey, VERTUS partitions a number of variables to better represent reality. First, estimates are provided at two geographic scales; local and highway. These represent the assumption that commuters start their journey from their home, travel through local streets, and eventually gain access to a highway for faster travel to work. Thus, local emissions are those generated during the commute from home to highway access points (HAPs) with highway emissions representing those from the start of the highway to places of work. This differentiation allows users to see emissions generated at the local and regional level across multiple counties. VERTUS has a local (Fig. 2) and highway (Fig. 3) interface to model these emissions.

Second, emission rates are calculated for two broad categories of vehicles fueled by gasoline: passenger cars (PCs) and light-duty vehicles (LDVs). LDVs consist of trucks, vans, and sport utility vehicles (SUVs). Categorizing the vehicle fleet is significant as different classifications of vehicles emit different amounts of emissions. Typically, LDVs emit more than PCs as they have less restrictive emissions, lower fuel efficiency, and bigger engines (Davis and Truett, 2000). Algorithms within the model calculate the number of PCs and LDVs according to vehicle registration, income, and number of persons per household. Research has shown that larger and higher income households are more likely to purchase LDVs than PCs (Zhao and Kockelman, 2000; Niemeier et al., 2001). Based on these findings, the model allocates a greater percentage of LDVs to municipalities with larger and higher income households.

Model output is provided for the following five vehicle emissions: hydrocarbons (HC), nitrogen oxides (NO_x), carbon monoxide (CO), particulate matter 10 (PM_{10}), and carbon dioxide (CO_2).

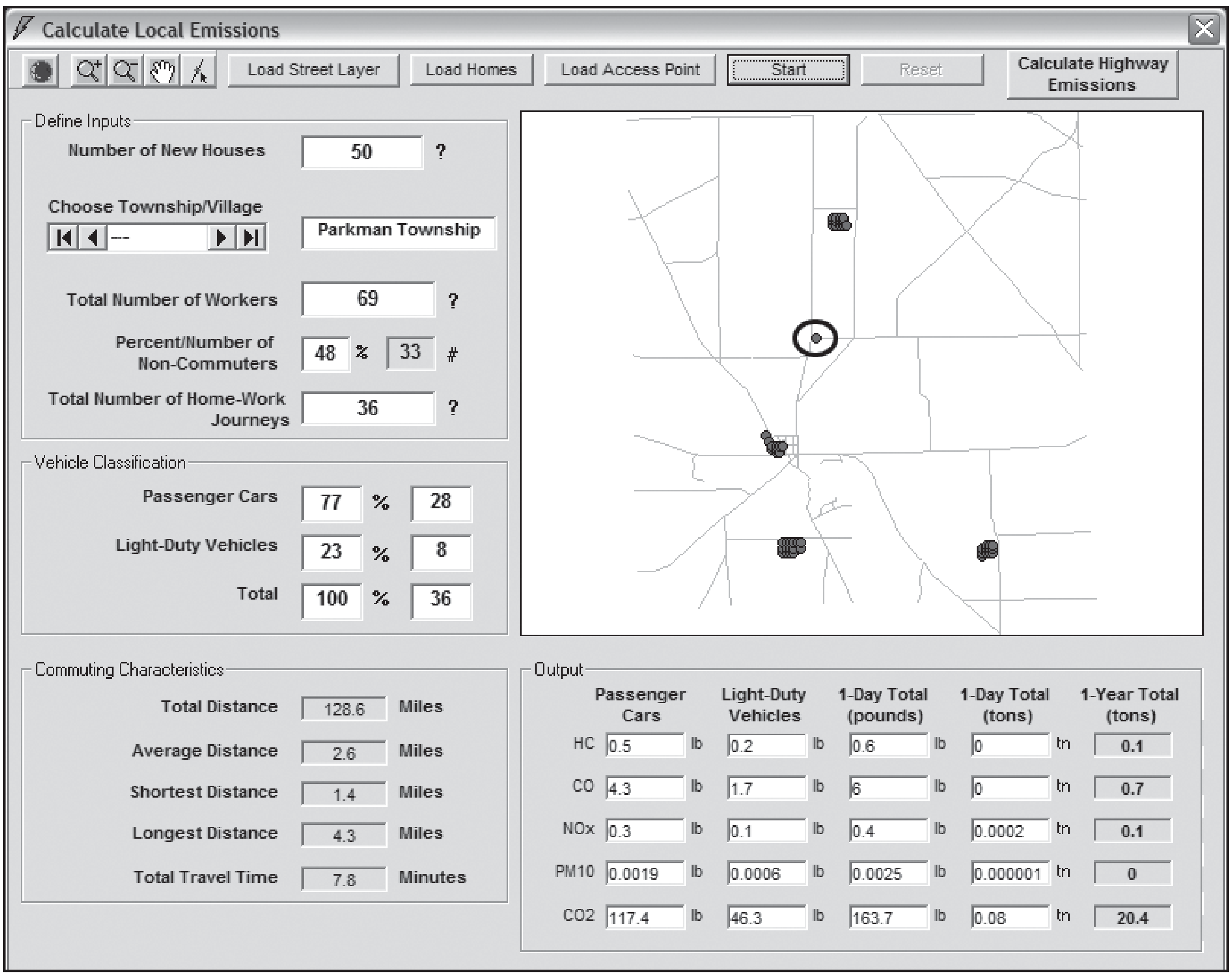

FIGURE 2. VERTUS local emissions interface representing Parkman Township, Geauga County, Ohio. Lines represent the street network with points representing housing locations. The circled point is a highway access point.

The final output of the model expresses the amount of emissions generated as tons per year. Estimates are based on the distance traveled from new housing developments to the HAP (local emissions) and from the HAP to employment centers (highway emissions). Travel distance is calculated as the EPA and other organizations do not have emissions as a rate per time basis. Travel simulation and all computational components were integrated using Microsoft Visual Basic (VB) programming language and ESRI's (Environmental Systems Research Institute, Redlands, California) MapObjects and NetEngine. Output can be saved in a text file format for further analysis (Fig. 4).

Case Study

VERTUS, in conjunction with UGS, were applied to Geauga County, Ohio, (Fig. 5) as a case study to estimate how projected growth in housing would impact the spatial distribution of vehicle emissions. The county serves as a suitable study area because of past and current growth in housing and the anticipated growth expected to occur in the future. The county is subdivided into 22 municipalities (townships and villages) and is one of several counties surrounding Cuyahoga County that has absorbed a large portion of suburbanites moving away from the city of Cleveland. Over the 30-year period from 1970 to 2000, Geauga County's population increased from 60,977 to 90,895, a 49 percent increase. From 2000 to 2030, the county estimates a 23 percent increase in population (Geauga County Planning Commission, 2003). Similar to the county population trends, the number of housing units per square mile is expected to increase over the 30-year period by 43 percent. Also, about 88 percent of the county (230,388 acres) is zoned for residential purposes with the average lot size ranging from 1.5 to five acres (Geauga County Planning Commission, 2003).

Using data from the US Census Bureau and the county's Comprehensive Housing Improvement Strategy (CHIS) plan, the Geauga County Planning Commission estimate an additional 7,226 (22 percent) households from 2000 to 2020. Growth is primarily due to in-migration of residents from surrounding counties. The plan directs growth in housing where adequate infrastructure exists to ensure affordable single-family housing for residents. Based on current infrastructure, therefore, most development will occur in the western municipalities of the county.

Year 2000 housing characteristics (Table 1) serve as the baseline for establishing vehicle emissions. Locations of housing were represented using the UGS residential land use layer. Future emission estimates were then calculated based on housing growth from 2000 to 2020 (Table 2). Projected housing estimates were first simulated in UGS to derive their locations. These locations were then simulated in VERTUS to estimate the additional amount of emissions generated at the local and highway levels. Home-work journey emissions from Geauga County residents can only emanate from the private automobile as no public transportation exists within the county. A HAP was established in each municipality to model local emissions. CTPP data indicates that a total of 11 counties serve as locations of employment for Geauga County residents. One employment center was established in each of these counties.

In performing simulation for each municipality, the projected number of additional households were entered into UGS with half cluster and half frontage, each one acre in size; for example Auburn Township, 1,320 additional households from 2000-2020,

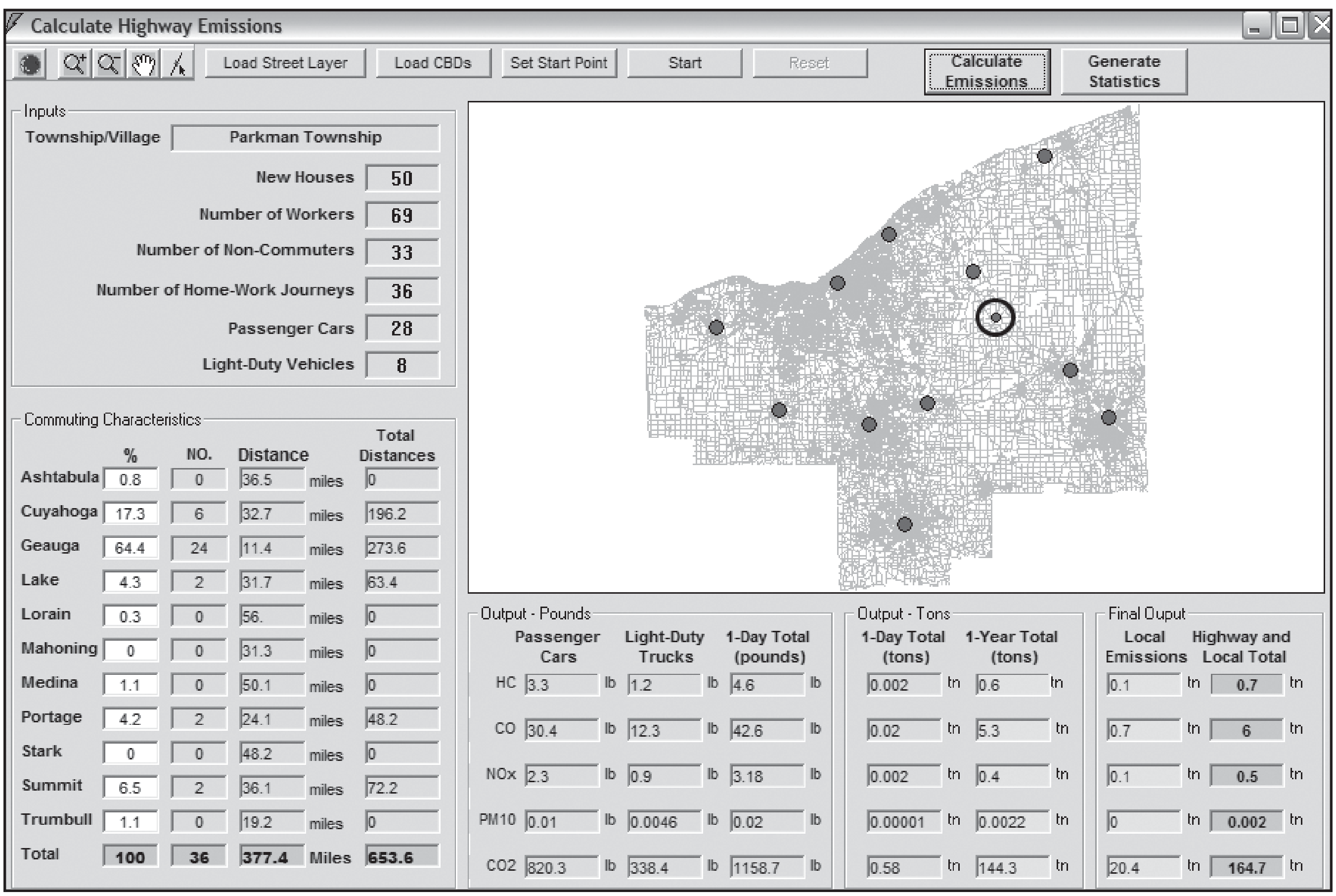

Figure 3. VERTUS highway emissions interface representing Parkman Township, Geauga County, Ohio.

660 cluster, 660 frontage, one acre in size. Because UGS varies the location of each simulation, 20 separate simulations were performed for each municipality. These locations were then modeled in VERTUS with the final result for each municipality being the average of the 20 simulations.

The villages of Aquilla, Burton and Hunting Valley were excluded from this portion of the analysis for either one of two reasons: no land exists for future residential development (Aquilla Village and Hunting Valley Village); and although additional households are estimated, UGS is unable to fully simulate these projections (Burton Village). For instance, the planning commission projected an additional 120 houses for Burton Village. However, UGS can only simulate the development of 10 to 20 additional homes; not enough developable land exists to fulfill the user's input.

RESULTS

Local Emissions – Year 2000 (Baseline)

Based on year 2000 data, the county has a total of 32,815 households. The majority are located in the western municipalities. This area was first developed as suburbanites moved away from the city of Cleveland. Residential development progressed eastward as these areas become saturated. There are 37,699 home-work journeys among the 32,815 households. Collectively they emit 38,034 tons of emissions locally per year (Table 3).

The overall geographic pattern of local emissions coincides with locations of housing; residents of municipalities with large numbers of households comprise a larger portion of local emissions (Fig. 6). Thus, there is a geographic bias with the greatest absolute amount of emissions from residents in the seven western municipalities and

Table 1

Geauga County, Ohio, Housing and Community Characteristics --Year 2000

Community	Number Households	Average No. Workers	Number Workers	Number Non-Commuters	Number HWJs	Number PCs	Number LDVs
Aquila Village	146	1.48630	217	26	191	159	32
Auburn Township	1,765	1.41190	2,492	324	2,168	1,626	542
Bainbridge Township	3,840	1.38646	5,324	852	4,472	3,354	1,118
Burton Township	1,545	1.41553	2,187	503	1,684	1,297	387
Burton Village	610	1.39836	853	198	655	544	111
Chardon Township	1,605	1.44424	2,318	240	2,078	1,558	520
Chardon Village	2,225	1.24360	2,767	386	2,381	1,929	452
Chester Township	3,970	1.31763	5,231	523	4,708	3,625	1,083
Claridon Township	1,135	1.46960	1,668	200	1,468	1,160	308
Hambden Township	1,460	1.45822	2,129	234	1,895	1,497	398
Hunting Valley Village	317	1.26498	401	68	333	250	83
Huntsburg Township	855	1.43275	1,225	453	772	594	178
Middlefield Township	1,227	1.74328	2,139	868	1,271	979	292
Middlefield Village	1,015	1.72426	1,750	725	1,025	871	154
Montville Township	690	1.32029	911	109	802	634	168
Munson Township	2,095	1.48878	3,119	468	2,651	1,988	663
Newbury Township	2,105	1.57007	3,305	430	2,875	2,271	604
Parkman Township	905	1.38564	1,254	602	652	502	150
Russell Township	2,160	1.32685	2,866	487	2,379	1,832	547
South Russell Village	1,355	1.25461	1,700	221	1,479	1,080	399
Thompson Township	875	1.32457	1,159	197	962	760	202
Troy Township	915	1.22842	1,124	326	798	614	184
COUNTY TOTAL	32,815	1.40604	46,139	8,440	37,699	29,124	8,575

the least amount from residents of the nine eastern municipalities. Table 3 presents the absolute amount and percentage (emissions per household) of local emissions as well as local distances traveled. The 4,708 commuters from Chester Township accumulate the greatest local travel distance (5,861,460 miles) per year and thus the greatest amount of local emissions (5,397.9 tons per year). Neighboring Bainbridge Township with the greatest number of workers (4,472) generates a slightly lesser amount (4,278.3 tons per year). Residents of these townships represent one-fourth of local emissions generated. They are also two of five municipalities bordering Cuyahoga County. With a lesser amount of households and commuters, the eastern townships represent just over one-quarter of the county's local emissions; 28.6 percent compared to the 65.3 percent of the western townships.

Table 2

Geauga County, Ohio, Housing Projections -- 2000-2020

Community	Housing 2000	Housing 2020	Change 2000-2020	% Change 2000-2020
Aquila Village	146	146	0	0.0%
Auburn Township	1,765	3,085	1,320	74.8%
Bainbridge Township	3,840	4,840	1,000	26.0%
Burton Township	1,545	1,625	80	5.2%
Burton Village	610	610	0	0.0%
Chardon Township	1,605	2,205	600	37.4%
Chardon Village	2,225	2,255	30	1.3%
Chester Township	3,970	4,370	400	10.1%
Claridon Township	1,135	1,295	160	14.1%
Hambden Township	1,460	1,920	460	31.5%
Hunting Valley Village	317	317	0	0.0%
Huntsburg Township	855	1,195	340	39.8%
Middlefield Township	1,227	1,427	200	16.3%
Middlefield Village	1,015	1,101	86	8.5%
Montville Township	690	930	240	34.8%
Munson Township	2,095	2,735	640	30.5%
Newbury Township	2,105	2,465	360	17.1%
Parkman Township	905	1,205	300	33.1%
Russell Township	2,160	2,420	260	12.0%
South Russell Village	1,355	1,505	150	11.1%
Thompson Township	875	1,095	220	25.1%
Troy Township	915	1,295	380	41.5%
COUNTY TOTAL	32,815	40,041	7,226	22.0%

Residents of the villages contribute least to local emissions. This is a product of short local commutes to the HAP and a low number of households. For instance, Chardon Village contains 2,225 households but residents only generate 1,020 tons of local emissions per year. On average they travel 0.9 miles to the HAP. South Russell is the only village with a local travel distance greater than one mile. Residents of the villages may play a larger role at the highway level. Emissions from other municipalities are impacted by non-commuters. Huntsburg, Parkman, and Troy Township have a greater number of workers than households. Due to their high percentage of non-commuters (37, 48, and 29 percents respectively) their number of home-work journeys is less than the number of households and workers. For this reason, their emissions are smaller than municipalities with an equal or lesser amount of housing.

The average amount of emissions emitted per household via local travel is 1.02 tons per year (Table 3). The geographic pattern (Fig. 7) is comparatively the same as the absolute values. The primary difference is that the eastern townships represent a greater percentage of emissions. This is due in part to the lower housing numbers in the eastern townships. Conversely, those municipalities with large housing numbers and high absolute local emissions experience a decline. While taking emissions as a rate better represents the eastern municipalities share, the west maintains the largest representation.

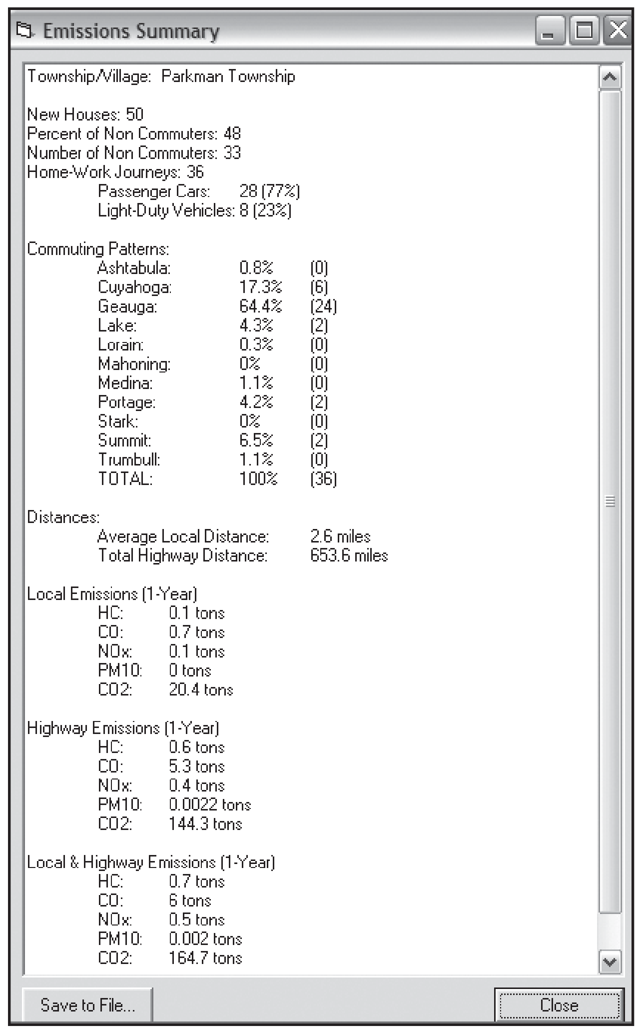

Figure 4. VERTUS summary statistics file representing Parkman Township, Geauga County, Ohio.

Highway Emissions – Year 2000 (Baseline)

Residents of Geauga County emit 283,234.9 tons of emissions per year via highway travel (Table 4). The overall geographic distribution is similar to local emissions as the highest absolute amounts emanate from residents in the western municipalities (Fig. 8). The townships of Chester and Bainbridge again represent one-fourth of all emissions. This is the same percentage that all nine eastern townships represent. Collectively, the seven western townships represent 60 percent of highway emissions generated. In comparing local and highway emissions, several differences exist between each municipality's share of the total. The villages have a larger impact at the highway level because the influence of the HAP is negated. Four of six villages represent a larger percentage of emissions at the highway level. Most notably these include South Russell and Chardon Villages. Five townships represent a greater percentage of highway emissions than local emissions generated.

Bainbridge and Chester Townships switch positions at the highway level with Bainbridge generating the greatest amount of highway emissions. Emissions here are 22 percent (7,418 tons per year) higher even though Bainbridge has 236 fewer home-work journeys than Chester. Similarly, Auburn Township generates more emission than Munson Township at the highway level compared

Table 3

Geauga County, Ohio, Baseline Local Emissions -- Year 2000

			Tons/Year		Miles	
Community	Houses	HWJ	Emissions	Emission/HH	Ave. Distance	1-Year Distance
Aquila Village	146	191	31.6	0.22	0.4	38,047.2
Auburn Township	1,765	2,168	2,738.0	1.55	2.7	2,915,092.8
Bainbridge Township	3,840	4,472	4,278.3	1.11	2.1	4,676,817.6
Burton Township	1,545	1,684	1,716.8	1.11	2.2	1,844,990.4
Burton Village	610	655	123.6	0.20	0.4	130,476.0
Chardon Township	1,605	2,078	2,902.6	1.81	3.0	3,104,532.0
Chardon Village	2,225	2,381	1,020.2	0.46	0.9	1,067,164.2
Chester Township	3,970	4,708	5,397.9	1.36	2.5	5,861,460.0
Claridon Township	1,135	1,468	1,534.8	1.35	2.3	1,681,447.2
Hambden Township	1,460	1,895	1,765.4	1.21	2.0	1,887,420.0
Hunting Valley Village	317	333	132.2	0.42	0.9	149,250.6
Huntsburg Township	855	772	817.4	0.96	2.3	884,248.8
Middlefield Township	1,227	1,271	1,561.3	1.27	2.7	1,708,986.6
Middlefield Village	1,015	1,025	286.4	0.28	0.6	306,270.0
Montville Township	690	802	753.0	1.09	2.1	838,731.6
Munson Township	2,095	2,651	3,246.2	1.55	2.6	3,432,514.8
Newbury Township	2,105	2,875	3,542.7	1.68	2.7	3,865,725.0
Parkman Township	905	652	771.4	0.85	2.6	844,209.6
Russell Township	2,160	2,379	2,717.0	1.26	2.5	2,961,855.0
South Russell Village	1,355	1,479	743.2	0.55	1.1	810,196.2
Thompson Township	875	962	1,069.4	1.22	2.4	1,149,782.4
Troy Township	915	798	884.4	0.97	2.4	953,769.6
COUNTY TOTAL	32,815	37,699	38,034.0	1.02	2.0	41,112,987.6

HWJ represents the number of home-work journeys. HH stands for household. Avg distance is the average distance traveled by each home-work journey to the highway access point. One-Year Distance is the total one-year distance accumulated by HWJs.

to the local level, even though Auburn Township has 483 fewer home-work journeys and a lesser number that commute via LDVs. These differences demonstrate how commuting patterns and distances travelled to employment centers create variation among municipalities with equal numbers of housing and home-work journeys.

Emissions from other municipalities are influenced by vehicle classification. Chardon Village and Russell Township have approximately the same number of home-work journeys; 2,381 and 2,379. However, their vehicle classification differs with 19 percent being LDVs for the former and 23 percent for the latter. This translate to 452 and 547 LDVs; a difference of 95 more home-work journeys via LDVs in Russell Township than Chardon Village. In addition to commuting patterns, vehicle classification is a contributing factor to residents of Russell Township generating an additional 3,395.7 tons of highway emissions per year.

When taken as a rate, each household emits an average of 8.3 tons of emissions per year via highway travel (Table 4). The geographic bias of the western municipalities comprising the largest percentage is eliminated as the western and eastern municipalities each represent half of the total emissions generated per household (Fig. 9). The largest is Thompson Township with 11.8 tons/household. Thompson is one of 13 municipalities that represent a larger percent of emissions per household compared to the absolute total.

Local Emissions – Year 2020

Based on new housing construction between 2000 and 2020, an additional 4,936.8 tons of local emission will be generated

Table 4

Geauga County, Ohio, Baseline Highway Emissions -- Year 2000

Community	Houses	HWJ	Tons/Year Emissions	Tons/Year Emissions/HH	Miles 1-Year Distance
Aquila Village	146	191	1,067.8	7.3	1,179,164.4
Auburn Township	1,765	2,168	19,144.7	10.8	20,554,701.0
Bainbridge Township	3,840	4,472	39,864.4	10.4	42,800,211.6
Burton Township	1,545	1,684	9,462.1	6.1	10,229,766.6
Burton Village	610	655	3,613.7	5.9	3,990,125.4
Chardon Township	1,605	2,078	16,938.5	10.6	18,186,063.6
Chardon Village	2,225	2,381	14,315.4	6.4	15,695,864.4
Chester Township	3,970	4,708	32,446.1	8.2	35,080,116.0
Claridon Township	1,135	1,468	7,949.8	7.0	8,653,995.0
Hambden Township	1,460	1,895	14,396.6	9.9	15,673,952.4
Hunting Valley Village	317	333	2,371.8	7.5	2,546,423.4
Huntsburg Township	855	772	4,972.3	5.8	5,375,810.4
Middlefield Township	1,227	1,271	8,587.7	7.0	9,284,512.8
Middlefield Village	1,015	1,025	6,018.7	5.9	6,693,618.0
Montville Township	690	802	6,992.5	10.1	7,612,975.8
Munson Township	2,095	2,651	18,661.1	8.9	20,035,287.0
Newbury Township	2,105	2,875	23,739.4	11.3	25,845,652.2
Parkman Township	905	652	5,678.9	6.3	6,139,642.8
Russell Township	2,160	2,379	17,711.1	8.2	19,147,950.6
South Russell Village	1,355	1,479	11,957.4	8.8	12,749,497.2
Thompson Township	875	962	10,288.0	11.8	11,200,567.8
Troy Township	915	798	7,057.1	7.7	7,629,609.0
COUNTY TOTAL	32,815	37,699	283,234.9	8.3	306,305,507.4

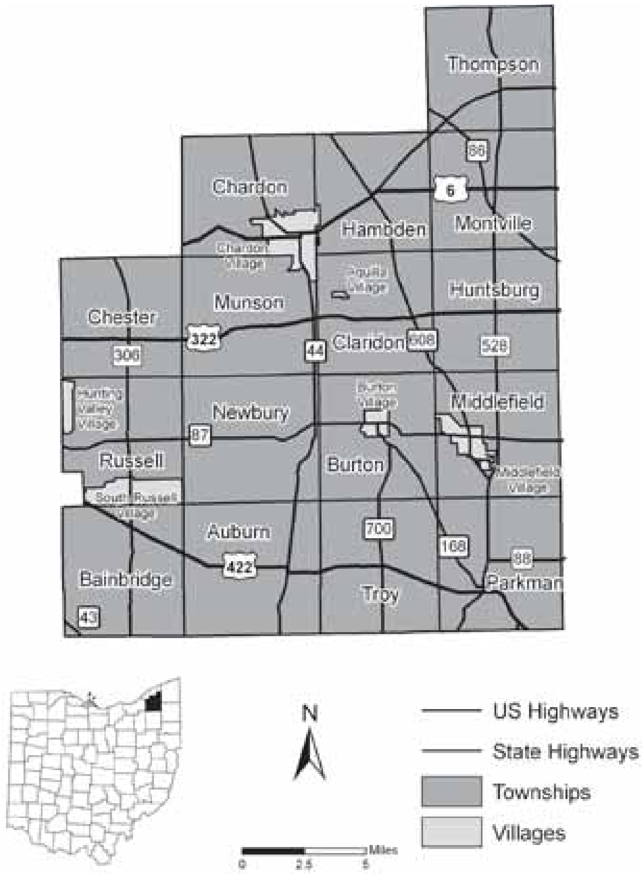

FIGURE 5. Geauga County, Ohio -- Municipalities and major highways.

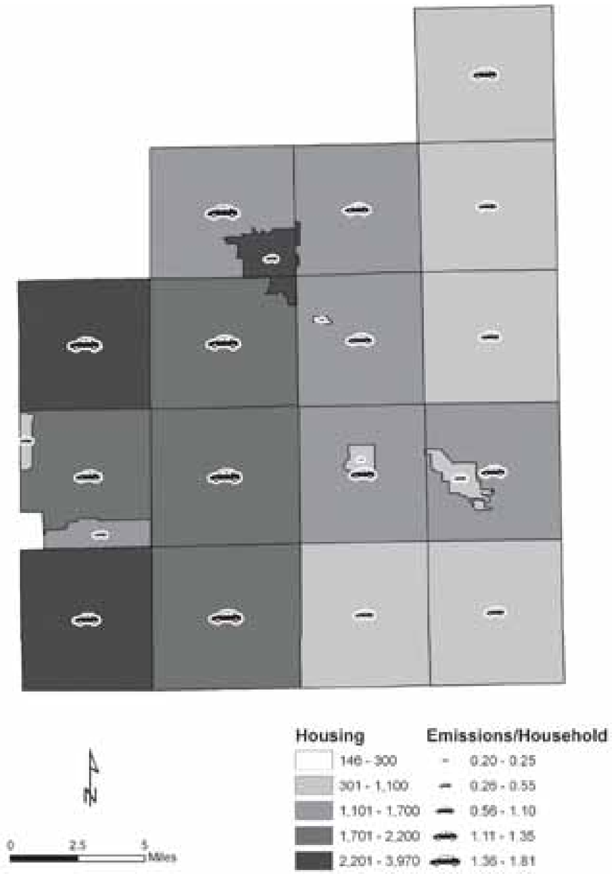

FIGURE 7. Geauga County, Ohio, baseline local emissions per household -- Year 2000.

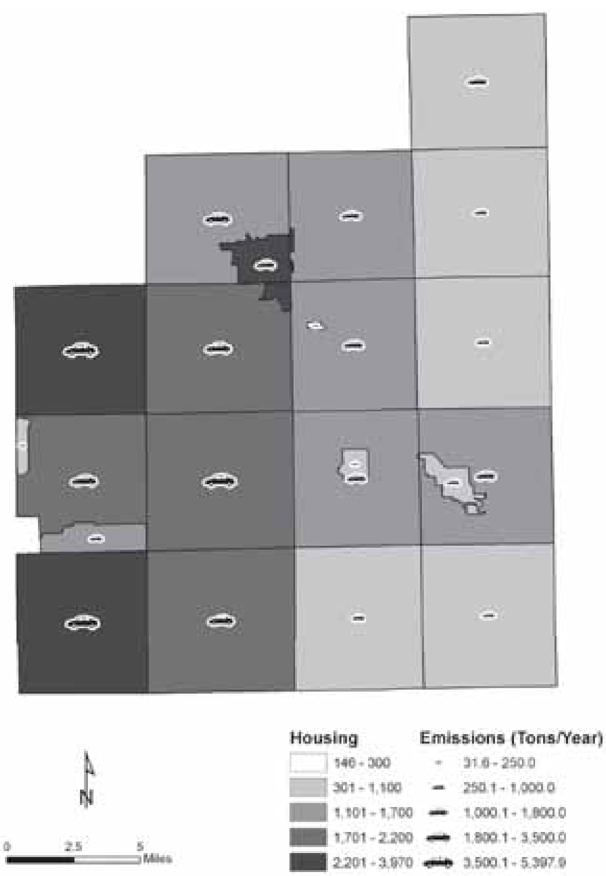

FIGURE 6. Geauga County, Ohio, baseline local emissions -- Year 2000.

FIGURE 8. Geauga County, Ohio, baseline highway emissions -- Year 2000.

per year (Table 5); a 13 percent increase. The largest increases coincide with the west-to-east housing growth trend (Fig. 10). The largest absolute increase of 1,008.6 tons per year results from new residents in Auburn Township; a 36.8 percent increase from the baseline. With 320 fewer homes than Auburn Township, Bainbridge Township has the second highest absolute increase at 641.8 additional tons per year; a 15 percent increase. However, the number of additional households is not always indicative of the amount of emissions generated. For instance, note Chardon and Munson Townships; 600 additional households equaling 496.0 tons of emissions compared to 640 houses generating 388.2 tons of emissions. Even with 40 more houses and 48 more home-work journeys, residents of Munson generate 107.7 fewer tons per year. This is due to Chardon's longer travel distance to the HAP. Additionally, Troy Township's 380 additional households (186.8 tons per year) generate 156.6 tons per year less than Newbury's 360 additional households (343.3 tons per year). This is primarily a result of Newbury having 162 more home-work journeys than Troy. Other townships that exhibit these relationships are Chester and Hambden, Thompson and Montville, and Middlefield and Russell. Given projected housing increases to year 2020, the spatial distribution of vehicle emissions is such that two-thirds of local emissions will emanate from residents of western municipalities (Fig. 11).

Table 5

Increase in Local Emissions resulting from new housing developments, 2000-2020 -- Geauga County, Ohio

Community	Housing Change	Housing % Change	Commuting HWJs	Commuting Distance (mi)	Emissions (Tons/year) Increase	Emissions (Tons/year) % increase	Percent of Total
Aquila Village	0	0.0%	N/A	N/A	N/A	N/A	N/A
Auburn Township	1,320	74.8%	1,622	2,180,941.2	1,008.6	36.8%	20.4%
Bainbridge Township	1,000	26.0%	1,164	1,391,212.8	641.6	15.0%	13.0%
Burton Township	80	5.2%	88	96,412.8	45.0	2.6%	0.9%
Burton Village	0	0.0%	N/A	N/A	N/A	N/A	N/A
Chardon Township	600	37.4%	762	1,062,532.8	496.0	17.1%	10.0%
Chardon Village	30	1.3%	64	35,059.2	15.6	1.5%	0.3%
Chester Township	400	10.1%	476	734,848.8	335.4	6.2%	6.8%
Claridon Township	160	14.1%	208	238,243.2	109.2	7.1%	2.2%
Hambden Township	460	31.5%	596	712,339.2	328.4	18.6%	6.7%
Hunting Valley Village	0	0.0%	N/A	N/A	N/A	N/A	N/A
Huntsburg Township	340	39.8%	308	368,121.6	171.0	20.9%	3.5%
Middlefield Township	200	16.3%	206	338,540.4	155.2	9.9%	3.1%
Middlefield Village	86	8.5%	172	68,524.8	32.4	11.3%	0.7%
Montville Township	240	34.8%	278	276,888.0	130.2	17.3%	2.6%
Munson Township	640	30.5%	810	847,098.0	388.2	12.0%	7.9%
Newbury Township	360	17.1%	492	759,549.6	343.4	9.7%	7.0%
Parkman Township	300	33.1%	216	268,920.0	125.0	16.2%	2.5%
Russell Township	260	12.0%	286	313,341.6	145.0	5.3%	2.9%
South Russell Village	150	11.1%	336	301,190.4	144.2	19.4%	2.9%
Thompson Township	220	25.1%	242	289,238.4	135.6	12.7%	2.7%
Troy Township	380	41.5%	330	410,850.0	186.8	21.1%	3.8%
COUNTY TOTAL	7,226	22.0%	8,656	10,693,852.8	4,936.8	13.0%	100.0%

NOTE: Percent of total represents each community's percentage of the total increase in emissions.

Highway Emissions – Year 2020

New housing will contribute an additional 34,731.4 tons of emissions per year via highway travel (Table 6). This represents a 13 percent increase from the baseline. Increases at the highway level are similar to those at the local level as residents in the western townships account for the largest absolute increases (Fig. 12). The seven western townships account for two-thirds of the total increase. The largest absolute increases come from the townships of Auburn and Bainbridge; together they account for one-third of the total increase. Russell Township is the only western township with an absolute increase at or below that of eastern townships. Even with more additional housing and home-work journeys than the eastern townships of Montville and Thompson, residents of Russell contribute less to the increase in emissions. The primary difference between these three townships is the total highway distance travelled as simulated in VERTUS. Thompson's 242 home-work journeys accumulate an annual travel distance of 2,821,269 miles compared to 2,282,234 miles driven by Russell's 286 commuters. Montville's 278 home-work journeys travel 2,712,008 miles per year. Similarly, a longer travel distance results in Chardon Township's 762 commuters generating more emissions than Munson Township's 810 commuters; approximately 281 more tons per year. Overall, six municipalities contribute more to the increase in highway emissions than local emissions. Like local emissions, residents of western municipalities generate the greatest absolute amount of highway emissions (Fig. 13) after housing development through year 2020.

Table 6

Increase in Highway Emissions resulting from new housing developments, 2000-2020 -- Geauga County, Ohio

Community	Housing Change	Housing % Change	Commuting HWJs	Commuting Distance (mi)	Emissions (Tons/year) Increase	Emissions (Tons/year) % increase	Percent of Total
Aquila Village	0	0.0%	N/A	N/A	N/A	N/A	N/A
Auburn Township	1,320	74.8%	1,622	15,418,378.8	7,180.4	37.5%	20.7%
Bainbridge Township	1,000	26.0%	1,164	11,117,352.0	5,177.2	13.0%	14.9%
Burton Township	80	5.2%	88	547,003.2	253.0	2.7%	0.7%
Burton Village	0	0.0%	N/A	N/A	N/A	N/A	N/A
Chardon Township	600	37.4%	762	6,712,840.8	3,126.2	18.5%	9.0%
Chardon Village	30	1.3%	64	384,157.2	175.0	1.2%	0.5%
Chester Township	400	10.1%	476	3,513,987.6	1,625.0	5.0%	4.7%
Claridon Township	160	14.1%	208	1,209,343.2	555.4	7.0%	1.6%
Hambden Township	460	31.5%	596	4,969,342.8	2,282.0	15.9%	6.6%
Hunting Valley Village	0	0.0%	N/A	N/A	N/A	N/A	N/A
Huntsburg Township	340	39.8%	308	2,143,690.8	991.4	19.9%	2.9%
Middlefield Township	200	16.3%	206	1,446,192.0	669.0	7.8%	1.9%
Middlefield Village	86	8.5%	172	1,089,723.6	489.8	8.1%	1.4%
Montville Township	240	34.8%	278	2,712,008.4	1,245.6	17.8%	3.6%
Munson Township	640	30.5%	810	6,109,663.2	2,845.2	15.2%	8.2%
Newbury Township	360	17.1%	492	4,419,750.0	2,030.0	8.6%	5.8%
Parkman Township	300	33.1%	216	2,037,218.4	942.2	16.6%	2.7%
Russell Township	260	12.0%	286	2,282,234.4	1,055.4	6.0%	3.0%
South Russell Village	150	11.1%	336	2,844,177.6	1,333.6	11.2%	3.8%
Thompson Township	220	25.1%	242	2,821,269.6	1,295.6	12.6%	3.7%
Troy Township	380	41.5%	330	3,155,427.6	1,459.4	20.7%	4.2%
COUNTY TOTAL	7,226	22.0%	8,656	74,933,761.2	34,731.4	13.0%	100.0%

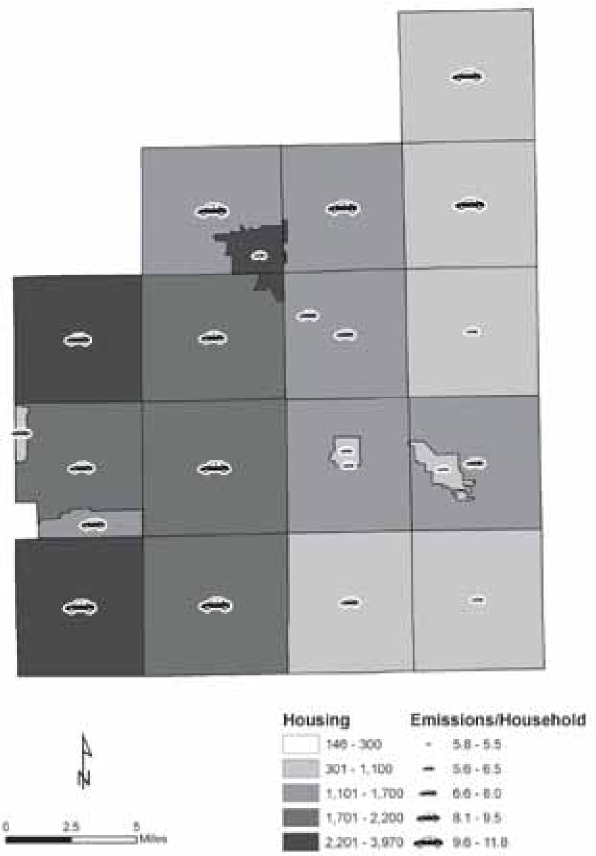

FIGURE 9. Geauga County, Ohio, baseline highway emissions per household -- Year 2000

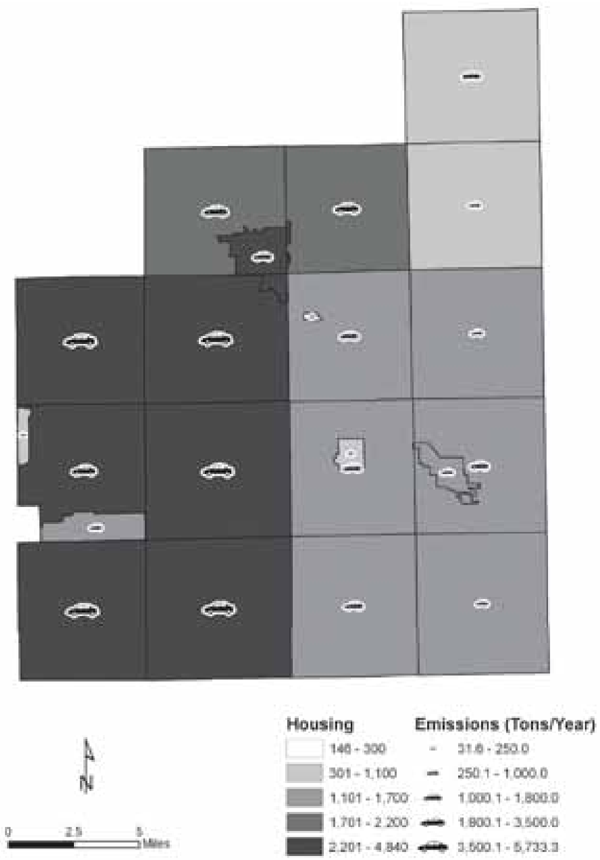

FIGURE 11. Geauga County, Ohio, local emissions -- Year 2020.

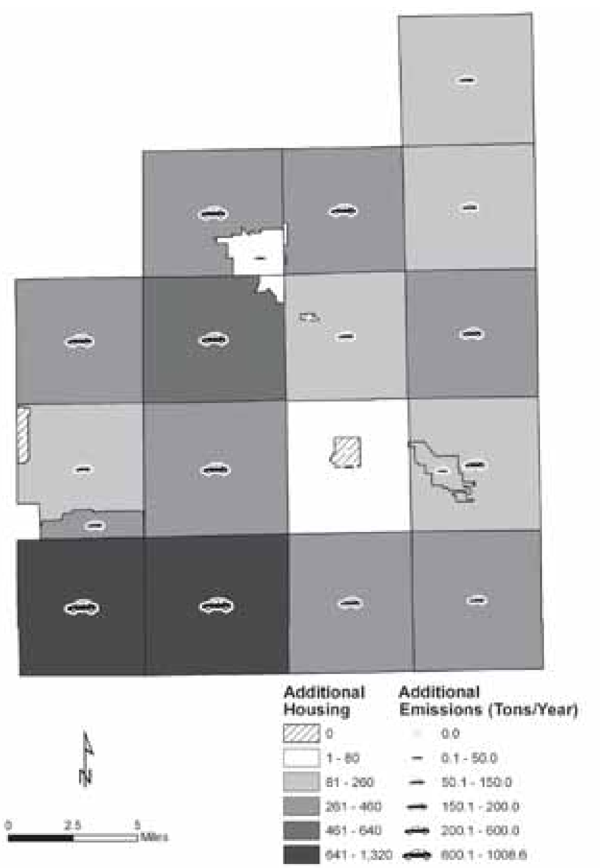

FIGURE 10. Increases in housing and local emissions from 2000-2020 -- Geauga County, Ohio.

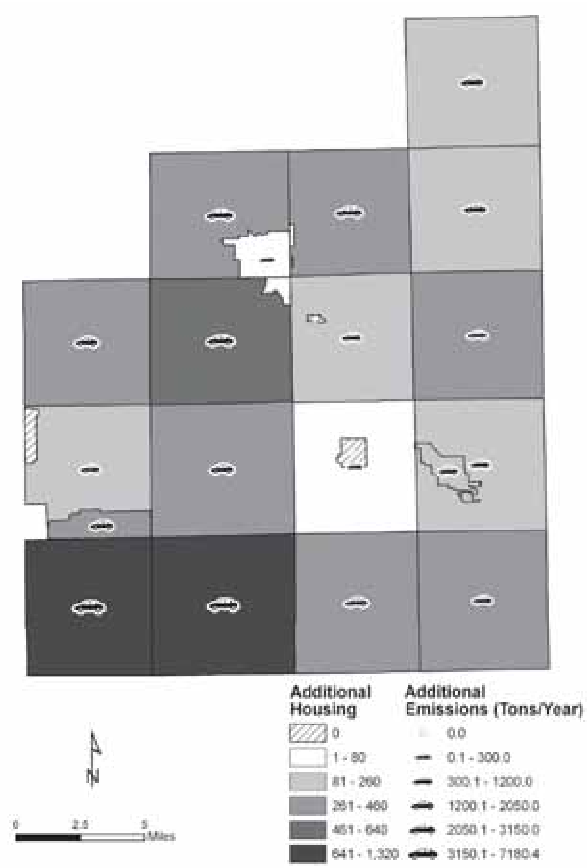

FIGURE 12. Increases in housing and highway emissions from 2000-2020 -- Geauga County, Ohio.

DISCUSSION

The higher predicted emissions in western Geauga County may be attributed to the historical development of the county. Geauga County's housing development began prior to 1970 as Clevelanders began moving out of the city into the western areas up to State Route 306. From 1970–1980, the movement began moving eastward up to State Route 44. Even though the population sprawled away from the city of Cleveland, they settled in western Geauga County closest to the city. New housing coincides with this west-to-east trend as western municipalities have the infrastructure to support housing growth. Such growth is further exasperating emissions in western Geauga County. This pattern of housing growth presents interesting planning scenarios for the county to consider. Once the western municipalities become saturated, housing growth will spread into the eastern municipalities. The longest one-day travel distances to employment centers are those from the eastern municipalities. Will the population be willing to compensate longer commutes for settlement in newly sprawled developments? If not, perhaps the trend in housing development might be reversed to the point where the population locates near their place of work. This is a future area of research given the current state of the US economy and gas prices.

Emissions are highest in western Geauga County primarily due to the greater concentration of housing located there. However, the use of CTPP for establishing worker and commuting characteristics reveals other geographic differences that influence emissions between the west and east. CTPP data indicate the western municipalities contain a smaller percentage of non-commuters; more residents participate in the home-work journey by driving alone rather than working at home, walking, carpooling, or riding their bike to work. Conversely, the eastern municipalities have the largest percentage of non-commuters. Reasons for this disparity found through this research are the locations of employment. Cuyahoga County (city of Cleveland) is a major pull-factor of employment for Geauga County residents; approximately 38 percent of Geauga County workers (Geauga County Planning Commission, 2003). Over half emanate from the western municipalities. This percentage progressively decreases west to east with approximately 20 percent traveling from the eastern municipalities. Workers in the east that commute to Cuyahoga County may be more willing to carpool to work than those in the west due to the longer travel distance. Additionally, while the population in the west works in Cuyahoga County, approximately two-thirds of eastern residents work in Geauga County. Workers may walk or ride their bike due to the close proximity of a major employment center in Middlefield Village; no public transportation exists within the County. Similarly, the data and methodology used to establish the vehicle classification found that the highest percentages of LDVs are driven by residents of western municipalities. Differences in non-commuters and vehicle classification are contributing factors to residents of western municipalities generating more emissions.

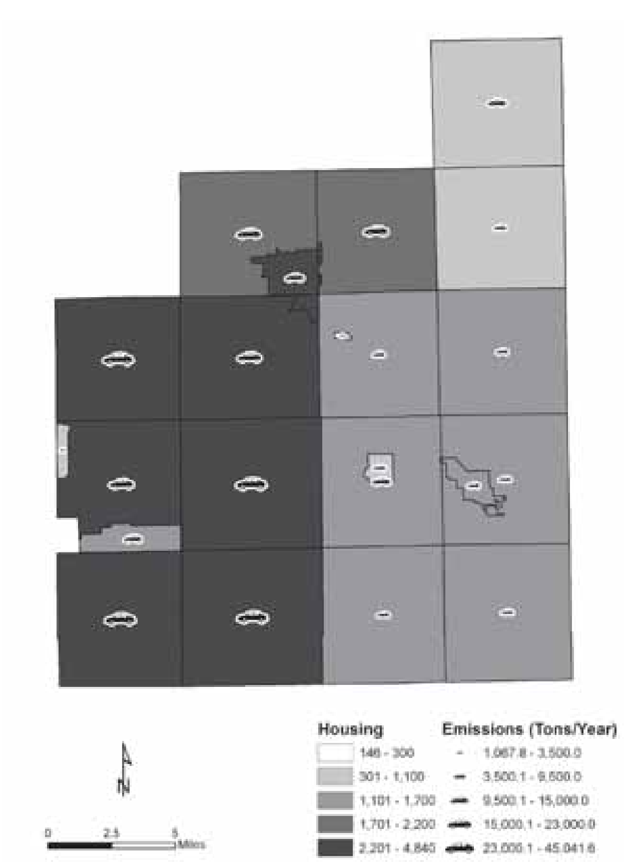

FIGURE 13. Geauga County, Ohio, highway emissions -- Year 2020.

Findings from baseline and projected emissions demonstrate how worker and commuting characteristics create differences among municipalities with equal numbers of households. For instance, a municipality may have a large number of households but due to a low number of workers per household and a high percentage of non-commuters, residents generates fewer emissions than a municipality with the same or lesser number of households. Conversely, a municipality with a small number of households generates more emissions due to a greater number of workers per household and percentage of LDVs. Such relationships among these variables and each municipality produce geographic variations in the amount of emissions generated. Consideration must also be given to each municipality's commuting patterns and distances traveled via local and highway networks. While social and economic factors dictate residential decisions, commuting patterns of current Geauga County residents indicate that the location of work may be among the most influential.

Local Commuting

The location of each municipality's HAP is influential in determining the amount of local emissions generated. This is evident with Chardon Village as it has the third highest number of households but ranked thirteenth highest in local emissions due to the low average travel distance to its HAP. Travel distances among the villages are the lowest in the county due to their small land area size. However, each township is relatively the same size and each has their HAP located directly in the center part of the township. Thus, their average local travel distances should be similar if not identical. This is not the case as average distances range from a low of 2.1 to a high of 3.0 miles. Analyzing these distances geographically, the higher amounts are located in the western townships and the lowest in the eastern townships. These differences may coincide with existing land use patterns; western townships are more developed residentially then eastern townships. With residential development comes the need for additional roads. As western townships have the highest road density in the county, a more advanced road network in the west may complicate travel distance to HAPs resulting in longer local travel distances.

Highway Commuting

Modeling emissions at the highway level demonstrate the influence commuting patterns and distances traveled to the employment centers have on emission generated. This is apparent by further analyzing the relationship between the top two townships in terms of highway emissions; Chester and Bainbridge townships. Bainbridge has 236 fewer home-work journeys than Chester but generates more highway emissions. Bainbridge is the only municipality with home-work journeys that travel to each of the 11 employment centers. It also has the third lowest amount of commuters (31.4 percent) that remain in the county for work. Further, Bainbridge has a total of 12 and eight home-work journeys to the employment centers in Mahoning and Medina counties. The one-day distance (home-to-work, work-to-home) from Bainbridge Township to these employment centers as simulated in VERTUS is 90.4 and 74.4 miles. Residents of Chester Township do not commute to these employment centers. Even though Chester has 236 more home-work journeys than Bainbridge, the mileage accumulated by the 20 home-work journeys that travel to Mahoning and Medina counties results in Bainbridge generating more emissions.

Similarly, commuting pattern result in Auburn Township's 483 fewer home-work journeys generating more emissions than Munson Township. This presents an interesting case in that their commuting patterns are relatively the same. Munson has a higher number traveling north to the employment center in Lake County but this is off-set by Auburn's home-work journeys to Cuyahoga County and the southern counties. The primary difference is Munson has 254 more home-work journeys that remain in Geauga County for work. Further, it takes twice as long from Auburn then Munson to reach Geauga's employment center; 26.2 and 12.6 one-day miles. Differences in the number of home-work journeys and travel distance contribute to Auburn generating more emissions even though it has fewer home-work journeys.

Applicability of VERTUS Model

Assumptions within VERTUS were minimized by using real-world data, most notably the CTPP. Additionally, the County's housing projections are based on data from the US Census Bureau and the county's Comprehensive Housing Improvement Strategy (CHIS) plan. Lastly, home-work journeys were modeled using US Census TIGER Line data and algorithms developed by ESRI, the leading producer of GIS software. VERTUS also offers the benefit of allowing user intervention. In simulating local and highway emissions, it provides a pre-defined value for each worker and commuting variable but allows the user to override these values. Allowing user intervention permits testing altering scenarios to see how each variable affects the amount of emissions generated.

Given the reliable data-source and user intervention, VERTUS can assist several areas of planning. First, urban planners and the like can utilize VERTUS to assist in maintaining air quality according to the EPA's National Ambient Air Quality Standards (NAAQS) for their region. These standards were implemented to protect public health and the environment from pollutants considered harmful. Similarly, an April 2007 US Supreme Court decision ruled the EPA violated the Clean Air Act by failing to regulate vehicle emissions standards of greenhouse gases that scientists claim contribute to global warming (Greenhouse, 2007). While the ruling does not force the EPA to regulate automobile emissions, they would face further legal action if they failed to do so. Former President George W. Bush ordered federal agencies to find ways for regulating vehicle emissions by the time he left office (January 20, 2009) (Greenhouse, 2007). Most recent, the EPA and Transportation Department announced they would regulate greenhouse gas emissions from automobiles (Reuters, 2010). These rulings make it evident that planning tools such as VERTUS are needed to assist planners and government officials in maintaining acceptable pollution and emissions levels. Second, VERTUS as a planning tool can be used to examine how changes in the locations of employment centers affect distances traveled and the amount of emissions generated. In relation to home-work journey travel, new subcenters of employment can have positive and negative effects by increasing and decreasing distance traveled. When new subcenters of employment are proposed for development, their locations can be tested within VERTUS to examine how distance and emissions are affected.

While simulation is an effective approach to better understanding how certain phenomena are to evolve when, in reality, it is impossible to obtain that understanding through actual implementation or real operations. Being that urban sprawl is a long term and irreversible process, simulation is the best way to study how it will proceed and impact the environment. However, it should be noted that simulations can only offer one realization of many possible scenarios under a specific set of conditions set forth by a model's assumptions. Regarding VERTUS, it utilizes a single employment center and HAP per county when in fact multiple exist within each. Additionally, emissions are calculated according to travel distance while travel time is a key variable in predicting running exhaust emissions as emissions are directly related to hours of vehicle operation (Bachman et al., 2000). Given today's popularity with green vehicles, the vehicle fleet must expand to incorporate hybrid, electric, and hydrogen based vehicles into addition to how income and family size influence ownership of these vehicles. Future refinements to VERTUS must consider expanding the representation of these variables. Thus, results should be interpreted with caution as the reliability of the simulated results depends entirely on the accuracy of input data and the simulation algorithms.

CONCLUSION

Many major urbanized areas are growing outward rather than upward contributing to the problem of urban sprawl in the US. With this movement has come a fair amount of debate on what exactly constitutes urban sprawl and whether it is necessarily hazardous to the environment. This has prompted research relating sprawl and land use patterns to quantify their effects on the environment. Few, if any, attempted to extend this relationship to household travel patterns. This research utilized the VERTUS model to examine the spatial distribution of vehicle emissions in Geauga County, Ohio, resulting from urban sprawl. Focus was placed on emissions generated at the local and highway levels through the home-work journey. Results indicate that emissions are highest in those municipalities with the greatest number of households. While more housing translates to higher emissions, incorporating CTPP data into the design of VERTUS produced geographic variations among municipalities with similar numbers of households or additional households. Results provide the needed contribution to the literature on growth induced emissions and the relationships between housing, travel patterns, and vehicle emissions.

VERTUS coupled with UGS provides users with a planning tool that can estimate the environmental impact of urban sprawl in the form of farmland and critical nature areas lost, nutrient loading into the soil, and vehicle emissions generated. Planners can utilize their capabilities when new communities are planned or when existing communities are reviewed for future development. In addition to urban planning, VERTUS is a feasible tool for planners and decision makers to use in response to current and proposed laws related to air quality standards such as the NAAQS and establishing a gas tax. Future locations of employment could also be simulated to estimate changes in home-work journeys and emissions generated. Future areas of research need to address the number of assumptions incorporated into VERTUS. Reducing the number of assumptions whether employment centers, HAPs, calculating emissions, or the vehicle fleet, must be performed individually to determine how a change with each influences model output. Refinements to the model will only strengthen its usability as federal, state, and local governments continually seek ways to assist their efforts to maintain healthy air and optimal development.

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