Impact of Urban Development Alternatives on Transportation Fuel Consumption

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Local officials need information about the transportation fuel consumption impacts of alternative urban development patterns to improve the local land use decision-making process. In this study, the feasibility of using simplified travel demand and fuel consumption models to evaluate the transportation fuel requirements of urban development alternatives is demonstrated. The greater Madison, Wisconsin, urban area is used as a case study to examine the marginal impacts of three alternative residential and two alternative commercial development scenarios for the year 2000. Simplified modal choice and automobile occupancy models are used to test the impacts of transit, ridesharing, and vehicle fuel economy improvements on transportation fuel requirements. To reduce the computing time requirements, the highway network speeds are assumed to be the same for all scenarios. Thus only a single trip distribution (gravity) model is required to evaluate each scenario. The fuel consumption analysis provides support for several regional development plan policies. Average trip length can be reduced by locating population and employment in the same subregion. Concentration of commercial development in the central Madison area will reduce fuel consumption somewhat, primarily because of higher transit use. Development in rural areas should be limited because of high per capita fuel consumption. The reductions in fuel consumption for the most energy efficient development scenarios range from 7 to 15 percent, which are similar to the reductions that were obtained with the transit and ridesharing improvement options. In contrast, reductions of 38 percent are expected from improvements in vehicle fuel economy.

Achievement of the long-term regional goal of minimizing transportation fuel consumption requires implementation of the most energy efficient urban development alternatives. A number of studies have shown clear relationships between transportation fuel requirements and alternative urban development patterns *(1–4)*. Although these studies have provided some general guidelines, local decision makers are more likely to be convinced by studies based on analysis of their own region. The purpose of this study is to demonstrate the feasibility of using simplified travel demand and fuel consumption models to evaluate the transportation fuel requirement of urban development alternatives. Because the travel demand models include simple modal choice and auto occupancy models, the impacts of changes in transit and automobile use can also be evaluated.

RELATED RESEARCH

Schneider and Beck *(5)* studied the impact of the redistribution of population and employment on urban travel requirements. They used an automated search algorithm to find a new distribution of population and employment that would improve the performance of the highway network. Application of the algorithm to a simple 12-node network for the greater Seattle region resulted in reductions in total travel time of 40 to 60 percent. This result was achieved by balancing population and employment at each node but required redistribution of up to 56 percent of the population and 38 percent of the employment.

Edwards and Schofer *(1)* focused specifically on the relationship between transportation energy consumption and urban form. A Lowry model was used to allocate land use subject to constraints on urban form. The Lowry model outputs were merged with a conventional urban travel demand model. Fuel consumption was estimated from the resulting all-or-nothing traffic assignment by using Claffey's curves as a function of link speed *(6)*. A modal choice model was not used. Rather, a range of transit shares was specified for each urban form. Analysis of 37 variations of three basic urban forms (concentric ring, linear, and polynucleated) showed that transportation energy requirements could be reduced by controlling the spread of cities and by channeling development into higher density polynucleated forms.

Peskin and Schofer *(2)* extended Edwards and Schofer's Lowry-based urban development model *(1)* by adding a binary logit modal choice model and a capacity-restrained assignment model. More than 400 experiments were conducted, using concentric ring, one-sided, or polynucleated development together with variations in transit service and pricing, vehicle occupancy, freeway construction, and gasoline pricing. In general, the results showed that polynucleated cities would consume considerably less fuel than concentric ring cities.

Recently, Kim and Schneider *(3)* used Peskin and Schofer's urban development model and Schneider's urban form statistics program to identify relationships between urban form and transportation fuel consumption. Six alternative patterns of basic employment were evaluated for each of three city types—concentrated, dispersed, and polynucleated. The study showed "that higher concentrations of population in the center of the city, better access to the center, and higher population densities can reduce transportation energy consumption." While the polynucleated cities generally required more energy, some

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polynucleated cities were more energy efficient than some concentrated cities because of congestion on central streets. Thus major suburban employment centers surrounded by relatively dense residential development were recommended as a realistic urban development strategy to conserve transportation fuel.

The four studies mentioned *(1–4)* clearly show that urban form and transportation energy consumption are directly related. Although these studies focused on the generation of alternative urban forms, improvements in the methodology used to estimate transportation fuel consumption are also of interest. Janson et al. *(4)* developed a methodology for computing zone-to-zone transportation fuel consumption by mode by using standard transportation planning databases. Highway link speeds were obtained from an equilibrium network assignment, whereas transit fuel consumption per person-trip was based on average loads per transit vehicle mile. Application to Chicago showed the importance of accounting for the relationship between traffic volume and speed. Direct energy consumption per person-kilometer increased for zones closer to the central business district (CBD) because of traffic congestion. The reverse was true for transit because of higher average vehicle loadings and less use of the automobile access mode. One limitation of the methodology was the lack of a fully consistent set of curves for automobile fuel consumption versus speed. Curves developed from field data collected by the General Motors Research Laboratories for arterial streets and freeways from the Characteristics of Urban Transportation Systems (CUTS) manual were selected as the most reliable data available.

An alternative approach to estimating transportation fuel consumption was recently developed by the Dane County Regional Planning Commission *(7)*. The objective of the study was to provide information on the transportation energy impacts of single- versus multiple-family residential development for use by local officials. Annual vehicle trips per dwelling unit (DU) and average vehicle trip length by DU type were estimated for urban zones and rural units of government using available data. Vehicle miles of travel (VMT) per DU were then computed as the product of vehicle trips per DU and average trip length. Finally, fuel consumption per DU per year was estimated by factoring VMT by average vehicle fuel efficiency ratings for the urban and rural areas separately. The study was limited by the lack of travel demand models covering the rural area of the county. Consequently, the impact of changes in employment location on residential travel could not be analyzed.

The research on the relationships between transportation fuel consumption and urban development patterns just reviewed provides a sound basis for evaluating these relationships in a particular urban area. All of the studies except the Seattle *(5)* and the Dane County *(7)* studies used travel demand and supply models to estimate transportation fuel consumption. The complexity and sophistication of the various models, however, varied considerably. Selection of the appropriate set of travel demand and supply models for a particular urban area requires judgments about the level of sophistication required to address the relevant policy issues.

CASE STUDY APPROACH

This study is designed to provide transportation planners with a practical tool for quickly and easily evaluating the impacts of alternative land use policies on transportation fuel consumption. Rather than reallocating population and employment with a Lowry model, a simple proportional allocation of population and employment growth is used to test the marginal impact of highly simplified alternative growth patterns. Available trip generation and trip distribution models are used to estimate the person-trip demand for each development alternative. Transit and vehicle trips are then estimated by assuming that base year transit and automobile occupancy rates will apply in the future.

Estimation of zone-to-zone fuel consumption is simplified by assuming that highway network link speeds are not affected by additional traffic. Thus the minimum time paths required by the gravity trip distribution model can be used to compute fuel consumption from the fuel consumption versus speed curves. Total fuel consumption can then be obtained as the product of fuel consumption and vehicle trip matrices.

CASE STUDY AREA

The area selected for the case study is the Madison, Wisconsin, urban area located in Dane County. The Dane County Regional Planning Commission (DCRPC) is responsible for developing transportation, land use, and other long-range plans for the entire county. The Regional Development Plan includes several policies that could have an impact on transportation fuel consumption: (a) encourage balanced growth of both population and employment opportunities in satellite communities, (b) encourage retail and commercial development in the central Madison area, and (c) preserve agricultural land by limiting development in rural areas.

Evaluation of these policies requires travel demand models that cover the entire county, including the rural areas. Because the available travel demand models only covered the Madison urbanized area, considerable work was required to extend the highway network and travel demand models to the entire county. The years 1980 and 2000 were selected as the base and forecast years, respectively, consistent with the DCRPC regional planning database.

FUEL CONSUMPTION MODEL

Automotive fuel consumption is primarily a function of speed, stops, speed cycle changes, grade, and percent curvature. These relationships vary by vehicle type, but composite curves based on the mix of vehicles in the fleet have been developed. The effects of the vertical and horizontal alignment (grade and percent curvature) are generally insignificant in urban areas and, lacking detailed data, will be ignored for the rural areas as well. On urban streets, the number of stops and speed cycle changes is a function of the level of service and the spacing of signalized intersections. Precise estimation of the level of service on urban networks and the resulting effect on fuel consumption requires use of the macroscopic TRANSYT or the microscopic NETSIM model, but neither of these models is feasible for a regional-scale network. If the level of service is constant or the impact of level of service changes on fuel consumption can be neglected, then the only remaining variable is speed.

The curve for fuel consumption versus speed is U shaped, with higher fuel consumption at low speeds decreasing to a minimum between 30 to 35 mph and then increasing as speed increases. Fuel consumption curves based on a mix of vehicles that represents the late 1970s' automobile fleet are available from a number of sources *(6, 8–10)*. To simplify the analysis in this study, a single composite fuel consumption curve was constructed as shown in Figure 1. Atherton and Suhrbier's *(8)* urban arterial curve is used for the 5- to 40-mph range; above 40 mph it is extrapolated on the basis of the CUTS freeway and Claffey curves. Thus, as a first approximation, fuel consumption is assumed to be a function only of highway network speed.

The fuel consumption curve was developed on the basis of the best information available in 1984 when the study was conducted. Future applications should use the most recent fuel consumption data, such as those reported by McGill *(11)*. Light trucks should also be incorporated in the fuel consumption curve because they now account for about 18 percent of household vehicle miles of travel.

By using the fuel consumption curve, the fuel consumed per trip from Zone *i* to Zone *j* for Network *k* can be computed as

$$FUEL_{ijk} = \sum_{l} f(SPEED_{lk}) \times DIST_{lk} \qquad (1)$$

where

$SPEED_{lk}$ = average speed on the *l*th link on the minimum time path between Zones *i* and *j* for the *k*th network,
$f(SPEED_{lk})$ = fuel consumed in gallons per mile at the given speed, and
$DIST_{lk}$ = distance in miles in the *l*th link for the *k*th network.

The possibility of using multiple networks such as peak and offpeak networks is included because in many urban areas, peak-hour speeds are much lower than offpeak-hour speeds. Total fuel consumption can then be computed by multiplying the fuel consumption matrix, $FUEL_{ijk}$, by the corresponding trip matrix, T_{ijk}, and summing over all *ij* pairs and networks. The fuel consumption model represented by Equation 1 gives zone-to-zone-based estimates in contrast to the direct link-based estimates that are available from the Urban Transportation Planning System (UTPS) traffic assignment model UROAD *(12)*. The zone-to-zone-based model permits direct estimation of fuel consumption from zone-to-zone trips obtained from a trip distribution (gravity) model as long as the network level of service, and hence link speeds, remain constant over the range of alternatives considered. The assumption of constant link speeds was made in this study to eliminate the need for separate traffic assignments for each of the alternative development patterns considered. This assumption reduces the computational requirements for evaluating the alternatives significantly. The trade-off is that some bias is introduced by neglecting congestion-induced speed changes. The magnitude of the bias, however, should be small even in the year 2000 because the Madison area highway network is not expected to be highly congested. Also, the marginal impacts of changes in population and employment assuming reasonable levels of congestion are of primary interest. The development simply would not occur if the highway network became too congested.

TRAVEL DEMAND MODEL DEVELOPMENT

Expansion of the existing urban area travel demand models to the entire county was hindered by the lack of a county-wide home interview origin-destination (OD) survey. The county-wide 1975 U.S. Census journey-to-work survey provided the primary basis for the expansion. Data from the 1977 Nationwide Personal Transportation Study were also useful *(13)*.

In the rural area, U.S. Census-defined minor civil divisions (MCD) were used as zones so that population and employment data would be readily available. The highway network was developed to provide logical connections between the MCD-based zones. The speeds on the rural highway network were based on location and functional classification. The county was divided into six basic geographic subregions, as shown in Figure 2. The second, third, and fourth subregions form

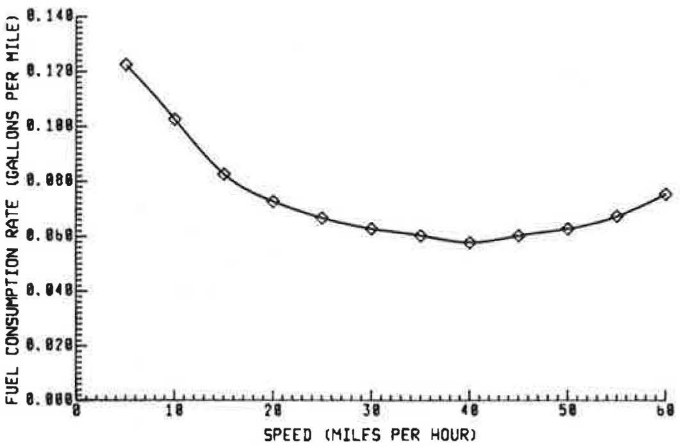

FIGURE 1 Fuel consumption curve.

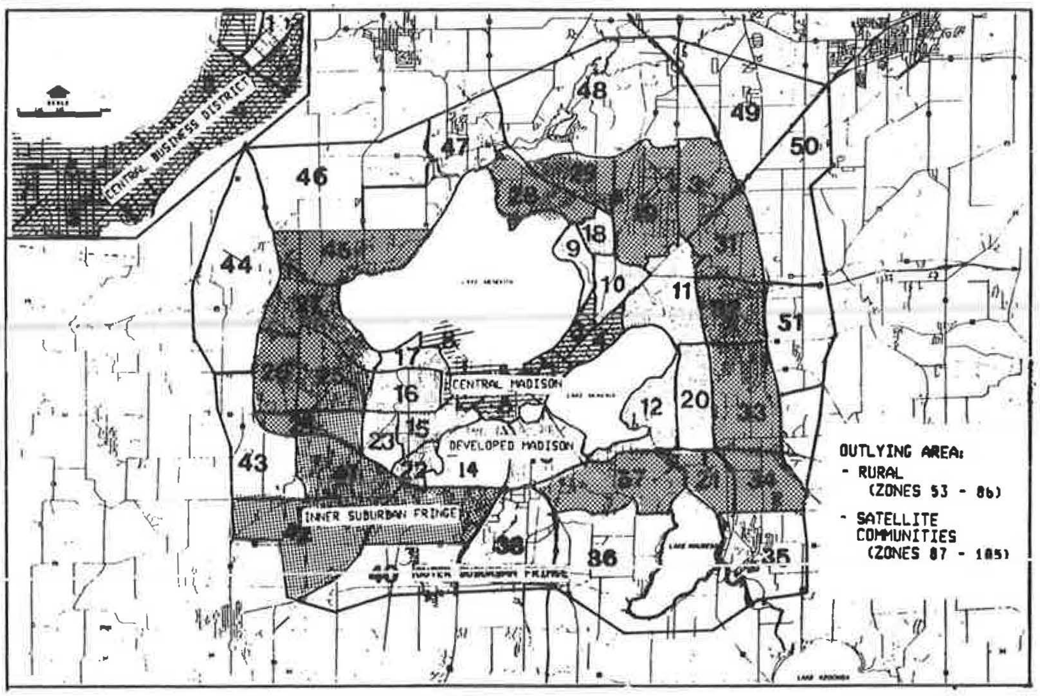

FIGURE 2 Location of subregions in Dane County.

partially complete concentric rings around the central Madison subregion. The "outlying area" is divided into rural and satellite community subregions.

A simple trip rate, trip generation model was developed both for the urban and outlying areas. Only two purposes, home-based work (HBW) and home-based nonwork (HBNW), were used. Non-home-based trips were neglected because of the lack of data on such trips in the outlying area.

The trip production model is shown in Table 1. The trip rates for the outlying area are stratified by rural versus satellite community subregions and single-family versus multifamily DU types. For the outlying area, the HBW rates were obtained from the 1975 Census journey-to-work data. The outlying HBW rates were then factored by the ratios of nonwork to work trips for single-family and multifamily dwelling units obtained from the 1977 Nationwide Personal Transportation Study. For the urban area the trip rates were obtained directly from prior estimates of trip productions.

TABLE 1 AVERAGE DAILY TRIP PRODUCTION RATES PER HOUSEHOLD

Geographic Area	Home-Based Work	Home-Based Nonwork
Central Madison	1.01	4.12
Developed Madison	1.85	5.93
Inner suburban fringe	2.11	6.63
Outer suburban fringe	1.91	7.37
Rural area[a]	2.3	4.98
Single family	2.34	5.43
Multiple family	2.18	4.72
Satellite communities[a]	2.18	4.73
Single family	2.26	5.25
Multiple family	2.12	4.58

[a] Average.

No data were available on trip attraction rates for the outlying area. Consequently, the trip attraction rates suggested in the Quick Response report were used, with trade and service employment substituted for retail employment *(14)*.

The trip distribution (gravity) model was calibrated on the basis of the average trip length standards shown in Table 2 and the HBW trip length frequency distribution from the 1975 Census journey-to-work data. A reasonable fit was obtained for HBW trips both in the urban and outlying areas, but for HBNW trips the gravity model substantially underestimated the desired average trip length in the outlying area. The gravity model estimate in the outlying area however, appears to be more reasonable than the standard because the estimated outlying HBNW trip length is less than the HBW trip length, which follows the urban area pattern.

TABLE 2 GRAVITY MODEL CALIBRATION

Geographic Area and Purpose	Average Trip Length (min) Gravity Model	Standard	Percent Difference
Urban			
Home-based work	11.6	12.0	−3.3
Home-based nonwork	10.1	10.1	0.0
Outlying			
Home-based work	17.3	15.9	8.8
Home-based nonwork	12.4	17.0	−27.1

A simplified modal choice model was developed on the basis of 1980 estimates of transit use within the urban area and 1975 Census journey-to-work data for the outlying area. The resulting model is a 6 × 6 matrix of transit trip percentages for HBW and HBNW trips between the six geographical subregions presented in Table 3. A similar model for automobile

TABLE 3 PERCENTAGE OF TRIPS BY TRANSIT

	DESTINATION SUBREGION					
ORIGIN SUBREGION	(1)	(2)	(3)	(4)	(5)	(6)
Central Madison (1)	44.2[a] (17.5)[b]	12.2 (1.0)	10.9 (0.7)	2.2 (0.5)	0.0 (0.0)	0.0 (0.0)
Developed Madison (2)	21.9 (7.6)	6.8 (0.5)	2.6 (0.2)	1.4 (0.1)	0.0 (0.0)	0.0 (0.0)
Inner Suburban Fringe (3)	12.9 (4.6)	1.7 (0.1)	1.6 (0.2)	1.0 (0.2)	0.0 (0.0)	0.0 (0.0)
Outer Suburban (4)	8.2 (5.0)	0.8 (0.3)	0.7 (0.2)	0.2 (0.4)	0.0 (0.0)	0.0 (0.0)
Rural Area (5)	1.1 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Satellite Communities (6)	3.5 (0.0)	0.8 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)

[a] Percent Home Based Work

[b] Percent Home Based Non-Work

occupancy was developed from the same sources. Because fuel consumption can be estimated directly from the vehicle trip tables obtained from application of the modal choice and automobile occupancy models, a trip assignment model was not needed for this study. Elimination of trip assignment significantly reduces the computer time required for the fuel consumption analysis.

SCENARIO DEVELOPMENT

Future levels of transportation fuel consumption will be affected by both residential and commercial development patterns. To highlight potential differences in fuel consumption among development alternatives, highly idealized development patterns were selected that represent the widest possible range of alternatives. Thus, although none of the alternatives may actually occur in pure form, the results will provide a basis for policies to guide growth in a particular direction.

To keep the computer and analysis time to a manageable level, only three residential and two commercial development options were selected, resulting in six development scenarios. The three residential options concentrate all the predicted population growth between 1980 and 2000 into the specified geographic area for that scenario: (a) central Madison, (b) suburban fringe, and (c) satellite communities. In actually allocating the population growth, the population was first converted to dwelling units, using the persons per DU factors presented in Table 4. The additional dwelling units were then allocated to the zones in that geographic area in proportion to the 1980 dwelling units in each zone. Although the three residential growth options have different numbers of dwelling units estimated for 2000, the impact on total person-trips is mitigated by the differences in the trip generation rates (person-trips per DU) among the areas. The net impact on trip generation is given in Table 4 in terms of person-trips per person. The central Madison and satellite communities subregions have about the same trip rate (2.45 and 2.50 person-trips per person, respectively), while the suburban fringe rate is about 25 percent higher. The higher suburban fringe rate is reasonable, considering the lower density, the greater reliance on the automobile, and higher income levels. The two commercial development options concentrate all of the predicted employment growth between 1980 and 2000 into the central Madison and suburban fringe subregions. The increased employment was allocated to each zone in proportion to its 1980 employment. Trade and service employment was estimated by assuming that the 1980 percentage would be maintained.

TRAVEL DEMAND MODEL APPLICATION

The trip generation, trip distribution, modal choice, and automobile occupancy models were applied to determine the vehicle trip table for each scenario. The 1980 highway network and *F* factor curves were used for the gravity model. The fuel consumption for each scenario was then estimated by multiplying the 1980 zone-to-zone fuel consumption per vehicle trip matrix by the vehicle trip matrix for each scenario.

Ideally, the 1980 fuel consumption matrix would have been developed as initially proposed by using zone-to-zone fuel consumption computed as the sum of the fuel consumption per vehicle over all links on the minimum time path between any two zones. Unfortunately, the version of the UROAD computer program used for this study did not permit user-coded subroutines. Consequently, only average zone-to-zone speeds were available to estimate fuel consumption.

Because of the U-shaped relationship between fuel consumption and speed, the use of average zone-to-zone speed, in general, will give biased estimates of fuel consumption. A matrix of correction factors for travel between the urban, suburban-fringe, and outlying areas was developed on the basis of hand calculation of fuel consumption for link-based versus average speeds between zones. The average speed method underestimated zone-to-zone fuel consumption by 3.5 to 14.0

TABLE 4 1980 PERSON-TRIP AND DEMOGRAPHIC DATA BY GEOGRAPHIC SUBREGION

Geographic Sub-region	Total Daily Person Trips	Dwelling Units	Persons per DU	Person Trips per DU	Person Trips per Person
Central Madison	132,400	25,830	2.09	5.13	2.45
Developed Madison	240,700	30,940	2.37	7.78	3.29
Inner Suburban Fringe	268,700	30,700	2.96	8.75	2.96
Outer Suburban Fringe	57,400	6,180	2.70	9.29	3.44
Rural Area	71,600	9,790	3.00	7.32	2.44
Satellite Communities	125,900	18,200	2.77	6.92	2.50
Region	896,800	121,680	2.59	7.37	2.85

percent, with the greatest bias occurring for travel between the outlying area and the urban and suburban fringe areas in which the speed variations are greatest.

MODELING RESULTS

The basic base year 1980 fuel consumption and travel characteristics for the six geographical subregions are presented in Table 5. Three measures of fuel efficiency are included. The fuel consumption per capita measure is the most comprehensive; it includes the impacts of trips per capita, trip length, transit use, and automobile occupancy. Central Madison residents consume the least fuel because they make fewer, shorter trips and use transit to a much greater extent. In contrast, rural residents consume the most fuel, primarily because they make long trips and make almost no use of transit. The gallons-per-person trip measure of fuel efficiency takes into account the variations in trip length, transit use, and automobile occupancy. The rank order of the geographic subregions in terms of gallons per person-trip is the same as for the gallons-per-capita measure, except that the positions of the outer suburban fringe and satellite communities are reversed as the result of the much higher level of trips per capita for the outer suburban fringe. Miles per gallon, the final measure of fuel efficiency, only includes the effect of speed on fuel consumption. The urban area (central and developed Madison) is the least efficient, followed by the suburban area. The rural and satellite communities subregions are the most efficient in terms of direct fuel use per vehicle mile, but the differences are not large.

The overall results for the six scenarios for 2000 are presented in rank order by annual fuel consumed per capita in Table 6. At the regional scenario level, trip length and transit use are the major determinants of the rank order. The central Madison residential scenarios have the shortest trip lengths and the highest transit use. The suburban fringe scenarios have intermediate range trip lengths and moderate to low levels of transit use, whereas the satellite communities scenarios have the longest trip lengths and transit use that is similar to the suburban fringe scenarios.

The impact of commercial development location on the rank order presented in Table 6 is highly consistent. The central Madison commercial scenario is always more fuel efficient than the suburban fringe commercial scenario for the same residential scenario. In this case, transit use is the determining factor because both for the suburban fringe and satellite communities residential scenarios, the trip lengths for the central Madison commercial development scenarios are slightly greater than for the suburban fringe scenarios. Thus, if transit use were equal, the suburban fringe commercial development location would be the most fuel efficient for two of the three residential development scenarios.

The average trip lengths presented in Table 6 are logical. For a given residential development scenario, the trip length should be and is shorter when the new commercial development is located in that same subregion or in the nearest adjacent subregion.

The transit use by scenario presented in Table 6 exhibits a regular pattern. Transit use declines with increasing distance from the central area both for the new residential development and the new commercial development. In contrast, automobile occupancy varies little across the scenarios, with the highest levels occurring for the satellite communities scenarios.

At the subregional scale, average trip lengths for a subregion are primarily affected by the location of the commercial development. As presented in Table 7, average trip length in a subregion is shorter when the commercial development is located in the same or an adjacent subregion. The satellite communities subregion is an exception in which the commercial development that is farthest away produces the shortest average trip length. Apparently, the central Madison commercial development is so far away that the satellite communities are forced to turn inward. The energy efficiency of this development pattern is further reinforced by the higher transit use.

The base year average trip lengths by subregion presented in Table 7 fall in between those for the central Madison and

TABLE 5 BASE YEAR (1980) FUEL CONSUMPTION AND TRAVEL CHARACTERISTICS

	ANNUAL FUEL CONSUMPTION			TRAVEL CHARACTERISTICS			
GEOGRAPHIC SUBREGION	TOTAL[1]	PER HOUSEHOLD (PER CAPITA)	GALL. PER TRIP[2] (MILES PER GALL.)[3]	ANNUAL TRIPS:[4] PER HOUSEHOLD (PER CAPITA)	AVERAGE TRIP LENGTH[5]	PERCENT TRANSIT	VEHICLE OCCUPANCY
Central Madison	4,259	164.9 (78.8)	.107 (14.41)	1,538 (735)	2.66	15.9	1.45
Developed Madison	13,821	446.5 (188.6)	.191 (14.40)	2,333 (986)	4.18	5.1	1.44
Inner Suburban Fringe	18,745	610.3 (206.5)	.233 (14.72)	2,624 (888)	5.02	2.6	1.43
Outer Suburban Fringe	5,273	852.8 (315.5)	.306 (14.73)	2,786 (1,031)	6.70	2.0	1.46
Rural Area	10,913	1115.0 (372.0)	.508 (14.79)	2,196 (733)	11.95	0.1	1.59
Satellite Communities	12,570	690.6 (249.2)	.333 (15.19)	2,075 (749)	7.96	0.4	1.57
REGION	65,581	539.0 (208.5)	.244 (14.73)	2,211 (855)	5.53	4.7	1.47

[1] Thousands of Gallons
[2] Gallons of Fuel per Person Trip
[3] Automotive
[4] Home-Based Person Trips Only
[5] Automobile Trips in Miles

TABLE 6 REGIONAL FUEL CONSUMPTION AND TRAVEL CHARACTERISTICS BY SCENARIO

LOCATION OF NEW DEVELOPMENT:	ANNUAL FUEL CONSUMPTION			TRAVEL CHARACTERISTICS			
RESIDENTIAL [COMMERCIAL]	TOTAL[1]	PER HOUSEHOLD PER CAPITA)	GALL. PER TRIP[2] (MILES PER GALL.)[3]	ANNUAL TRIPS:[4] PER HOUSEHOLD (PER CAPITA)	AVERAGE TRIP LENGTH[5]	PERCENT TRANSIT	VEHICLE OCCUPANCY
Base Year (1980)	65,581	539.0 (208.5)	.244 (14.73)	2,211 (855)	5.53	4.7	1.47
CENTRAL MADISON							
[Central Madison]	69,376	441.2 (178.3)	.214 (14.79)	2,059 (832)	5.06	8.0	1.47
[Suburban Fringe]	75,541	480.4 (194.2)	.233 (14.65)	2,059 (832)	5.29	5.6	1.46
SUBURBAN FRINGE							
[Central Madison]	83,847	569.6 (215.5)	.249 (14.56)	2,287 (865)	5.63	5.5	1.47
[Suburban Fringe]	85,301	579.5 (219.3)	.253 (14.65)	2,287 (865)	5.59	3.4	1.45
SATELLITE COMMUNITIES							
[Central Madison]	85,537	575.9 (219.9)	.263 (14.69)	2,187 (835)	6.13	5.1	1.50
[Suburban Fringe]	88,054	592.8 (226.3)	.271 (14.69)	2,187 (835)	6.10	3.2	1.48

[1] Thousands of Gallons
[2] Gallons of Fuel per Person Trip
[3] Automotive
[4] Home-Based Person Trips Only
[5] Automobile Trips in Miles

TABLE 7 AVERAGE TRIP LENGTH AND PERCENTAGE OF TRANSIT BY COMMERCIAL AND RESIDENTIAL SCENARIO

Geographical Subregion	Central Madison Commerical			Base Year	Suburban Fringe Commercial		
	Central Madison[a]	Suburban Fringe[a]	Satellite Communities[a]		Central Madison[a]	Suburban Fringe[a]	Satellite Communities[a]
Central Madison	1.93[b] (18.6)[c]	2.17 (18.8)	2.14 (18.9)	2.66 (15.9)	3.18 (14.0)	3.15 (13.8)	3.15 (13.8)
Developed Madison	4.34 (6.5)	4.15 (6.8)	4.14 (6.9)	4.18 (5.1)	4.30 (4.0)	4.34 (3.9)	4.31 (4.0)
Inner Suburban Fringe	5.21 (3.4)	5.19 (3.7)	5.20 (3.7)	5.02 (2.6)	4.81 (2.0)	4.81 (2.0)	4.81 (2.0)
Outer Suburban Fringe	7.02 (2.8)	7.01 (2.9)	6.75 (2.9)	6.70 (2.0)	6.54 (1.5)	6.77 (1.5)	6.54 (1.5)
Rural Areas	13.23 (0.2)	12.58 (0.2)	12.51 (0.2)	11.95 (0.1)	12.63 (0.1)	12.60 (0.1)	12.54 (0.1)
Satellite Communities	7.20 (0.5)	8.56 (0.6)	8.57 (0.6)	7.96 (0.4)	8.75 (0.3)	8.82 (0.3)	8.46 (0.3)
Region							

[a] Residential scenario
[b] Average auto trip length in miles
[c] Percent transit

suburban fringe commercial development scenarios, with the exception of the outlying rural and satellite communities subregions. The base year development pattern has a more uniform distribution of commercial development compared with the 2-year 2000 extremes, which logically produces trip lengths in between the two extremes. The pattern of transit use by geographic subregion is entirely consistent; the use declines with increasing distance from central Madison and with increasing distance of the commercial development from the central area.

ADDITIONAL FUEL CONSERVATION OPPORTUNITIES

To assess the importance of urban development options in comparison with other means of reducing transportation fuel consumption, the effects of transit, ridesharing, and vehicle fuel economy improvements were considered both separately and in conjunction with each of the six urban development scenarios. The transit improvements were assumed to generate a 50 percent increase in transit trips for all trip purposes and trip interchanges plus an additional 50 percent increase above the initial increase for suburban fringe work trips and for work trips from the outlying areas. The ridesharing improvements were assumed to increase the work trip automobile occupancy rates by 50 percent. These levels of improvements are not likely to be achieved by the year 2000; rather, they represent upper-bound base lines for comparison with the urban development scenarios.

In contrast with the assumed transit and ridesharing improvements, the assumption of a 62 percent increase in average vehicle fuel economy from 14.7 to 23.8 miles per gallon is much more realistic. This increase is based on the assumption that the congressionally mandated new-car-fleet fuel economy standard of 27.5 miles per gallon is achieved by 1985 and considers the effect of older vehicles on the overall fleet average *(15)*. Although some slippage has occurred in implementing the standard, the projected increase in fuel economy is still achievable by the year 2000.

The impacts of the three additional fuel conservation opportunities are compared with the development alternatives presented in Table 8. The range shown for each alternative and opportunity is based on the range over the six development scenarios. The reductions in fuel consumption that would have occurred in 1980 if the three fuel conservation opportunities had been applied are also presented in Table 8. These 1980 fuel consumption levels form a base line for evaluation of the incremental impact of the development alternatives.

Of the residential development alternatives presented in Table 8, only the central Madison scenarios reduce the fuel consumption per capita from the 1980 base level (a 6.9 to 14.5 percent reduction). If the transit or the ridesharing improvement opportunities had been implemented in 1980, a similar reduction in per capita fuel consumption would have been achieved (of 5.7 and 10.8 percent, respectively), whereas implementing the vehicle fuel economy standards would have had a dramatic impact (38.2 percent reduction). The satellite communities residential scenarios generate the greatest increase in fuel consumption per capita over the 1980 base level, but the increase is not large (5.5 to 8.5 percent). Analysis of the joint impact of the three additional fuel conservation opportunities and the development alternatives for the year 2000 for the marginal reduction in fuel consumption (percent of 1980 per capita fuel consumption) show that the two are not independent (see Table 8). The most energy efficient development scenario

TABLE 8 IMPACT ON ANNUAL FUEL CONSUMPTION OF THE ADDITIONAL FUEL CONSERVATION OPPORTUNITIES COMPARED WITH THE DEVELOPMENT SCENARIOS

Scenario	Range in Fuel Consumption per Capita[a] (gallons per year)	Change as Percent of Base Year
Base Year (1980)	208.5	--
All Development Scenarios	178.3 to 226.3	-14.5 to +8.5
Residential Scenarios		
- Central Madison	178.3 to 194.2	-14.5 to -6.9
- Suburban Fringe	215.5 to 219.3	+ 3.4 to +5.2
- Satellite Comm.	219.9 to 226.3	+ 5.5 to +8.5
Commercial Scenarios		
- Central Madison	178.3 to 219.3	-14.5 to +5.2
- Suburban Fringe	194.2 to 226.3	- 6.9 to +8.5
Transit Improvements		
- 1980	196.6	-5.7
- 2000	163.1 to 219.5	-21.8 to +5.3
(Increment due to Transit)	(-15.2) (-6.8)	(-7.3) (-3.3)
Ridesharing Improvements		
- 1980	185.9	-10.8
- 2000	159.4 to 209.6	-23.6 to +0.5
(Increment due to Ridesharing)	(-18.9) (-16.7)	(-9.1) (-8.0)
Vehicle Fuel Economy Improvements		
- 1980	128.9	-38.2
- 2000	110.2 to 139.9	-47.1 to -32.9
(Increment due to Veh. Fuel Economy)	(-68.1) (-86.4)	(-32.7) (-41.4)

[a] Range over the relevant development scenarios

also improves the energy efficiency of the transit improvement opportunity. That development scenario results in an additional 7.3 percent reduction attributable to transit compared with only a 5.7 percent reduction for the same transit improvements in 1980. Conversely, the least energy efficient development scenario reduces the incremental reduction in fuel consumption from the transit improvement from 5.7 percent (1980) to 3.3 percent (2000). For the ridesharing opportunity, both the most and least energy efficient development scenarios reduce the marginal effectiveness of that option (9.1 and 8.0 percent, respectively, versus a 10.8 percent reduction in 1980). Vehicle fuel economy improvements reverse the pattern of the transit opportunity in that the vehicle fuel economy improvements are least effective for the most energy efficient development scenario and most effective for the least energy efficient scenario. This is logical because transit use is enhanced by high-density compact development, whereas improved vehicle fuel efficiency will have the greatest impact on development patterns that generate the most automobile travel.

CONCLUSIONS

The primary purpose of this study was achieved. Simplified travel demand and fuel consumption models were developed that produced reasonable estimates of the fuel efficiency of idealized urban development alternatives. The models are simple enough to be understood by many local decision makers. Moreover, the models are relatively easy to calibrate by using U.S. Census and basic travel demand data so that many small- to medium-sized urban areas can undertake similar analyses with minimal effort. The cost and time required to run the models is small because only one gravity model application is required for each development scenario to be evaluated.

Specifically, for the case study area of Dane County, Wisconsin, the fuel consumption analysis of the six development scenarios provides at least indirect support for the three regional development plan policies identified earlier. First, the analysis clearly shows that the average trip length for a subregion is reduced both when population and employment growth are located in that subregion. Thus, the regional plan's policy of encouraging balanced growth both of population and employment in outlying communities should reduce fuel consumption. Second, the analysis gives direct evidence that the policy of encouraging retail and commercial development in the central Madison area will reduce fuel consumption. Compared with suburban fringe commercial development, the central Madison development resulted in lower fuel consumption per capita for all three residential scenarios. Finally, because the rural subregion had the highest fuel consumption per capita by a substantial margin, the policy of limiting development in rural areas will reduce fuel consumption.

The current development trend in the case study area is for both population and employment growth occurring primarily in the suburban fringe subregion. The fuel consumption analysis in part explains the location of this development and why it is likely to continue. Land for residential development is available primarily in the suburban fringe areas. Not surprisingly, the average trip lengths for residents of the suburban fringe areas are less when commercial development is also located in the suburban fringe areas. New businesses and offices are likely to locate where it is most convenient for their customers. The trade-off is that trip lengths for most other residents of the region are increased somewhat. On balance for the year 2000, the overall regional average trip length for the suburban fringe commercial development scenario was just slightly less than for the central Madison scenario.

The primary advantage of the central Madison commercial development scenario is the potential for higher transit use with less fuel consumption. Thus the state of Wisconsin's policy of centralizing state employment in the central Madison area is supported by the projected regional transportation fuel savings. In contrast, the private sector commercial development is likely to locate where their market is growing and where land is available at a lower cost.

Of the three additional fuel conservation opportunities considered, only vehicle fuel economy improvements are likely to have a significant impact on future regional transportation fuel consumption. Even with quite dramatic changes in transit use and ridesharing, the baseline (1980) estimated fuel savings per capita for the transit and ridesharing options were only one-sixth and one-third as large, respectively, as the fuel savings from the currently expected vehicle fuel economy improvements. Additional improvements in vehicle fuel economy would increase those large savings even further. The baseline fuel savings per capita for the transit and ridesharing opportunities were also somewhat less than the maximum fuel savings that could be achieved with the most energy efficient year 2000 development scenario.

The most probable residential development scenario produces an estimated 3 to 5 percent increase in fuel consumption per capita compared with 1980. However, when this scenario is combined with the vehicle fuel economy opportunity, savings of more than 35 percent are possible. In contrast, the transit and ridesharing opportunities produce less than 5 percent savings. The fuel consumption impacts of the urban development alternatives considered in this study appear to be generally consistent with the research based on the Lowry model by Edwards and Schofer *(1)* and Kim and Schneider *(3)*. These two studies found that centralization of population led to reductions in fuel consumption as was found for Dane County in this study. Peskin and Schofer's *(2)* conclusion that polynucleated cities consume less transportation energy than concentric ring cities also is supported by the Dane County analysis if the impact of transit is neglected. Average trip lengths were minimized by locating the population growth in the suburban fringe subregion given that the employment growth was also located in the suburban fringe. If a transit system could be developed to serve the resulting suburban employment centers (polynucleated form) effectively, then such development might be as energy efficient as the highly centralized development scenario.

To reduce the travel demand modeling costs, highway network speeds were assumed to be the same for all scenarios. Thus no traffic assignment model was required. The impact of this assumption on fuel consumption needs to be evaluated. If a traffic assignment model is used, then the potential for substantial overloading on the highway network must be recognized because of the idealized nature of the development scenarios. Consequently, marginal analysis based on incremental additions of population and employment until the network reaches saturation would be appropriate. The sensitivity of the simplified models to less extreme development scenarios should also be evaluated. The impact of a range of residential densities on land that will be available for development could be examined. Potential higher-density suburban development nodes could be identified together with improved transit service to the nodes.

The trip generation models available for the Madison urban area did not explicitly include household size. Analysis of the sensitivity of transportation fuel consumption to the joint effects of household size and household location within the region is needed.

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