

# COMPARISON OF AUTOMOBILE EMISSIONS BASED ON TRIP TYPE IN TWO METROPOLITAN AREAS

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Estimates of the distribution of automobile emissions among various trip types in the Washington, D.C., area are developed and compared with analogous estimates previously reported for Allegheny County, Pennsylvania. Work trips produce approximately equal proportions of emissions in both regions. However, trips to and from the central area and short trips are of considerably lesser importance in Washington than in Allegheny County. In addition, cold starts and evaporations produce a smaller proportion of emissions in the Washington area than in Allegheny County. These results suggest several ways in which measures that are effective in reducing automobile emissions in Washington are likely to differ from measures that are effective in achieving the same objective in Allegheny County. For example, improved suburban transit service and disincentives to suburban automobile travel are likely to be of greater importance in the Washington area than in Allegheny County. Jitney service or other measures oriented toward short trips may be of greater value in Allegheny County. In both regions, however, control of emissions from trips with one or both ends in the suburbs is necessary to achieve substantial reductions in regional automobile emissions.

•REDUCTION of automobile emissions of carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NO<sub>x</sub>) is a major objective of programs to improve air quality in urban areas. One of the many possible approaches to achieving this objective is to reduce automobile travel. Measures through which this might be accomplished include car pooling, transit improvements, and fees for or restrictions on automobile use.

Many measures to reduce automobile use can be expected to most significantly affect certain clearly identifiable portions of urban area automobile travel and to have little or no effect on other portions of automobile travel. For example, increased use of freeway bus systems and bus priority are most likely to affect long trips; however demand-responsive transit might be best suited to short trips. Park-and-ride transit service may reduce automobile vehicle miles (kilometers) traveled (VMT) but is unlikely to reduce automobile trip frequencies. Transit improvements generally may be best suited to work trips or trips to and within high-density areas, but other types of trips may be responsive to certain kinds of automobile fees or restraints. Because measures to reduce automobile use do not affect all types of trips equally, the potential effectiveness of emissions reduction of such measures depends on the distribution of automobile emissions among trips of various purposes, lengths, origins, and destinations.

The distribution of emissions among trip types and the potential effectiveness of measures to reduce automobile use and emissions can be expected to vary from city to city, depending on such factors as the lengths and geographical distribution of trips. Estimates of the automobile emissions attributable to various types of trips in Allegheny County, Pennsylvania, were presented in a previous paper (1). In this paper, the analysis is extended to the Washington, D.C., area. Estimates are presented of diurnal evaporative HC emissions, which are independent of travel behavior; cold-start and hot-soak emissions, which depend on trip volume but not on trip length; and the distributions of emissions according to trip purpose, length, origin and destination, and

time of day. The Washington results are compared with those previously obtained for Allegheny County, and implications for the potential emissions-reduction effectiveness of measures to reduce automobile use in the two regions are discussed.

## METHODOLOGY

The Washington emission estimates were developed for an 870-mile<sup>2</sup> (2250-km<sup>2</sup>) area surrounding Washington, D.C. (Figure 1). Data from the 1968 Washington transportation survey were obtained from weekday automobile driver trips between traffic zones in the Washington area for home-based (HB) work, shopping, school, social-recreational, and all other trips during peak and off-peak periods. Peak-period trips were defined as trips terminating in the periods from 7:10 to 9:10 a.m. and from 4:40 to 6:40 p.m. Roadway distances between each zone pair and zone-to-zone travel times were also obtained. Average zone-to-zone speeds were computed by dividing trip lengths by travel times.

The data were used to develop projections of automobile emissions attributable to Washington area internal trips in 1975 subject to the assumption that travel patterns in 1975 will be the same as those in 1968. This approach, which was also used in the Allegheny County study, enables the emission estimates to reflect the effects of automobile emission controls and avoids the need to develop projections of growth. The emission estimates presented therefore apply to a hypothetical region whose 1975 travel patterns are the same as the Washington area internal trip patterns of 1968.

Emissions were computed for each trip in the Washington area data set and then were summed over trip types to obtain emission estimates by trip type. Since the age of the vehicle used for a given trip is not included in the data, emissions for each trip were averaged over the age distribution of the Washington area automobile population. The emission estimation model that was used is described in detail elsewhere (1) and is presented in abbreviated form as follows:

$$E_p = L[s_p(v)e_p + k_p] + \alpha c_p + h_p \quad (1)$$

where

- $E_p$  = emissions of pollutant  $p$  attributable to a trip in kilograms,
- $L$  = length of trip in miles (kilometers),
- $s_p(v)$  = speed adjustment factor for pollutant  $p$  and trip speed  $v$ ,
- $e_p$  = running exhaust emissions of pollutant  $p$  in kilograms per mile (kilometer) averaged over the vehicle population,
- $k_p$  = crankcase emissions of pollutant  $p$  in kilograms per mile (kilometer) averaged over the vehicle population (nonzero only for HC),
- $\alpha$  = 1 if trip begins with a cold start and zero otherwise,
- $c_p$  = cold-start emissions of pollutant  $p$  in kilograms averaged over the vehicle population, and
- $h_p$  = hot-soak evaporative emissions of pollutant  $p$  in kilograms averaged over the vehicle population (nonzero only for HC).

The first term of equation 1 gives hot-running emissions, the second term gives cold-start emissions, and the third term gives hot-soak evaporative emissions. The hot-running, cold-start, and hot-soak emissions attributable to a specific trip type were obtained by summing the corresponding terms of equation 1 over all trips of the specified type. Total emissions attributable to a trip type were obtained by summing  $E_p$  over all trips of the specified type.

In addition to the trip-related emissions of equation 1, each automobile maintained in the Washington area was assumed to produce diurnal evaporative HC emissions regardless of the use it received. Thus, total daily emissions were obtained by summing

$E_p$  over all trips and by adding diurnal evaporations to the resulting sum.

Equation 1 emission factors for both the Washington area and Allegheny County are given in Table 1. Cold-start and running exhaust emissions were estimated from emissions data reported by Automotive Environmental Systems, Inc., (2) and by using methods suggested by Martinez et al. (3). Cold starts were associated with trips that originated at home or at work. Based on results obtained by General Motors (4), 50 percent of the evaporative emissions measured by the federal test procedure (5) was attributed to hot soaks. The other 50 percent was attributed to diurnal evaporations. Average federal test procedure evaporative emissions and crankcase emissions were obtained from Sigworth (6), and speed adjustment factors are from Kircher (7).

## RESULTS

Table 2 gives Washington area emissions, VMT, and trip volumes according to trip purpose. Diurnal HC evaporations, which are not related to travel behavior, are displayed separately from the travel-dependent HC emissions. HB work trips cause 35 to 40 percent of automobile emissions, depending on pollutant, and generate more emissions than any other trip purpose generates. Unidentified other trips, whose emissions are nearly as large as those of work trips, and HB shopping trips are next in importance. Within trip-purpose classes, emissions of all pollutants are approximately proportional to VMT.

The effects of cold starts and hot-soak evaporations on the emissions attributable to the various trip purposes are given in Table 3. Cold starts, which are related to trip volumes but not to trip lengths or speeds, cause 21 percent of CO emissions and 13 percent of trip-related HC emissions. Hot soaks, which are also independent of trip lengths and speeds, contribute an additional 20 percent of trip-related HC. Thus, 33 percent of trip-related HC emissions are independent of trip lengths and speeds. The cold-start contribution to  $\text{NO}_x$  emissions is slightly negative (-2 percent); this indicates that trips beginning with cold starts have somewhat lower  $\text{NO}_x$  emissions than trips beginning with hot starts. This reflects the high engine temperatures required for  $\text{NO}_x$  formation. Cold starts are of greater importance for HB work trips than for other trips because HB work trips are the only trips that have cold starts in both the home-to-destination and destination-to-home directions.

The effects of cold starts and evaporations are also shown in Table 4, which gives the emissions attributable to the running portion of trips; 79 percent of CO emissions and 63 percent of HC emissions occur during actual running.

Table 5 gives the grams per mile (kilometer) emission rates of trips in the Washington area together with emission rates obtained from emissions factors in the federal test procedure adjusted for variations in trip speeds (7). The average Washington area CO and HC emissions rates are respectively 9 and 13 percent higher than the federal test procedure rates. This is caused by differences between Washington area travel characteristics and those assumed in the federal test. In the Washington area, 60 percent of trips begin with cold starts; the average trip length is 5.9 miles (9.5 km), and cars travel 19 miles (30 km) per day on an average. In the federal test, 43 percent of trips begin with cold starts, the trip length is 7.5 miles (12 km), and vehicles are assumed to travel 26 miles (42 km) per day. Moreover, the federal test weights each model year's contribution to diurnal evaporative emissions in proportion to that model year's VMT; however, the weights used here are proportional to each model year's prevalence in the vehicle population. Agreement between Washington area and federal test emissions rates is achieved when the Washington rates are adjusted to reflect federal test travel characteristics.

$\text{NO}_x$  emissions have no evaporative sources and are relatively insensitive to cold starts. Hence, Washington and federal test  $\text{NO}_x$  emissions rates are approximately equal.

The distribution of Washington area emissions by time of day for work trips and all trips is given in Table 6. Peak-period trips cause 35 to 39 percent of daily automobile emissions, depending on the pollutant. Peak-period work trips cause 23 to 26 percent

Figure 1. District map of Washington, D.C., area.

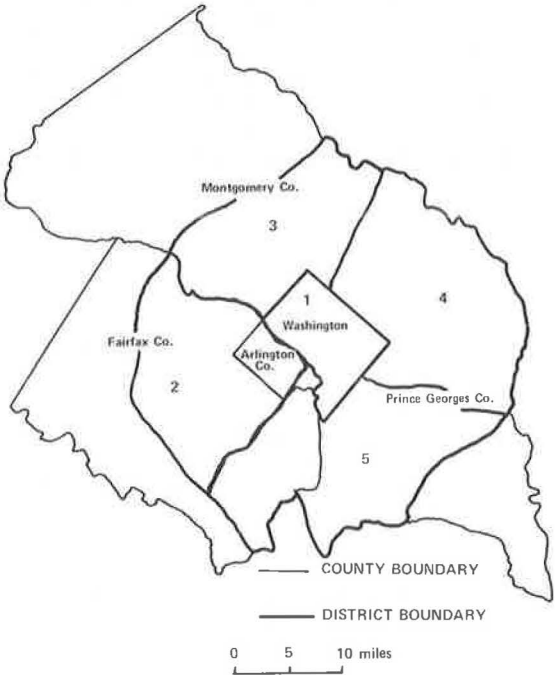


Table 1. Average emission factors.

Pollutant	Factor <sup>a</sup>	Emissions (kg/mile)	
		Washington, D.C.	Allegheny County
CO	e	0.0271	0.0332
	c	0.0723	0.0850
NO <sub>x</sub>	e	0.0035	0.0037
	c	-0.0008	-0.0009
HC	e	0.0028	0.0033
	k	0.0001	0.0001
	c	0.0053	0.0061
	h	0.0048	0.0067
	d	0.0062 <sup>b</sup>	0.0084 <sup>b</sup>

Note: 1 kg/mile = 0.62 kg/km.  
<sup>a</sup>As in equation 1.  
<sup>b</sup>Diurnal evaporations are in kilograms per vehicle per day.

Table 2. Washington emissions per day, VMT, and trip volumes by trip purpose.

Item	Trips		VMT		CO		NO <sub>x</sub>		HC	
	Number	Percent	Amount	Percent	Amount (kg)	Percent	Amount (kg)	Percent	Amount (kg)	Percent
Trip purpose										
HB work	922,000	29	7,100,000	38	257,000	40	25,300	37	29,400	35
HB shopping	639,000	20	2,560,000	14	95,000	15	9,400	14	12,200	14
HB social-recreational	311,000	10	1,890,000	10	60,000	9	7,000	10	7,500	9
HB school	82,000	3	498,000	3	16,000	3	1,800	3	2,000	2
Other	1,250,000	39	6,700,000	36	215,000	33	24,700	36	27,400	32
All <sup>c</sup>	3,200,000	100	18,700,000	100	643,000	100	68,100	100	78,600	93
Emission										
Diurnal									6,200	7
Total									84,700	100

Note: 1 mile = 1.6 km.  
<sup>a</sup>May not agree with column totals due to rounding.

Table 3. Washington cold-start and hot-soak emissions per day by trip purpose.

Trip Purpose	CO			NO <sub>x</sub>			Cold-Start HC			Hot-Soak HC		
	Amount (kg)	Percent		Amount (kg)	Percent		Amount (kg)	Percent		Amount (kg)	Percent	
		Purpose <sup>a</sup>	Total <sup>c</sup>		Purpose <sup>a</sup>	Total <sup>b</sup>		Purpose <sup>a</sup>	Total <sup>b</sup>		Purpose <sup>a</sup>	Total <sup>b</sup>
HB work	67,000	26	10	-740	-3	-1	4,900	17	6	4,400	15	5
HB shopping	23,000	24	4	-260	-3	0	1,700	14	2	3,100	25	4
HB social-recreational	11,000	19	2	-130	-2	0	800	11	1	1,500	20	2
HB school	3,000	18	0	-30	-2	0	200	11	0	400	19	0
Other	34,000	16	5	-340	-2	-1	2,500	9	3	6,000	22	7
All <sup>c</sup>	138,000	21	21	-1,530	-2	-2	10,100	13	12	15,400	20	18

<sup>a</sup>Cold start emissions as percentage of trip purpose emissions.  
<sup>b</sup>Hot soak emissions as percentage of total emissions.  
<sup>c</sup>May not agree with column totals because of rounding.

**Table 4. Washington running emissions per day by trip purpose.**

Trip Purpose	CO		NO <sub>x</sub>		HC	
	Amount (kg)	Percent	Amount (kg)	Percent	Amount (kg)	Percent
HB work	190,000	30	26,000	38	20,100	24
HB shopping	72,000	11	9,700	14	7,500	9
HB social-recreational	48,000	8	7,100	10	5,100	6
HB school	13,000	2	1,800	3	1,400	2
Other	161,000	28	25,000	37	18,900	22
All <sup>a</sup>	505,000	79	69,700	102	53,100	63

Note: Emissions include hot-running exhaust and crankcase emissions.

<sup>a</sup>May not agree with column totals because of rounding.

**Table 5. Washington emissions per mile by trip purpose.**

Trip Purpose	CO	NO <sub>x</sub>	HC	Avg Miles	Avg mph
HB work	36	3.6	4.1	7.7	20
HB shopping	37	3.7	4.8	4.0	19
HB social-recreational	32	3.7	4.0	6.1	21
HB school	33	3.6	4.1	6.1	20
Other	32	3.7	4.1	5.4	20
All	34	3.6	4.5 <sup>a</sup>	5.9	20
Federal test	31	3.7	4.0 <sup>a</sup>	7.5	20

Note: Emissions are in grams per mile. 1 g/mile = 0.62 g/km, 1 mile = 1.6 km.

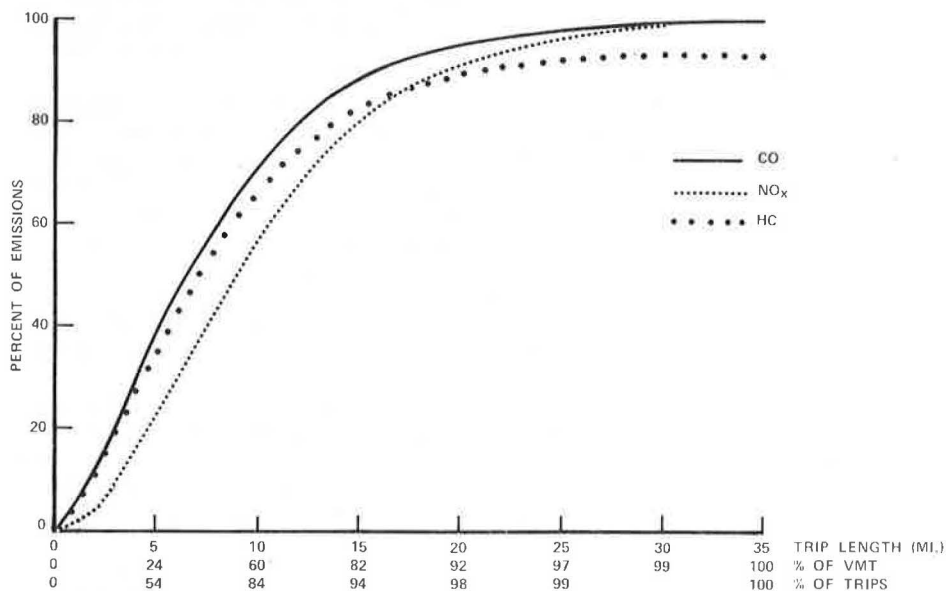
<sup>a</sup>Includes diurnal evaporations.

**Table 6. Washington emissions per day by time of day.**

Time	Trips		VMT		CO		NO <sub>x</sub>		HC	
	Number	Percent	Amount	Percent	Amount (kg)	Percent	Amount (kg)	Percent	Amount (kg)	Percent
Peak	1,020,000	32	6,900,000	37	252,000	39	24,500	36	29,400	35
Off-peak	2,180,000	68	11,900,000	63	391,000	61	43,700	64	49,100	58
Peak HB work	570,000	18	4,600,000	24	168,000	26	16,200	24	19,100	23
Off-peak HB work	350,000	11	2,500,000	13	88,000	14	9,100	13	10,300	12

Note: 1 mile = 1.6 km.

**Figure 2. Cumulative distribution of Washington, D.C., emissions by trip length.**



of daily automobile emissions and about 65 percent of daily work-trip emissions.

The relationship between emissions and trip lengths is shown in Figure 2 by the cumulative distribution of Washington area emissions according to trip length; 53 percent of CO emissions and 50 percent of HC emissions are caused by trips whose length is less than 7 miles (11 km). However, these trips are responsible for only 39 percent of the VMT and indicate that CO and HC emissions per VMT are higher for short trips than for long trips. This is caused by cold starts and evaporations, whose contribution to average emissions per mile (kilometer) increases as trip length decreases, and by the low speeds of short trips compared with long trips in the Washington area [e.g., 4 mph (6.4 km/h) for a 1-mile (1.6-km) trip compared with 22 mph (35 km/h) for a 10-mile (16-km) trip]. NO<sub>x</sub> emissions rates, which are relatively insensitive to cold starts and variations in speeds, do not vary greatly with trip length. Thus, only 37 percent of NO<sub>x</sub> emissions are caused by trips that are less than 7 miles (11 km) long.

Despite the high CO and HC emissions per VMT for short trips, they have lower emissions per trip than long trips. Trips less than 7 miles (11 km) long, which produce 37 to 53 percent of automobile emissions, account for 69 percent of all trips.

The relationship of emissions to trip origins and destinations was investigated by dividing the Washington area into five districts (Figure 1). District 1 is the city of Washington. Table 7 gives the emissions attributable to trips of all purposes that originate or terminate in each district and the emissions produced by district 1 internal and peak-period trips. Table 7 also gives the same information for HB work trips. District 1 trips for all purposes produce 33 to 37 percent of total automobile emissions. District 1 work trips produce 17 to 20 percent of total emissions or roughly half of all work-trip emissions; peak-period district 1 trips cause 15 to 17 percent of total emissions. Roughly 75 percent of the emissions attributable to trips originating or terminating in district 1 are caused by trips that cross the district boundary. This proportion increases to about 80 percent when only work trips are considered.

#### COMPARISON OF RESULTS FROM WASHINGTON, D.C., AND ALLEGHENY COUNTY

Table 8 gives aggregate demographic, geographic, and travel characteristics of the Washington area and Allegheny County. The Washington area has more people and cars and a larger geographic area than Allegheny County. Accordingly, Washington has more trips and VMT per day. The average trip is longer and faster in Washington than in Allegheny County; moreover, Washington area cars are somewhat newer than Allegheny County cars and, on average, travel farther per day.

The aggregate characteristics of automobile emissions in Washington and Allegheny County are given in Table 9. Total emissions of all pollutants are considerably greater in Washington than in Allegheny County; this reflects the greater amount of travel in Washington. However, emissions per VMT are lower in Washington than in Allegheny County. This is attributable to several factors. Because cars in Washington are newer, the emissions are cleaner. Thus, the equation 1 emission parameters are lower for Washington than for Allegheny County (Table 1). The higher average trip speed in the Washington area also reduces average emissions per mile (kilometer). In addition, Washington's longer trip length and greater daily VMT per car reduce the contribution of evaporative and cold-start emissions to average emissions per VMT in the region.

The federal test method of computing emissions underestimates them in both Washington and Allegheny County (Table 9). However, the federal test assumptions of a 7.5-mile (12-km) average trip length and 26 miles (42 km) of travel per vehicle per day are more nearly met in Washington than in Allegheny County. Accordingly, the federal test method approximates Washington area emissions better than Allegheny County emissions.

The distribution of emissions in the two regions according to percentages of emissions and trip types is shown in Table 10. Evaporations are less important relative to other emissions sources in Washington than in Allegheny County; this reflects the

Table 7. Geographic characteristics of Washington emissions per day for all purposes and home-based work trips.

Trip Purpose	District	Trips		VMT		CO		NO <sub>x</sub>		HC		Avg Miles	Avg mph
		Number	Percent	Amount	Percent	Amount (kg)	Percent	Amount (kg)	Percent	Amount (kg)	Percent		
All	1 <sup>a</sup>	400,000	12	1,220,000	7	64,000	10	4,100	6	7,700	9	3.1	13
	1 <sup>b</sup>	391,000	12	2,860,000	15	108,000	17	9,900	15	12,400	15	7.3	17
	1	1,020,000	32	6,630,000	35	237,000	37	23,300	34	28,100	33	6.5	18
	2	830,000	26	5,570,000	30	183,000	28	20,300	30	22,100	26	6.7	20
	3	830,000	26	5,420,000	29	174,000	27	19,800	29	21,400	25	6.5	21
	4	800,000	25	5,350,000	29	168,000	26	19,700	29	20,700	24	6.7	21
Work	5	759,000	24	5,780,000	31	177,000	27	21,500	32	21,500	26	7.6	21
	1 <sup>a</sup>	119,000	4	470,000	3	26,000	4	1,600	2	2,900	4	4.0	13
	1 <sup>b</sup>	269,000	8	2,170,000	12	84,000	13	7,500	11	9,400	12	8.1	18
	1	428,000	13	3,380,000	18	126,000	20	11,800	17	14,400	18	7.9	18
	2	241,000	8	2,120,000	11	72,000	11	7,600	11	8,300	11	8.8	20
	3	242,000	8	2,110,000	11	71,000	11	7,500	11	8,200	10	8.7	21
	4	221,000	7	2,000,000	11	66,000	10	7,200	11	7,600	10	9.1	21
	5	253,000	8	2,280,000	12	76,000	12	8,300	12	8,700	11	9.0	21

Note: 1 mile = 1.6 km.  
<sup>a</sup>Internal trips.      <sup>b</sup>Peak period trips.

Table 8. Aggregate characteristics of Washington and Allegheny County.

Characteristic	Washington	Allegheny County
Population	2,520,000	1,610,000
Area, miles <sup>2</sup>	870	728
Area of district 1, miles <sup>2</sup>	61	55
Cars	1,010,000	519,000
Average car age, years	3.4	4.2
Total daily trips	3,200,000	1,720,000
Total daily VMT	18,700,000	7,280,000
Average trip length, miles	5.9	4.2
Average trip speed, mph	20	18
Average daily VMT per car	19	14
Average daily trips per car	3.2	3.3

Note: 1 mile<sup>2</sup> = 2.6 km<sup>2</sup>. 1 mile = 1.6 km.

Table 9. Aggregate emission characteristics of Washington and Allegheny County.

Pollutant	Washington	Allegheny County
CO		
Total, kg/day	643,000	348,000
Per trip, g	201	202
Per VMT, g	34	48
Per VMT, g, based on federal test	31	42
NO <sub>x</sub>		
Total, kg/day	68,100	27,500
Per trip, g	21	16
Per VMT, g	3.6	3.8
Per VMT, g, based on federal test	3.7	3.9
HC		
Total, kg/day	84,700	48,200
Per trip, g	26	28
Per VMT, g	4.5	6.6
Per VMT, g, based on federal test	4.0	5.1

Note: 1 mile = 1.6 km. 1 g/mile = 0.62 g/km.

Table 10. Comparative distribution of emissions by percentages of trips, VMT, and emissions.

Item	Region	Number of Trips	VMT	CO	NO <sub>x</sub>	HC
Emission						
Diurnal-evaporative	Washington					7
	Allegheny					9
Hot-soak	Washington					18
	Allegheny					24
Cold-start	Washington	60 <sup>a</sup>		21	-2	12
	Allegheny	57 <sup>a</sup>		24	-3	12
Trip purpose						
HB work	Washington	29	38	40	37	35
	Allegheny	28	39	39	39	33
HB shopping	Washington	20	14	15	14	14
	Allegheny	14	10	11	10	11
HB social-recreational	Washington	10	10	9	10	9
	Allegheny	8	8	7	8	7
Other	Washington	41	38	36	39	35
	Allegheny	50	43	43	43	40
Trip type						
Shorter than 5 miles	Washington	54	24	38	22	35
	Allegheny	70	33	53	31	49
District 1, all trips	Washington	32	35	37	34	33
	Allegheny	41	40	49	50	43
District 1, work trips	Washington	13	18	20	17	17
	Allegheny	14	23	22	22	19

Note: 1 mile = 1.6 km.  
<sup>a</sup>Fraction of trips beginning with cold start.



**Table 11. Geographic characteristics of emissions for nonwork trips by percentages of trips, VMT, and emissions.**

Region	District	Number of Trips	VMT	CO	NO <sub>x</sub>	HC
Washington	1	19	17	17	17	16
	2	18	19	17	19	16
	3	18	18	16	18	15
	4	18	16	16	18	15
	5	16	19	15	20	16
Allegheny	1	27	27	27	28	24
	2	19	19	17	18	16
	3	21	19	18	19	19
	4	12	14	11	15	10
	5	11	13	10	13	10

Note: Percentages refer to travel to or from district. 1 mile = 1.6 km.

greater average trip length and prevalence of evaporative emission controls in newer cars in Washington. The cold-start proportions of emissions are similar in the two regions. Given that all other things are equal, the greater average trip length in Washington would tend to reduce the importance of cold starts there compared with that in Allegheny County. However, the greater prevalence of evaporative emission controls in Washington tends to increase the proportion of emissions attributable to cold starts and approximately cancels the effects of the increased trip length.

HB work, shopping, and social-recreational trips produce a slightly greater proportion of emissions, and other trips produce a slightly smaller proportion in the Washington area than in Allegheny County. Short trips are a considerably more important emissions source in Allegheny County than in Washington; this reflects Allegheny County's relatively short average trip length. Trips less than 5 miles (8 km) long produce roughly half of the CO and HC and a third of the NO<sub>x</sub> in Allegheny County; in the Washington area, the proportions are approximately one-third and one-fifth respectively.

Work trips originating or terminating in district 1, the principal city, generate similar proportions of total emissions in Allegheny County and the Washington area. In both regions, district 1 work trips produce more emissions than work trips associated with any other district. However, Washington's district 1 is of considerably lesser importance than Allegheny County district 1 when trips of all purposes are considered. District 1 trips for all purposes produce approximately one-third of Washington area emissions; however, they produce roughly half of Allegheny County emissions. This is a consequence of the relative dispersion of nonwork trips in the Washington area compared with those in Allegheny County (Table 11). Although district 1 trips dominate both nonwork travel and emissions in Allegheny County, all Washington districts are of approximately equal importance for nonwork travel and emissions.

## CONCLUSIONS

The results suggest several ways in which measures that are effective in reducing automobile use and emissions in the Washington area are likely to differ from measures that are effective in achieving the same objectives in Allegheny County. One difference concerns the length of trip, to which emissions reduction measures should be oriented. In the Washington area, approximately two-thirds of the CO and HC emissions and three-quarters of the NO<sub>x</sub> emissions are caused by trips that are at least 5 miles (8 km) long. Thus, measures designed to affect relatively long trips, such as freeway bus service and bus priority, may be especially useful in reducing Washington area automobile emissions. In Allegheny County, trips less than 5 miles (8 km) long and those longer than 5 miles (8 km) generate roughly equal quantities of CO and HC. Measures serving long trips and measures oriented to short trips, such as jitney and demand-responsive transit service, are both likely to be important in Allegheny County.

A second difference between Washington and Allegheny County concerns the geographic orientation of the trips, to which emissions reduction measures should also be directed. Trips to or from the central area of Allegheny County produce approximately half of the county's automobile emissions and, depending on the pollutant, cause 50 to



60 percent more emissions than trips associated with any other part of the county. Thus, measures whose principal orientation is trips to or from the central area, such as improved radial transit service and restrictions on central-area automobile use, might be highly effective in reducing Allegheny County automobile emissions. In Washington, trips to or from the central area are responsible for only about 35 percent of regional automobile emissions and produce only 10 to 30 percent more emissions than trips associated with certain other parts of the region. Therefore, measures directed at noncentral travel, such as improved intersuburban transit service and extension of automobile use disincentives to the suburbs, could be important supplements to central travel measures in the Washington area. In both Washington and Allegheny County, central travel measures must affect trips between the suburbs and the central area as well as trips within the central area to be effective in reducing regional emissions.

There are also several ways in which the Washington area and Allegheny County are similar. Work trips cause approximately 35 percent of automobile emissions in both the Washington area and Allegheny County. District 1 work trips produce about 20 percent of automobile emissions in both regions. Thus, measures directed primarily at work trips, such as improved peak-period transit service and increased long-term parking fees, may have similar effects on automobile emissions in the Washington area and Allegheny County.

Cold-start and evaporative emissions, which are independent of trip lengths and speeds, can significantly impair the emissions reduction effectiveness of park-and-ride transit in both regions. The impairment is most severe in the case of HC. For example, park-and-ride transit in Allegheny County that requires a 1-mile (1.6-km) home-to-transit automobile trip and serves work trips whose length exceeds 5 miles (8 km) would achieve 62 percent of the reduction in automobile HC emissions that would be achieved by a transit system that had equal ridership but did not require automobile access. In Washington, where trips are longer and evaporations are somewhat less important than in Allegheny County, the equivalent proportion would be 66 percent.

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