that should be considered at least qualitatively, but also quantitatively where data and methodologies are available, in an alternatives analysis include (a) air quality, (b) energy consumption, (c) community, (d) financial, (e) economic, (f) travel, and (g) related impacts.

The magnitude as well as the incidence of these impacts should be estimated carefully. The incidence of impacts rather than the magnitude of the impacts is frequently the source of controversy in many transportation planning analyses. The potential implementation of travel disincentives will require thorough analyses to ensure that the benefits and negative impacts of a transportation control package are distributed equitably and that the air quality impacts are not achieved by the creation of serious hardships for selected population subgroups.

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Exhaust Emissions, Fuel Consumption and Traffic: Relations Derived from Urban Driving Schedule Data

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Traffic variables were calculated from the defined speed-time history of the LA-4 driving schedule for each of the 18 stop-to-stop cycles that constitute this schedule, in a manner similar to that previously applied to field data. The ability of these traffic variables to explain emissions and fuel consumption was examined by using data from 12 automobiles run on federal test procedure dynamometer tests. It was found that hydrocarbon emissions can be expressed as a linear function of average trip time per unit distance for urban driving at low speeds. Relations of variables that are more difficult to measure for actual traffic are required for carbon monoxide and oxides of nitrogen. Data collected from a single test can yield a relation from which a vehicle's fuel consumption at any urban speed can be estimated.

When a vehicle is driven in urban traffic it undergoes frequent changes in speed as a result of interactions with other vehicles and the complex traffic control system. Despite the complexities of urban speed-time histories, a simple relation has been found between fuel consumption and average traffic speed (1-3). On the basis of experiments conducted in street traffic, it was concluded that the fuel consumed per unit of distance (ϕ) can be expressed as a linear function of the trip time per unit of distance ($\bar{t}$) for average traffic speeds less than about 60 km/h. That is,

$$\phi = k_1 + k_2\bar{t} = k_1 + k_2/\bar{v} \quad \bar{v} < \sim 60 \text{ km/h} \qquad (1)$$

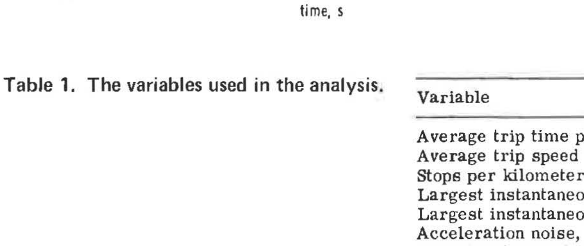
where $\bar{v}$ is the average trip speed, and k_1 and k_2 are vehicle-dependent parameters (1-3).

Equation 1 has previously been used successfully to explain fuel consumption measured in the field (1-5), measured by using different fixed-urban-driving schedules (5), and calculated by others by use of computer simulation (6, 7). One reason why a simple relation can explain fuel consumption so well in such a complex process as urban driving is that other variables important to the determination of fuel consumption were shown (1, 2) to be correlated with $\bar{t}$ in actual urban traffic. Therefore, their effects are implicitly imbedded in Equation 1.

It was found (2) that when a long speed-time record of a vehicle was analyzed, the relation (Equation 1) applied with essentially the same parameters irrespective of which of four different sampling methods was chosen. One of these sampling methods used "microtrips", which are defined as portions of travel between consecutive stops of the vehicle (2).

The LA-4 fixed-urban-driving schedule, which is the basis of the federal test procedure (FTP) used by the U.S. Environmental Protection Agency (EPA) to estimate official emissions and city fuel economy, consists of 18 stop- (in one case a near stop) to-stop cycles (see Figure 1). Each execution of the LA-4 driving schedule provides 18 microtrip data. The nine traffic variables shown in Table 1 were computed for the 18 cycles from the speed-time definition of the LA-4 driving schedule (8) in a similar manner to the approach used previously (1). The cycle, or microtrip, is defined from the beginning of the stop to the moment that the vehicle again comes to a stop; that is, stopped portions occur at the beginning of the cycles. One of the variables considered is stops per kilometer (S), defined as follows: Each cycle involves one stop and has an associated distance of travel (D). If the cycle is repeated N times, N stops are generated in ND kilometers. Hence, we may consider the individual cycle to be characteristic of a speed-time profile with D^{-1} stops per kilometer. The other variables in Table 1 are

Figure 1. Speed-time history of the LA-4 driving schedule and three phases of the 1975 FTP.



defined in the same way as those introduced in other reports (1, 2).

The intercorrelations among the traffic variables defined in Table 1 for the LA-4 driving schedule were examined in the same way as was previously done for data collected in the Detroit metropolitan area. The results are discussed in a more detailed version of this paper (9).

We will use the speed-time definition of the LA-4 driving schedule and data collected from automobiles driven on this schedule on a chassis dynamometer (a) to explore whether emissions for a fully warmed vehicle can be explained in terms of simple traffic variables, as was previously done for fuel, and (b) to investigate whether one test on the LA-4 driving schedule can provide enough information to derive Equation 1 for a particular automobile.

RESULTS

In the 1975 FTP, which is used to measure official EPA emissions and city fuel economy, vehicles execute the LA-4 fixed-urban-driving schedule on a chassis dynamometer. A 12-h soak at normal room temperature precedes the test. The first five cycles, from time 0 to 505 s, are referred to as the cold-start phase. Cycles 6-18 (505-1372 s) are called the stabilized phase. At the end of cycle 18 the engine is switched off for 10 min. The first five cycles are then repeated (cycles 19-23); this third phase is called the hot start. To obtain the official FTP emissions and fuel economy values, the data from the cold-start and hot-start phases are weighted by factors of 0.43 and 0.57, respectively, to reflect estimated proportions of cold and hot starts.

By use of an approach similar to that we previously used (1), we apply multivariate analysis to emissions in the hope of identifying those independent (i.e., traffic) variables that best explain the various emissions. In an attempt to obtain data for vehicles after they have reached stable operating conditions, we exclude the cold phase (i.e., cycles 1-5) from the analysis. However, because the test includes a hot-start repeat of cycles 1-5, noncold data are available for each of the 18 cycles.

Exhaust emissions data are analyzed for 12 arbitrarily chosen 1975 and 1976 automobiles, which were run on the FTP by General Motors. Each automobile was equipped with a catalytic converter, so emissions both before (engine-out) and after (tail pipe) the catalytic converter are studied.

Hydrocarbons

Results of regression analyses of both engine-out and tail-pipe hydrocarbon (HC) emissions for the 12 automobiles are shown in Table 2. For tail-pipe HC, the best single variable is $\bar{t}$ for 5 automobiles, f_s^T for 3, and W for 1; however, no traffic variable has significant correlations for 3 automobiles.

The engine-out results show more consistency from

Table 1. The variables used in the analysis.

Variable	Symbol	Unit
Average trip time per unit distance	$\bar{t}$	s/km
Average trip speed ($= \bar{t}^{-1}$)	$\bar{v}$	km/h
Stops per kilometer or D^{-1}, where D is distance traveled in cycle	S	km^{-1}
Largest instantaneous deceleration, or braking, during cycle	b_{max}	m/s^2
Largest instantaneous acceleration during cycle	a_{max}	m/s^2
Acceleration noise, defined as $[(\int a^2\,dt)/T]^{1/2}$, where a is instantaneous acceleration and T is cycle duration	σ_a	m/s^2
Work performed per unit distance to accelerate the vehicle $= \int avdt/D$, where v is the instantaneous speed and integration occurs only for a > 0	W	m/s^2
Fraction of time spent stopped	f_s^T	
Fraction of distance traveled coasting or braking, defined as $a < -0.15$ m/s^2	f_c^D	

Table 2. Multiple correlation coefficient between HC(g/km) and the first two traffic variables to enter a linear piecewise regression, and the simple correlation coefficient with $\bar{t}$.

	Engine-Out			Tail Pipe		
Automobile	Best Single Variable and Second Variable Entering	Multiple Correlation Coefficient	Correlation with $\bar{t}$ Alone	Best Single Variable and Second Variable Entering	Multiple Correlation Coefficient	Correlation with $\bar{t}$ Alone
1	$\bar{t}$, W	0.984	0.951	f_a^T, a_{max}	0.890	0.819
2	-[a]	-[a]	-[a]	-[a]	-[a]	-[a]
3	$\bar{t}$, b_{max}	0.890	0.873	$\bar{t}$, a_{max}	0.737	0.626
4	$\bar{t}$, W	0.955	0.929	$\bar{t}$, -	0.537	0.537
5	$\bar{t}$, b_{max}	0.771	0.744	-[a]	-[a]	-[a]
6	W, σ_a	0.924	0.837	W, $\bar{v}$	0.852	0.526
7	$\bar{t}$, b_{max}	0.764	0.736	-[a]	-[a]	-[a]
8	$\bar{t}$, W	0.926	0.899	$\bar{t}$, W	0.954	0.944
9	$\bar{t}$, W	0.928	0.897	$\bar{t}$, $\bar{v}$	0.681	0.628
10	W, f_a^D	0.892	0.766	f_a^T, b_{max}	0.670	0.574
11	$\bar{t}$, f_a^T	0.888	0.861	$\bar{t}$, $\bar{v}$	0.849	0.782
12	$\bar{t}$, W	0.934	0.870	f_a^T, $\bar{v}$	0.721	-[a]

Note: Second variable explains insignificantly more variance.

[a] Regression not significant at $p = 0.05$.

Table 3. Engine-out HC emissions at arbitrary urban speed expressed in terms of those at average trip speed of LA-4 driving schedule.

Automobile	r	a^a (g/km)	b^a (g/s)	α^b (km/s)
1	0.951	0.15	0.0135	0.0080
2	(0.038)	-[c]	-[c]	-[c]
3	0.873	0.37	0.0063	0.0058
4	0.929	0.55	0.0076	0.0054
5	0.744	0.23	0.0030	0.0053
6	0.837	0.78	0.0094	0.0051
7	0.736	0.72	0.0045	0.0037
8	0.899	0.20	0.0097	0.0074
9	0.897	0.12	0.0066	0.0076
10	0.766	1.15	0.0062	0.0033
11	0.861	0.62	0.0084	0.0053
12	0.870	0.10	0.0225	0.0084
Average	0.851	0.45	0.0089	0.0059

[a] Parameters in regression $y(\bar{t}) = a + b\bar{t}$ where $y(\bar{t})$ is HC(g/km) at average trip speed $\bar{t}$ (s/km).

[b] The slope α is defined by $[y(\bar{t})]/[y(\bar{t}_0)] - 1 = \alpha(\bar{t} - \bar{t}_0)$ where $\bar{t}_0 = 114.4$ s/km is the average trip speed for the LA-4 driving schedule, and $\alpha = b/(a + b\bar{t}_0)$.

[c] Regression not significant at $p = 0.05$.

automobile to automobile. The best single variable is $\bar{t}$ for 9 of the automobiles and W for 2, but no traffic variable has any significant correlation with HC for 1 automobile. The single variable $\bar{t}$ explains more than half of the variance in HC for 11 of the 12 automobiles studied. The average variance explained by $\bar{t}$ is more than 70 percent for these 11 automobiles. Because of their higher correlations with traffic variables, we will first discuss engine-out HC for individual automobiles. Later we will show that similar results apply to tail-pipe values averaged over all of the automobiles.

For low-speed urban traffic we obtain a relation between engine-out HC and average trip time per unit distance similar to that found for fuel, namely

$$y(\bar{t}) = a + b\bar{t} \quad (2)$$

where $y(\bar{t})$ is HC emissions in grams per kilometers at average trip time per unit distance, $\bar{t}$. Specific values of a and b are given in Table 3.

Information was available that enabled us to compute the engine-out time rate of HC emissions at idle for three automobiles. The values are compared below to the parameter b in Equation 2 (see Table 3).

Automobile	b (mg/s)	HC Emission Rate at Idle (mg/s)
10	6.2	6.4
11	8.4	8.3
12	22.5	16.8

We see that, as in the case of fuel consumption (3), the coefficient of $\bar{t}$ can be associated with the time rate at idle.

A plot of $y(\bar{t})$ versus $\bar{t}$ is shown in Figure 2 for automobile 11, the automobile that has the just below median rank correlation coefficient (i.e., rank 7 out of 12, see Table 2). The broken line that extends beyond the data is to indicate the intercept (a) in Equation 2. This relation is not valid for high speeds ($\bar{t} < \sim 60$ km/h), where HCs, in fact, increase with speed. The correlation coefficients for $y(\bar{t})$ versus $\bar{t}$ are increased for all automobiles if cycle 19 (the first cycle after the 10-min soak) is deleted; further improvements result if cycle 20 is also deleted.

A relation of the form of Equation 2 enables us to express the fractional change (f) in emissions that corresponds to a change in trip time from $\bar{t}_0$ to $\bar{t}$ as a simple multiple of the change in trip time. The dependence of f on $\bar{t}$ can be expressed in terms of a single quantity (α) as follows:

$$f = [y(\bar{t}) - y(\bar{t}_0)]/y(\bar{t}_0) = \alpha(\bar{t} - \bar{t}_0) \quad (3)$$

where α is given explicitly by

$$\alpha = b/(a + b\bar{t}_0) \quad (4)$$

Values of α are given in Table 3 for the 11 automobiles that had significant correlations between $y(\bar{t})$ and t.

If R is the ratio of emissions at the two trip times $\bar{t}$ and $\bar{t}_0$ [i.e., $y(\bar{t})/y(\bar{t}_0)$], then

$$R = 1 + f = 1 + \alpha(\bar{t} - \bar{t}_0) \quad (5)$$

We take $\bar{t}_0 = 114.4$ s/km, the average value for the LA-4 driving schedule, and also the average value for an FTP test because the sum of the weighted factors in phases 1 and 3 is unity. One of the shaded areas in Figure 3 includes the relation (Equation 5) for our automobiles; i.e., the boundaries of the shaded area correspond to the largest and smallest of the 11 values of α.

Relations of the form

$$R = \exp(A + B\bar{v} + C\bar{v}^2) \quad (6)$$

are given in an EPA document (10) for the speed range 24-72 km/h for tail-pipe emissions for 11 different cases (high and low altitudes) together with separately determined values at the particular average speeds of 16 and 8 km/h. When each of these 11 relations (Equation 6) for HC is plotted over its stated range of validity as a function of $\bar{t}$, none shows other than small departures from linearity. All 11 curves are contained within the indicated area in Figure 3, which also shows the maximum and minimum of the specific values given for 16 and 8 km/h.

Figure 2. Engine-out HC emissions in g/km [= $y(\bar{t})$ versus $\bar{t}$ for automobile 11.

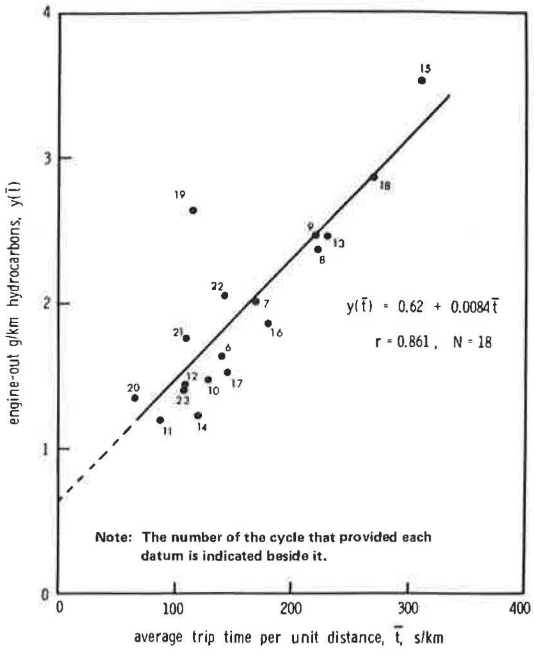


Figure 3. HC emissions versus $\bar{t}$, expressed as a multiple (R) of their value at the average trip time per unit distance of the LA-4 fixed driving schedule.

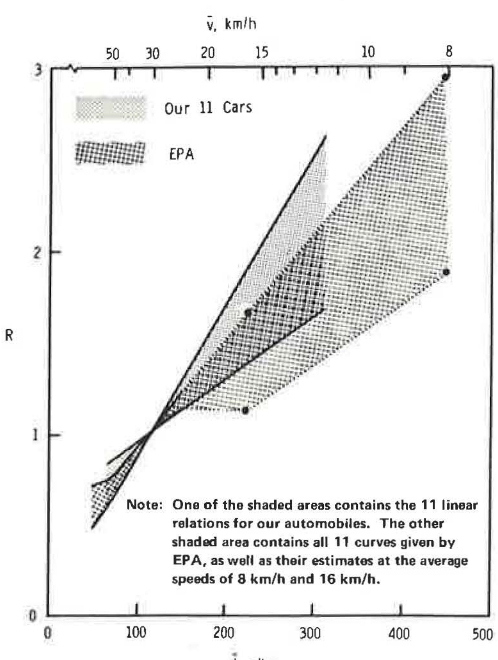


Figure 4 shows Equation 5 plotted with $\alpha = 0.0059$ km/s, the average value for the 11 of our automobiles that had significant correlations. A curve that represents the average values for the EPA data is also shown and is in reasonable agreement with our result. If $y(\bar{t})$ were directly proportional to $\bar{t}$ (i.e., $a = 0$ in Equation 2), then α would have the value 1/(114.4 s/km) = 0.0087 km/s, which may be compared to the observed values given in Table 3.

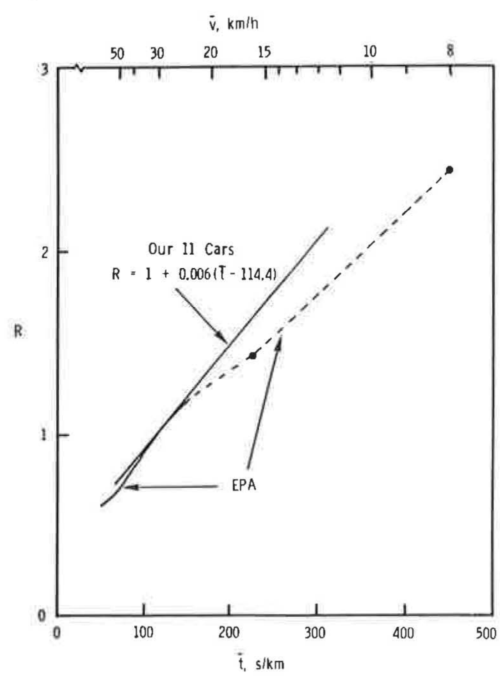
In the above analysis, for our automobiles only engine-out HC emissions were used because the larger variability of the tail-pipe emissions reduced correlations with traffic variables for individual automobiles (see Table 2). We averaged all of the automobiles in an attempt to reduce the effect of this variability. For each automobile, the ratio (p) of grams per kilometer HC for each cycle to the average value for that automobile for all cycles except 19 and 20 was determined. These two cycles, which occur just after the 10-min soak, sometimes have much higher HC emissions than do the other cycles. The average value of the ratio p over the 12 automobiles is shown plotted versus $\bar{t}$ for all 18 cycles in Figure 5. The least-squares fit to the data for 16 cycles (excluding 19 and 20) shown in Figure 5 leads, through Equation 4, to a value of $\alpha = 0.0067$ km/s for Equation 3. This may be compared to the average of the 11 engine-out values, namely, $\alpha = 0.0059$ km/s. Thus, the overall tail-pipe HC emissions exhibit a dependence on trip speed essentially similar to that found in the engine-out case.

The following statement summarizes all the data discussed above and shown in Figures 2-5: In low-speed urban driving, for each 1-s increase in trip time per kilometer, the HC emissions for a given vehicle increase by about 0.6 percent of their value at the average trip speed of the LA-4 driving schedule.

In general, the fractional difference between the HC emissions $\epsilon(\bar{t}_1)$ and $\epsilon(\bar{t}_2)$ at two different average trip times per unit distance $\bar{t}_1$ and $\bar{t}_2$ s/km, respectively, is expressed as

$$[\epsilon(\bar{t}_2) - \epsilon(\bar{t}_1)]/\epsilon(\bar{t}_1) = [0.006\,(\bar{t}_2 - \bar{t}_1)]/[1 + 0.006(\bar{t}_1 - 114)] \quad (7)$$

Figure 4. Average values of the Figure 3 representations.



Application to Published Computer Simulation Results

Lieberman and Cohen (11) calculated the effect on fuel economy and emissions of permitting right turns on red at signalized intersections. They applied a detailed computer simulation model to a network of streets in Washington, D.C. Emissions and fuel consumption were obtained by summing contributions from each individual vehicle maneuver.

Figure 5. Dependence of tailpipe HCs on average trip speed.

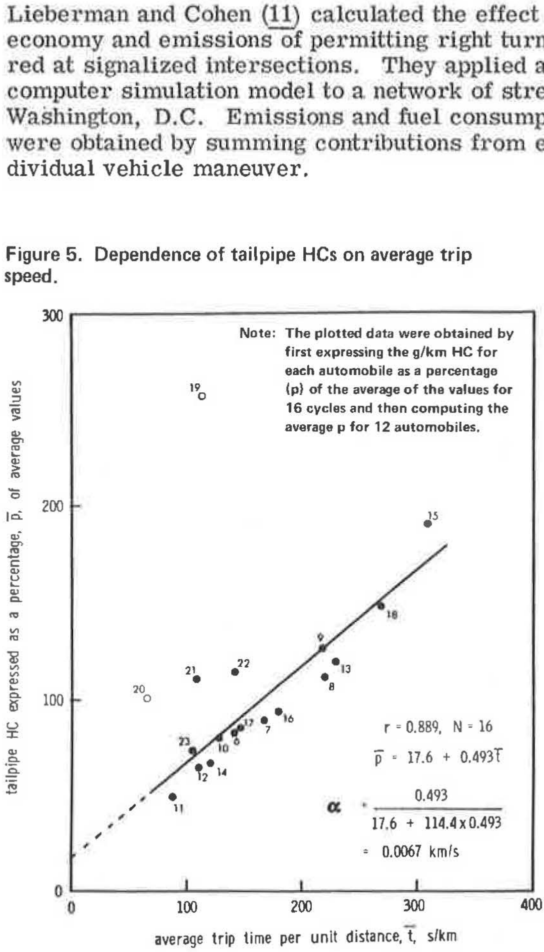
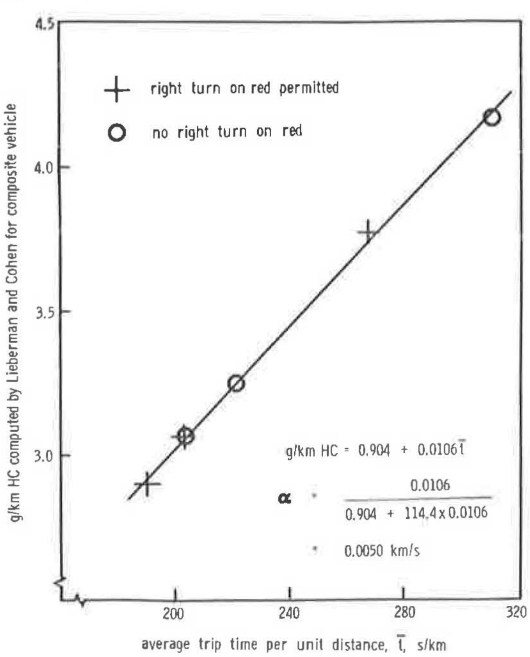


Figure 6. HC emissions estimated by using detailed computer simulation versus the corresponding average trip times per unit distance from the same simulation.



Three levels of flow were simulated (11), each with and without a right-turn-on-red policy, and the average speeds for these six cases were calculated. It was shown (6) that the six values of average speed alone may be used with the aid of Equation 1 to estimate effects on fuel consumption without performing the detailed summation of the computed fuel used for each detailed maneuver. Equation 1 has also been applied to right-turn-on-red field data (4). Further similar computer simulation data (12) were also shown (7) to fit the linear fuel consumption relation (Equation 1).

We now apply a similar approach to the HC emissions determined in the simulation (11). The six values of HC emissions given in Table 1 of Lieberman and Cohen (11) for a composite vehicle are shown in Figure 6 as a function of the value of $\bar{t}$ determined in their simulation. A linear relation between grams per kilometer and $\bar{t}$ fits the data very well. This relation may be written in the form of Equation 3 with $\alpha = 0.050$ km/s, which may be compared to the value, $\alpha = 0.0059$ km/s, obtained for our 11 automobiles.

As in the case of fuel consumption (4, 6, 7), the effect of traffic changes on HC emissions may be explained in terms of a simple linear function of $\bar{t}$, irrespective of whether the changes are due to different traffic volumes or different operating policies.

Applications to HC Measured on Dynamometer Replications of Street Driving

Data are given for HC emissions for trips at the four urban speeds of 19, 29, 31, and 50 km/h in Figure 3 of Herman and others (13). A linear least squares fit to the four $[\bar{t}, y(\bar{t})]$ pairs derived from these data yields

$$y(\bar{t}) = 0.075 + 0.001\,84\,\bar{t} \qquad r = 0.918 \tag{8}$$

Substitution of the parameters of this regression into Equation 4 yields $\alpha = 0.0065$ km/s, which may be compared to the value, $\alpha = 0.0059$ km/s, derived for our 11 automobiles.

It would seem that the data currently available are not sufficient to support substantially more elaborate expressions of the speed dependence of HC emissions in urban traffic than the one proposed above. The degree of complexity of EPA's Equation 6 would appear to be difficult to support.

The simplicity of Equation 5 would allow us to make simple analytical estimates of the effect of increasing circulation speeds in congested central business district (CBD) networks on overall traffic system HC emissions, as we have previously done for fuel (14).

Carbon Monoxide

No consistent automobile-to-automobile interpretation of tail-pipe carbon monoxide (CO) emissions has emerged from this study. This may be due, in part, to the large effects that can result in tail-pipe CO due to small, essentially erratic, excursions into mixture enrichment. Note that, as before, cold-start data are excluded. For 7 of the 12 automobiles in the engine-out case, W (see Table 1) explained more variance in CO than did any other single variable. The variable W and grams per kilometer CO were significantly correlated ($p < 0.05$) for 11 of the 12 automobiles. The variable $\bar{t}$ had a correlation significant at this level for 8 automobiles.

Analysis of tail-pipe CO in a similar way to that represented in Figure 5 yields a weak correlation with $\bar{t}$ and a value of $\alpha \approx 0.01$ km/s. A treatment of the CO simulation data of Lieberman and Cohen (11) yields a

Table 4. Fuel consumption per unit distance (ϕ) as a function of $\bar{t}$ for 17 cycles of the LA-4 fixed driving schedule (cycle 15 has been excluded).

Automobile	$\phi = k_1 + k_2\bar{t}$ r	k_1 (mL/km)	k_2 (mL/s)	Idle Fuel Flow Rate (mL/s)	Inertia Weight Class (kg)	Multiple Correlation Between ϕ and $\bar{t}$, W
1	0.901	71.6	0.959	-	2500	0.964
2	0.943	61.9	0.689	-	2000	0.984
3	0.918	84.2	0.761	-	2300	0.983
4	0.929	74.5	0.558	-	1800	0.979
5	0.903	56.3	0.960	-	1400	0.976
6	0.885	75.8	0.578	-	2000	0.977
7	0.941	77.7	1.052	-	2500	0.990
8	0.921	68.8	0.773	-	2300	0.982
9	0.915	77.0	0.700	-	2000	0.986
10	0.883	74.1	0.516	0.392	2000	0.967
11	0.938	65.3	0.656	0.535	1800	0.984
12	0.890	74.8	0.540	0.431	2000	0.979

linear relation between grams per kilometer CO and $\bar{t}$ that has a similar absence of scatter to that found for HC (Figure 6). However, this near perfect fit to a linear relation [which also occurs for nitrogen oxides (NO_x) but with a very small slope] appears to result from the smooth analytic dependence of emissions on acceleration and speed that is built into the simulation model. The regression obtained from the results of the simulation for CO implies a value of α of 0.007 km/s.

Watson and Milkins (15) and Watson, Milkins, and Bulach (16) used computer simulation to obtain relations that have little scatter between CO and average speed and between HC and average speed. They concluded (16) that, for these emissions, models that accounted for variations in traffic speed alone were as reliable as more complex models. The present analysis of actual emissions data yields this same conclusion for HC but a less definitive result for CO. The analytic relation between CO and speed given (15) gives a value of α of 0.0085 km/s.

An analysis of the measured CO emissions that correspond to trips at the four urban speeds given in Figure 5 of Herman and others (13) gave no significant relation between grams per kilometer CO and $\bar{t}$, in contrast to the result discussed above for HC.

The coefficient of $\bar{t}$ in a regression of $\bar{t}$ on grams per kilometer CO is unlikely to be interpretable in terms of the time rate of CO emissions at idle, because this idle rate is so small. We find that, typically, the time rate of engine-out CO emissions at idle is about 0.15 times the average rate over the 18 warm LA-4 cycles.

NO_x

Although the catalyst has a much smaller effect on NO_x than on HC and CO, the correlations with traffic variables were nonetheless slightly higher for the engine-out emissions. The catalyst is an oxidizing device, so nominally, there should be no effect on NO_x.

One variable, W, had the highest correlation with engine-out grams per kilometer NO_x for 11 of the 12 automobiles. For all 12 automobiles the correlations between grams per kilometer NO_x and W ranged from 0.81 to 0.96; the average was 0.90 For the tail-pipe case the correlations between grams per kilometer NO_x and W ranged from 0.69 to 0.96; the average was 0.88.

An analysis of the type represented in Figure 5 provided no useful relationship between grams per kilometer NO_x and $\bar{t}$. The constant terms in the 12 linear regressions of W on grams per kilometer NO_x are relatively small and unsystematic in sign. This suggests a relationship of the form

$$\text{g/km } NO_x = aW \qquad (9)$$

for low-speed urban driving.

Fuel Consumption

The fuel consumed in each of the 18 cycles was calculated from the tail-pipe gaseous emissions by use of the carbon balance technique. The fuel consumed per unit distance (ϕ) has large correlations with both S (see Table 1) and $\bar{t}$ for all 12 automobiles. In no case was the simple correlation coefficient less than 0.9, in good agreement with earlier findings (2, 3, 5).

For a more detailed examination of the relations between ϕ and traffic variables, we excluded cycle 15, which has a distance of only 0.11 km. This corresponds to our previous treatment of field fuel consumption data, in which only data that represent more than 0.2 km of travel were analyzed (3).

For the remaining 17 cycles, the best single variable to explain ϕ was $\bar{t}$ for 10 of the automobiles and S for 2, although in no case were the correlation coefficients for these two variables substantially different. When $\bar{t}$ was forced to be the first variable, the second variable to enter a piecewise linear regression was W for all 12 automobiles. This result is in agreement with that obtained in urban street traffic (1, 2).

The parameters k_1 and k_2 of Equation 1 as determined from the 17 cycles are shown in Table 4. The average fuel flow rate (I) during periods when the vehicle was idling was calculated for three automobiles for which we had appropriate data available. For these k_2 is approximately proportional to I (see Table 4), in agreement with the result from urban street traffic (3). As was found for field data, the parameter k_1 is approximately proportional to the vehicle weight.

SUMMARY AND DISCUSSION

The results presented show that HC emissions (g/km) can be expressed approximately as a linear function of the average trip time per unit distance ($\bar{t}$). This result implies that the speed dependence of grams per kilometer HC may be characterized by a single parameter. The results are in reasonable quantitative agreement with information given by EPA. Both our results and those of EPA can be approximately summarized as follows: For each 1-s increase in $\bar{t}$, the grams per kilometer HC emissions increase by about 0.6 percent of their value at the average trip speed of the LA-4 driving schedule.

This simple result can be used to derive the speed dependence of results obtained by detailed computer simulation and by replicating an actual urban speed-time history on a chassis dynamometer.

The dynamic variable that best explains the emissions of NO_x and CO on an individual LA-4 test is W, the work performed per unit distance to accelerate the vehicle. This result is in accord with the usual association between NO_x and acceleration characteristics. It is difficult to characterize overall traffic characteristics of an urban system in terms of W. However, this finding does not preclude the possibility that speed characteristics alone, through their correlations with acceleration characteristics, might provide an adequate description of CO and NO_x emissions for a more extensive data set.

The fuel consumptions in individual cycles of one FTP were shown to fit a linear relation in $\bar{t}$, a result comparable to that obtained in urban street traffic. The parameters in this relation are interpretable in the same way as those for the field data. The FTP fuel economy is the fuel economy appropriate for a particular urban speed, namely, the average speed of the LA-4 driving schedule (5). The linear relation derived from the individual cycles of one FTP test permits fuel economy to be calculated at any urban speed.

We have organized the detailed information contained in one FTP test in a form different from that customarily used. The relations obtained show reasonable stability from automobile to automobile. This approach would appear to offer a fruitful method for investigation of system parameter changes. Information such as that in Figures 2 and 6 and Table 4 could be more instructive in before-and-after comparisons than the simple FTP overall values, especially since the overall values can be much affected by anomalous behavior in only one small part of a test.

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