TRAPOL: A COLD-START-SENSITIVE SIMULATION MODEL OF TRAFFIC-GENERATED AIR POLLUTION EMISSIONS

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Introduction

It should not be a surprise to anyone that the automobile is a primary source of the air pollutants Carbon Monoxide (CO), Hydrocarbons (HC), and Nitrogen Oxides (NOx). The severity of the issue is well documented, and the search for viable solutions to this complex problem is widely publicized, if still hesitant and speculative in nature.

The use of computer models for the analysis of air pollution problems, although widespread and increasing, is constrained by a problem of scale. HC and NOx display their most severe impact on a metropolitan-wide scale, where their presence contributes to the formation of photochemical smog. CO, on the other hand, is a local pollutant whose most adverse effects are felt relatively close to its source. This disparity in scale implies that different modeling techniques should be used for the two classes of pollutants. While a macro-scale is appropriate for HC and NOx, a micro- or meso-scale is correct for CO. Also, while a small-scale model of CO concentrations can be used to predict the HC and NOx contributions of a small area to the metropolitan area, a large scale HC/NOx model cannot easily be used to predict local CO concentrations.

The phenomenon of the "cold start" further aggravates the severity of CO pollution on the local scale. When a vehicle has sat for some time and is then started, CO emissions from the engine are considerably greater than usual until normal operating temperature is attained. This effect will become more pronounced in the future as catalytic converters with their high operating temperatures become widely used. For typical urban trips, currently manufactured vehicles emit about 50% of their total emissions during cold operation (10), and 1976 cars can be expected to emit 90% of their CO during the first two minutes of operation (17).

The cold start effect is most pronounced for engines that have sat for 12 hours or more, but the phenomenon is also observed after shorter periods, such as for sporting events, especially when ambient temperatures are low.

Since gasoline-powered vehicles account for over 90% of the total non-natural CO emitted per year in American cities (15), and since a large portion of these emissions can be attributed to cold starts, it is clear that cold start emissions are a major source of CO pollution. CO is an air pollutant which disperses relatively quickly and its concentrations may vary immensely over short distances. Differences of a factor of three are not uncommon for measurements on opposite sides of a given street (12). Since the effects of CO emissions are felt most intensely near their source, it is imperative that attention be given to the impact of cold-start CO emissions on a local scale. When a cold vehicle starts in a congested area, its total cold-start contribution may well be dumped into a single city block. If many vehicles in the block are starting cold, dangerous CO concentrations may result for that area. Fortunately most cold starts are widely dispersed over non-congested areas, as in the morning rush hour, when commuters all over the city and suburbs make cold starts. A less fortunate situation occurs during the evening rush hour or when a large sports event, for example, releases thousands of persons who start vehicles in a common parking area at about the same time. Concerts, entertainment events, public gatherings, and business firms with regular hours may cause similar local CO pollution episodes. Enclosed parking facilities aggravate such situations even further.

Once air quality standards have been attained they must be maintained. If a proposed construction project were known to endanger the maintenance of standards due to its potential for air pollution, the question should be raised as to whether the project should be completed or even started. In recognition of the fact that any facility which will attract motor vehicles is a potential air polluter, the U.S. Environmental Protection Agency (EPA) has proposed regulations (6) requiring the states to consider the air pollution implications of planned facilities and to prevent the construction of those whose completion would cause violation of air quality standards. Included within the scope of the regulations are "not only the types of facilities commonly known as stationary sources but also facilities such as airports, amusement parks, highways, shopping centers, and sports complexes."

The possibility that a new sports complex could create violations of CO standards is quite real in the light of cold-start considerations.

If a city were to build a new sports complex in a renovated area of the central business district, as some cities have done and others have proposed, it is quite probable that vehicles attempting to exit the area after an event would create additional congestion in the narrow downtown streets. With congestion, the cold-start emissions of vehicles leaving the event could become concentrated in a small area, causing a serious, although hopefully short-lived, CO pollution episode. To investigate the severity of such a possibility, a medium-scale, traffic-oriented, cold-start sensitive CO model is needed. It is hoped that the following development will lead to such a tool.

The modeling effort currently being pursued is in three parts: TRADYN, a meso-scaled traffic simulator; TRAPOL, a cold-start sensitive CO emissions model; and CODISP, a CO dispersion model, yet to be designed. The first part is being tested and refined, the second is nearing implementation, and the third is nearing conceptualization.

A. The Traffic Submodel, TRADYN

TRADYN (TRAffic DYNamics) is a simulation model of rush-period urban traffic. TRADYN monitors the flow of vehicles through links and nodes in a conceptualized urban street grid by treating traffic flow somewhat as a fluid. A link corresponds to a city block; a node to an intersection. A link may be one-way or two-way and is composed of several Traffic Pools (TP's), each of which can receive and discharge traffic flow in an aggregate sense. The flow from one TP to another is governed by four constraints. First, no more flow can occur from TP_i to TP_j during time period DT than there is traffic volume (occupancy) in TP_i. Second, the flow is limited so as not to exceed the effective capacity of the downstream TP to accept flow. Third, since vehicles are assumed to maintain about a two-second headway (H) from front bumper to front bumper, not more than DT/H vehicles per lane may pass any given point during time DT. Last, traffic lights at intersections may prohibit certain flows at appropriate times. Figure 1 shows schematically a one-directional link and a two-directional link as modeled in TRADYN.

The large, round TP's in Figure 1 are designated as Receptors (R), the triangular TP's are Intermediates (I), and the large, square TP's are Feeders (F). The small, round TP found in the middle of each link represents the aggregate parking facility (P) associated with that link. The capacity of P, which may vary over the time of the simulation, is the sum total of all parking spaces available to traffic flowing on that link, including both on- and off-street parking. The small, square TP represents the parking exit queue (Q) of vehicles attempting to leave the parking facilities to enter the moving flow on the link. Notice that both one- and two-way links have only one P and one Q. An appropriate directional split is maintained to accommodate non-symmetrical exit patterns from each Q on a two-way link.

The Receptors and Feeders are so named due to their function at intersections. See Figure 2. Each Feeder represents traffic waiting to be processed through the intersection into up to three waiting Receptors. From the Receptors, traffic flows into the Intermediates or into the Parking facilities. Flow from the Parking facilities to the parking exit Queues is governed by one or more parking exit patterns, made specific for each distinct type of Parking facility: residential, commercial, sports event, etc. Finally, flow occurs from the Intermediates to the Feeders for the next intersections, and from the parking exit Queues to the downstream Feeders. Actual processing of flows, however, proceeds in an upstream direction so that "virtual simultaneity" of all flows can be effected, e.g., within each link, the F to R flow is processed before the Q to F flow, which in turn is followed by the P to Q flow, etc.

The flow at intersections is modeled to incorporate dynamic feedback from earlier traffic interactions. The fact that turning movements delay the through traffic behind the turners and the fact that turning movements across opposing flows are impeded by the magnitude of that flow are both reflected in the design of TRADYN. The TP's of the model and the flow constraints between TP's can be identified with the levels and rates of Jay Forrester's system dynamics models (7). Thus, in a typical intersection, the impact of left-turning movements on other flows is a positive dynamic feedback loop, which can be seen as follows: assume that for a typical intersection the number of East-bound vehicles desiring to turn left during a given time period is known. Assume also that under normal conditions not all of these vehicles wishing to turn left are able to turn left within the designated time period because of opposing West-bound traffic. If by chance the left-turners find more gaps in the West-bound traffic than is usual, more potential left-turners will make the turn. In the normal case some of the East-bound through traffic will be delayed behind these left-turners, but in this special case fewer through vehicles will be so impeded. As a result, the East-bound through flow will be greater than usual and will show fewer gaps to the opposing West-bound left-turners. Consequently fewer left turns are made by the West-bound vehicles and more West-bound through traffic is bottled up behind the waiting left-turners, causing more gaps to appear to the East-bound left-turners. Thus it becomes even easier to turn left from the East and even more East-bound through flow is released. This process will continue until traffic signals interrupt it or until the East-bound flow is accommodated.

The TRADYN model is operated by first setting up a network of links and intersections. By allowing the user the option of specifying generalized link and intersection types in place of detailed field data, it is hoped that savings in time and money can be realized for specific applications. If, for the sake of accuracy, the user wishes to completely specify the network with detailed field data, that option is also available.

When the network is set up, the model is run by observing the traffic volumes, speeds, delays, etc., as they change every DT seconds. Every TP is processed and observed once during each DT period. The size of DT is chosen so that the propagation speed of vehicles through the network is comparable to the average route speed encountered in the real system. As a rule of thumb, DT is usually in the range of six to twelve seconds since progressive signal settings ordinarily allow vehicles to proceed about four intersections during a cycle, most cycle lengths are between 72 and 144 seconds in length, and TRADYN needs twelve DT periods to allow flow to proceed through four intersections.

Since each TP has an associated static capacity, the knowledge of current occupancy in each TP can be used to monitor the density of traffic flow in each link. Relationships between density and speed (3 and 11) can then be used to estimate the average vehicle flow speed. The number of stops can be monitored by observing traffic lights, parking vehicles, and instances where no flow occurs between an upstream TP and its downstream sink.

The flow in to and out of parking facilities is controlled by referencing inflow and outflow patterns of parking lots (8) and by scaling the responses to the capacity of the facility on the link being processed. To simulate a sports event, for example, the inflow pattern would show steady buildup over time and the exit pattern would show precipitous emptying after the event is completed. For each vehicle which moves from a P to a Q, an engine start can be counted. Only a fraction of the engine starts counted need to be considered as cold starts, since the vehicles starting up have not always sat for a full 12 hours, as is assumed in the Federal Driving Cycle data on cold starts. Roberts (16) gives by time of day the fraction of all engine starts that can be considered to be cold starts. See Table 1.

TABLE 1

Cold Start Fraction of All Engine Starts By Time of Day (16)

Time of Day	Cold Fraction
0:00 - 6:00	.90
6:00 - 9:00	.85
9:00 - 11:30	.25
11:30 - 13:30	.30
13:30 - 16:30	.20
16:30 - 18:30	.50
18:30 - 21:00	.15
21:00 - 24:00	.20

B. The Traffic Emissions Submodel, TRAPOL

By producing information on speed, stops, and cold starts, TRADYN can provide the necessary inputs to estimate CO emissions. TRAPOL (TRAffic POLlution) is an extension of TRADYN which is designed to model vehicle emissions as a function of traffic flow characteristics. Since TRADYN does not follow individual vehicles, each particular vehicle's emission characteristics as a function of time from engine start cannot be represented. Rather, the aggregate traffic flow must be processed so as to accommodate the variations between hot- and cold-running vehicles present in the flow. In order to predict the spatial distribution effects due to cold starts, one cannot simply multiply the number of cold starts by the cold-start contribution; rather, the cold emission rates must be applied over the appropriate warm-up period as the cold traffic moves about the network. Otherwise, the spatial distribution of emissions will be biased towards the trip origin point of the cold vehicles.

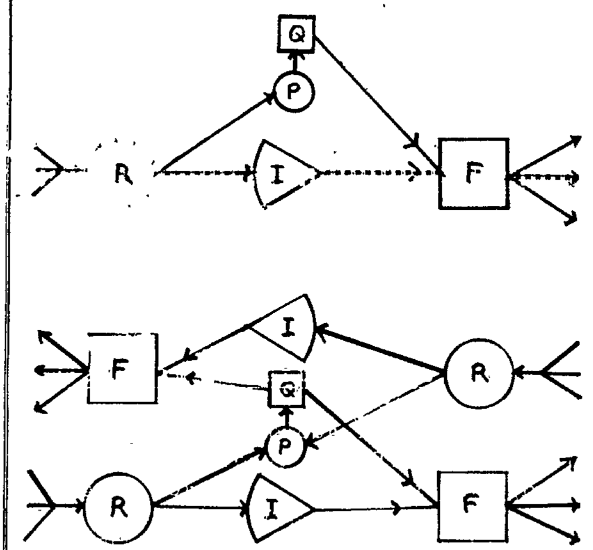
The equivalent emissions scheme

There are two sources of cold vehicles in the system: parking facilities and boundaries. The assumption is made that every cold vehicle which leaves parking operates in the cold mode for a period of time until it becomes a warm vehicle. Cold vehicles may also enter the system from the boundary inputs. For incoming vehicles, a decision must be made as to what portion of the newly arriving cars are running cold. Roberts (16) suggests that 37% might be a reasonable daily average for this quantity, since his assumed cold-start warm-up period of 8½ minutes is 37% of the average urban trip length of 23 minutes. But this figure cannot be used without taking into consideration the variations over time of day due to non-uniform starting patterns. Thus Table 1 can also be used to scale the 37% figure according to time of day.

Again, due to the fact that TRADYN does not follow individual vehicles, TRAPOL cannot transform each cold car into a hot car after its warm-up period has terminated. If, however, it can be assumed that the cold emission rate decays exponentially to the hot-running rate, then a good approximation to the overall effect can be established. The assumption that exponential decay is reasonable is borne out by evidence from General Motors (10). See Figure 3.

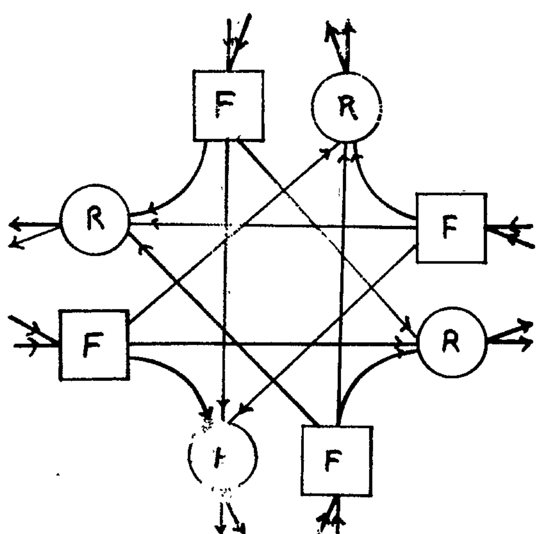
The following scheme for the representation of the decay of cold emission rates is based upon the realization that it is the total emissions pattern over time and space that is important, not the degree to which the method used reflects the actual process involved in the real world. For the sake of exposition, let there be two groups of vehicles, Group A and Group B, both of which exhibit the identical speed of flow. Groups A and B are both composed of N vehicles. In Group A, $\underline{n}$ vehicles have just been cold-started and N-$\underline{n}$ vehicles are hot-running. The $\underline{n}$ cold vehicles emit CO at a rate in grams per second, say, that decays exponentially from E_0^c at time t=0 to E_s^h, the hot-running emission rate at speed $\underline{s}$. After sufficient time, all N vehicles will be emitting at or arbitrarily near to the hot-running rate, E_s^h.

Figure 1.



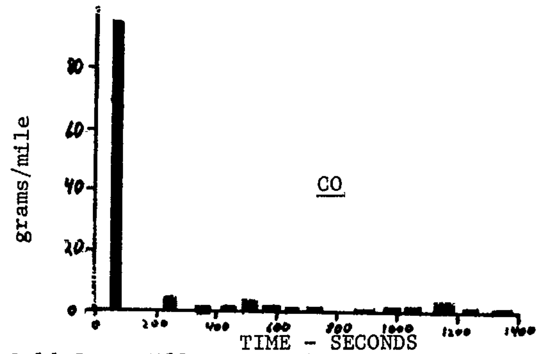
Flows in a one-way link (top) and in a two-way link (bottom). F: Feeder. R: Receptor. P: Parking Facility. Q: Parking Exit Queue. I: Intermediate.

Figure 2.



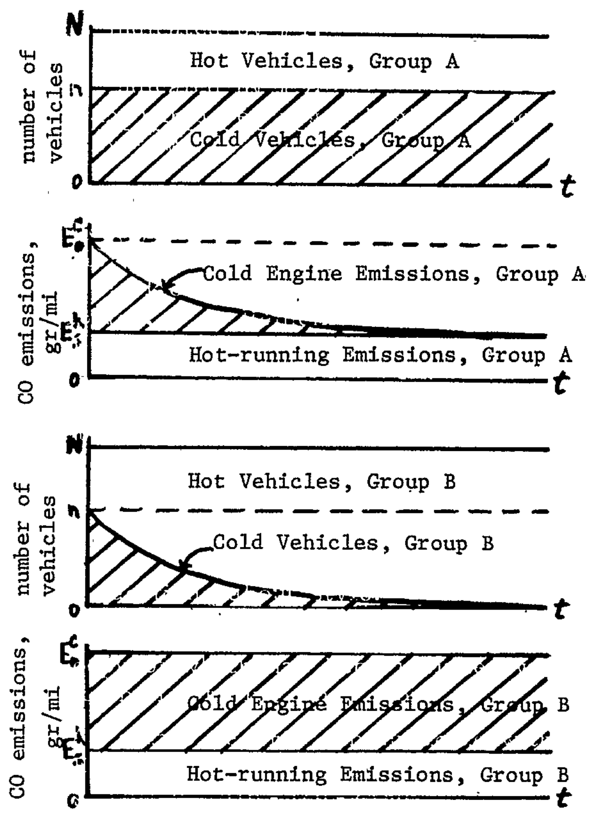
Flows in an intersection.
F: Feeder. R: Receptor.

Figure 3.



Cold Start Effect On Emission Test. CO emission decays rapidly to a low value after three minutes. (Adapted from (10))

Figure 4.



The Equivalent Emissions Scheme. In Group A (top two figures) the number of cold vehicles remains constant while the associated emission rate decays to the hot-running rate. In Group B (bottom two figures) the number of cold vehicles decays to zero while the associated emission rate is constant. The groups display identical emission patterns over time.

Group B consists of $\underline{n}$ newly cold-started vehicles and N-$\underline{n}$ hot vehicles, as in Group A, but every cold car emits at the constant rate E_0^c which is equal to the initial maximum emission rate of a newly cold-started vehicle in Group A. The other N-$\underline{n}$ cars emit at rate E_s^h. Instead of reducing the emission rate of the cold group, the occupancy of the cold group is reduced exponentially over time. A vehicle which leaves the cold group due to this process is transferred to the hot group. If the discrete nature of the traffic volume is ignored, Groups A and B will exhibit identical emission patterns over time, for any given speed $\underline{s}$. See Figure 4, where the occupancies and emission rates for both groups are displayed.

More formally, let E_t^* be the portion of the emission rate E_t^c (cold engine emission of CO in grams per second at time t) which is due entirely to the coldness of the engine. Then

(1) $E_t^c = E_s^h + E_t^*$.

The cold-only contribution to E_t^c decays exponentially with rate constant $\underline{\alpha}$ in units of seconds^{-1} :

(2) $E_t^* = E_0^* e^{-\alpha t}$,

where E_0^* is the initial cold-engine contribution over and above the hot-running emission rate E_s^h:

(3) $E_0^* = E_0^c - E_s^h$.

The total emissions to time $\underline{t}$ for Group A, $E_t^{T(A)}$, is then the sum of the cold emissions due to $\underline{n}$ vehicles and the hot emissions due to all N vehicles:

(4) $E_t^{T(A)} = n\int_0^t E_0^* e^{-\alpha\tau} d\tau + N\int_0^t E_s^h d\tau$.

Thus

(5) $E_t^{T(A)} = \frac{n}{\alpha} E_0^* (1 - e^{-\alpha t}) + N E_s^h t$.

For Group B, let $\underline{n}$ be the occupancy of the cold group at time $\underline{t}$. Let $\underline{n_t}$ decay exponentially at the same rate as did E_t^* :

(6) $n_t = n e^{-\alpha t}$.

where $\underline{n}$ is the initial population in the cold group.

The total emissions of Group B to time $\underline{t}$, $E_t^{T(B)}$, is, as for Group A, the sum of the contributions from the cold vehicles and the hot vehicles:

(7) $E_t^{T(B)} = E_0^c \int_0^t n e^{-\alpha\tau} d\tau + E_s^h \int_0^t (N-n e^{-\alpha\tau}) d\tau$.

Thus

(8) $E_t^{T(B)} = \frac{n}{\alpha} (E_0^c - E_s^h) (1-e^{-\alpha t}) + N E_s^h t$.

It then follows from equations (3) and (5) that

(9) $E_t^{T(B)} = \frac{n}{\alpha} E_0^* (1-e^{-\alpha t}) + N E_s^h t = E_t^{T(A)}$.

It has been proven that the two schemes outlined above produce identical emission patterns over time for a given speed $\underline{s}$. Thus it is possible to simulate the emissions of a population of cold and hot vehicles in such a manner as to duplicate the emission patterns theoretically expected from such a population.

A basic assumption here is that it is meaningful to speak of an average weighted emission pattern that is equally applicable to any mixed collection of vehicles in the network being modeled. Although emissions from trucks, busses, and other sources are not currently modeled in TRADYN, the omission is not considered critical for the purpose of the model, $\underline{viz.}$, to examine the additional air contamination caused by the attraction of many passenger vehicles to a proposed facility. It is assumed that truck traffic will be unaffected by the new structure; if bus traffic is affected, as for a sports event, the effects can be incorporated by weighting bus emissions proportionately to their presence in the vehicle population. Although there are problems in modeling aggregate emissions, it can be said that any effort to simulate emissions by examining each individual vehicle in the system will certainly be a much slower and more expensive proposition than the above indicated procedure.

Implementation

To implement the above scheme, each Feeder, Receptor, and Intermediate TP in the system is duplicated, $\underline{i.e.}$, split into two halves. In addition to the lines of flow indicated in Figures 1 and 2, further flows are allowed. See Figures 5 and 6. The newly introduced TP's (TPC's) represent Cold traffic from Parking structures or from the boundaries. The original TP's (TPH's) represent Hot-running vehicles. The exception is the parking exit Queues which hold a mixed group of hot and cold vehicles, the actual split being a function of time of day and specific knowledge about certain parking facilities. For example, if it is known that given parking lots hold vehicles for a football game, then this information can be used to adjust the hot/cold split exiting the parking facility in order to reflect the appropriate amount of engine "stopped-time" for these vehicles.

During the simulation, whenever a flow needs to be calculated in TRAPOL, the total pooled population of the appropriate TPH/TPC pair is used where a single TP occupancy was used in TRADYN. After the total outflow of the TPH/TPC pair has thus been calculated, account must be taken of the warming of cold vehicles. To accomplish this effect, a multiplicative constant $\underline{\beta}$ is selected so that equation (6) is reasonably well satisfied--$\underline{i.e.}$, during each discrete time period DT a fraction β of the cold vehicles are transferred to join the hot-running vehicles. If at any time $\underline{t}$, n_t cold vehicles are present, than at time t + DT the remaining number of cold vehicles is

(10) $n_{t+DT} = n_t e^{-\alpha DT}$.

Since, for $0 < x < 1$

(11) $1 - x \doteq e^{-x}$,

then

(12) $n_{t+DT} = n_t (1 - \alpha DT)$.

Thus it follows that

(13) $\beta = \alpha DT = \frac{n_t - n_{t+DT}}{n_t}$.

Note that even when the population of cold vehicles is composed of vehicles of various ages relative to starting time, the multiplicative nature of equation (12) still gives the correct result.

After the appropriate β-fraction of the TPC has been transferred to the TPH, the total outflow transferred downstream is then apportioned according to the occupancy ratio of the TPH to the TPC. A warm vehicle acts no differently than a cold vehicle as far as driving characteristics are concerned; therefore, if x% of the total TPH/TPC occupancy is to move downstream during a given DT period, then x% of the hot vehicles and x% of the cold vehicles in that TP are so processed.

Emissions Modeling

Since TRAPOL easily isolates hot and cold vehicle flows, the application of appropriate emission rates is straightforward. The establishment of correct rates is another question. Returning to equation (1), one notices that E^h_s is a function of speed s. TRADYN provides speed as an output, but the true relationship between hot-running emissions and speed is not well documented in the literature. EPA (6) and Wolsko (18) are of some help, but both are more applicable to large areas and average speeds. Ludwig (13), however, derives one relationship from Curry (4) approximately as follows:

$$(14) \quad E^h_s = 540 \; s^{-1.0} \quad , \; 0 < s \leq 7.7$$

$$(15) \quad E^h_s = 2350 \; s^{-1.72} \quad , \; 7.7 < s \leq 16.9$$

$$(16) \quad E^h_s = 86 \; s^{-0.55} \quad , \; 16.9 < s \leq 55$$

where s is in miles per hour. Curry's data was for a single 1968 "reference" automobile. Although data existence and reliability continue to be severe problems in air pollution modeling, the following methodology can be used with current data and can be easily adapted to better data as it becomes available.

TRAPOL uses approximations to Ludwig's equations and scales the leading coefficient to fit the mix of model years for each specific application time and place. This scaling will be detailed shortly. It is further assumed that the functional relationship of hot-running CO emission rates to steady speed is invariant in shape although variant in magnitude over differing mixes of model years.

To fit Ludwig's curves to a particular application area A in calendar year y, the leading coefficients in equations (14) through (16) are multiplied by $\bar{E}^h_y(A) / \mathcal{E}^h_{68}$, where the numerator is the weighted average hot-running CO emissions for calendar year y and application area A. The denominator is the average hot-running CO emission rate for model year 1968. From Martinez's (14) Federal Driving Cycle data, it is found that

$$(17) \quad \mathcal{E}^h_{68} = 37.23 \text{ grams CO / mile.}$$

To derive the weighted hot-running CO emission rate for calendar year y, $\bar{E}^h_y(A)$, one needs to have a distribution of model years for passenger vehicles in area A for calendar year y, a table of emission deterioration factors by age of vehicle, and average hot-running CO emission data by model year of vehicle:

$$(18) \quad \bar{E}^h_y(A) = \sum_{i=0}^{13} D_i \left(\frac{m_i \, r_i}{\sum_{j=0}^{13} m_j \, r_j} \right) \mathcal{E}^h_{y-i} \; .$$

Deterioration rates by age (D_i) and miles driven by age (m_i) can be found in Wendell (17); average hot-running CO emissions by model year can be found in Martinez (14). More detailed data in the form of CO percentages in exhaust gas by model make and year is available from the California Air Resources Laboratory (2). Vehicle age distribution in the form of fractional registration by age (r_i) needs to be derived from motor vehicle registration data for area A. This last item is of great significance, as can be seen in Figures 7 and 8, where registration data are compared for the following areas: national average (17); the state of Maryland; Howard County, Maryland; and Somerset County, Maryland. Data for the last three areas is for July, 1973.

The weighted hot-running emission rates in grams per mile as derived above cannot be directly applied to the hot vehicles in the TRAPOL model however, as not every moving vehicle in the network has an identifiable distance traveled every DT. For example, in slow but steadily moving traffic, every vehicle in a particular TP may be moving at the same known speed s, but only some fraction x of the occupancy of the TP is allowed to proceed downstream during time period DT. The movement from one TP to another has an associated distance with it, but monitoring only movements between TP's will not account for moving flow within TP's. Therefore, the appropriate emission rate in grams per mile at speed s should be multiplied by speed in miles per DT. The resulting rate in grams of CO per DT at speed s can then be applied to all vehicles every DT period. It is assumed that all vehicles within a TP experience the same speed for the duration of each DT period.

For cold vehicles, the weighted emission in grams of CO per start, E^c, can be derived from model year data as was done for hot-running emissions. Again Martinez (14) is the source of the raw data. The weighted cold start contribution can then be used to find E^c_0, the initial cold engine emission rate in grams per second. If E^c is the total cold start contribution in grams, then

$$(19) \quad E^c = \int_0^\infty E^*_0 \, e^{-\alpha t} \, dt,$$

where E^*_0 is the initial, exponentially decaying emission rate in grams per second which is due only to the coldness of the engine. (See equation (3)). It follows that

$$(20) \quad E^*_0 = \alpha \, E^c \; ,$$

and by equation (3)

$$(21) \quad E^c_0 = \alpha E^c + E^h_s \; ,$$

where E^h_s is the hot-running emission rate derived before. When E^*_0 is converted to grams per DT, equation (20) becomes

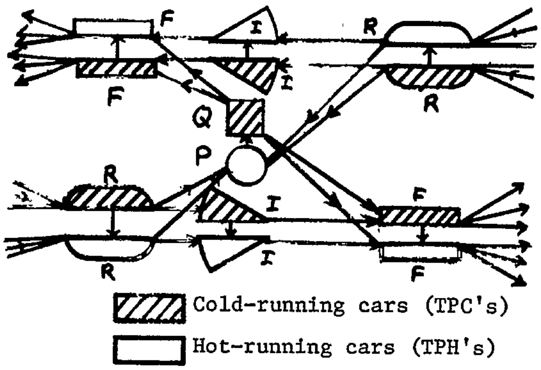
$$(22) \quad E^*_0 = (\alpha \, DT) \, E^c = \beta \, E^c$$

and equation (21) becomes

$$(23) \quad E^c_0 = (\alpha \, DT) \, E^c + (DT) \, E^h_s = \beta \, E^c + (DT) \, E^h_s.$$

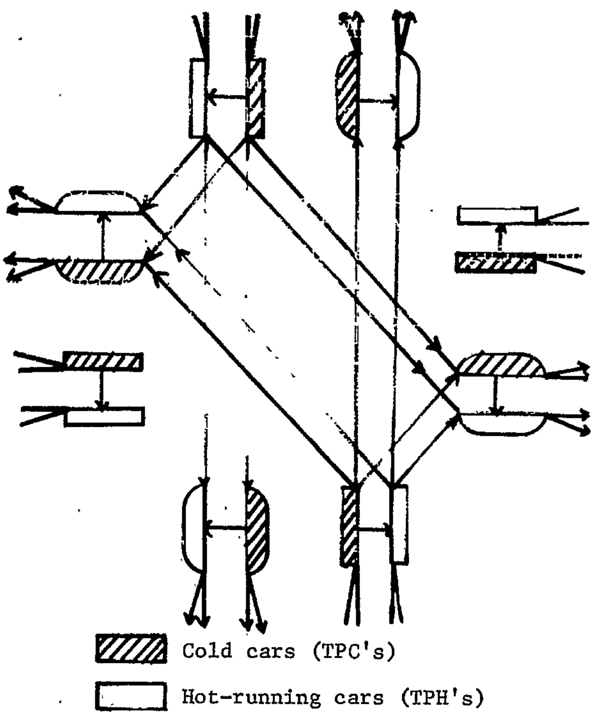
Once during each DT period, each TPC will

Figure 5.



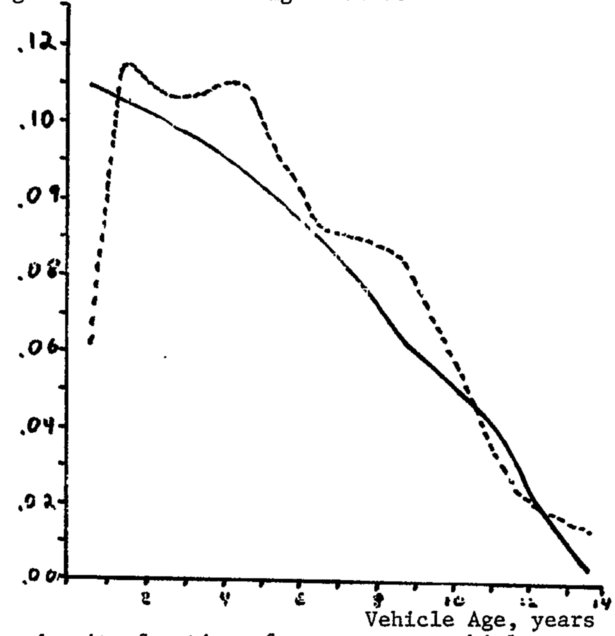
Hot and Cold Flows in a Two-Way Link in TRAPOL. Cold-running flow is shaded; hot-running flow is not. The parking exit Queue releases both hot and cold flow according to time of day.

Figure 6.



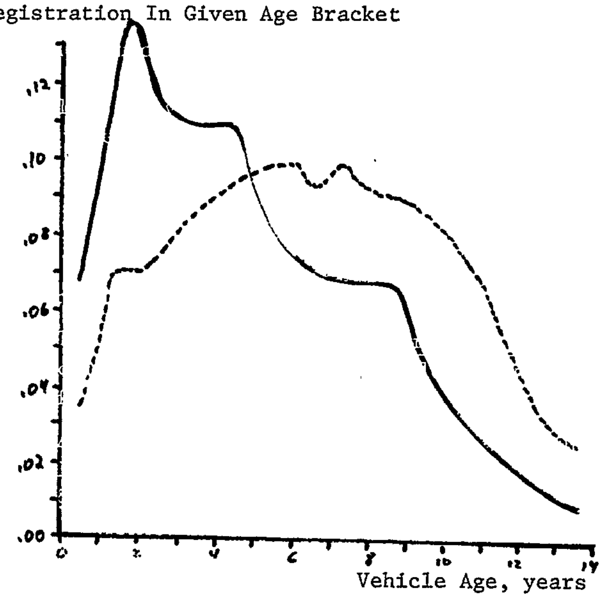
Hot and Cold Flows through an Intersection in TRAPOL. Cold-running flows are shaded; hot-running flows are not. (North/South phase only).

Figure 7.
Fraction of Total Vehicle
Registration In Given Age Bracket



Age density functions for passenger vehicles. Heavy line is a national average. Broken line is for the State of Maryland, July, 1973.

Figure 8.
Fraction of Total Vehicle
Registration In Given Age Bracket



Age density functions for passenger vehicles. Heavy line is for Howard County, Maryland, July, 1973. Broken line is for Somerset County, Maryland, July, 1973.

have equation (23) applied to its occupancy and each TPH will have (DT) E_s^h applied to its occupancy. Notice that whereas both emission rates are dependent upon speed s, it is only the hot-running portions which reflect the relationship--i.e., only the cold engine contribution is speed-independent.

For emissions due to decelerations and accelerations, Ludwig's (13) relationship can be used:

(24) $E_s^{A/D} = 0.009 \quad s^2$

Here $E_s^{A/D}$ is the emission of CO in grams per stop (and go) from speed s. Equation (24) is applied to all vehicles in every TP whose flow was found to have stopped during the last DT period. The speed s used in this application is the last recorded speed of flow into the stopped TP.

During each DT period, each TPH/TPC pair is examined and processed. The resultant CO emissions are then accumulated on the level of aggregation that is appropriate. The accumulation of emissions can give indications of preference between two alternative runs of the model in terms of gross pollutants emitted; but, to be more useful, the outputs of TRAPOL must feed into CODISP, the CO DISPersion model which has not yet been designed. Another option is to use the outputs of TRAPOL with an established urban air pollution dispersion model.

Conclusion

A simulation model has been described which is designed to be sensitive to the cold-start emissions resulting from passenger vehicles starting up from parking facilities in urban environments. Dynamic feedback is utilized to model traffic flow interactions at intersections, and vehicles flow through the modeled network in fluid-like batches. It is hoped that the design of the model is conducive to ease of operation and low cost. When coupled with a dispersion model yet to be designed, TRAPOL should provide a useful tool for predicting the air quality impact of proposed traffic generators.

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BIBLIOGRAPHY

1. Berwager, S.D. and Wickstrom (1972) "Estimating Automobile Emissions of Alternative Transportation Systems" NTIS # PB-209-914.

2. California Air Resources Laboratory (1973) "Exhaust Emissions from Privately Owned 1966-1972 California Automobiles--A Statistical Evaluation of Surveillance Data" 9528 Telstar Ave., El Monte, California.

3. Croke, E.J., K.G. Croke, and J.E. Norco (1972) "The Role of Transportation Demand Models in the Projection of Future Urban and Regional Air Quality" prepared for TRANSPO 72, Washington, D.C.

4. Curry, D.A., and D.G. Anderson (1971) "Procedures for Estimating Highway User Costs and Air and Noise Pollution Effects", Final Report, HRB Project 7-8, SRI, Menlo Park, California.

5. EPA (1972) "Compilation of Air Pollutant Emission Factors" AP-42, February.

6. Federal Register (1973) Volume 38, Number 74, April 18, p. 9599.

7. Forrester, J.W. (1968) Principles of Systems, Wright-Allen Press, Cambridge, Mass.

8. Friendship Heights Planning Commission (1972) "Friendship Heights Traffic Count", Friendship Heights, Maryland, November.

9. General Motors (1971) "Progress and Programs in Automotive Emissions Control", GM Research Laboratories, Warren, Michigan, March 12.

10. General Motors (1972) "Progress and Programs in Gasoline Emissions Relationships", GM Research Laboratories, Warren, Michigan, February.

11. Highway Research Board (1965) Highway Capacity Manual, Special Report 87, NAS/NRC Publication 1328.

12. Ludwig, F.L., et. al. (1972) "Evaluation of the APRAC-1A Urban Diffusion Model for CO", Final Report, SRI Project 8563, February.

13. Ludwig, F.L., et. al. (1972) "Preliminary Study of the Modeling of Air Pollution Effects from Traffic Engineering Alternatives", Final Report, SRI, Menlo Park, California, August.

14. Martinez, J.R., et. al. (1971) "Morning Vehicle-Start Effects on Photochemical Smog", General Research Corporation, Santa Barbara, California, June, NTIS #PB-203-872.

15. Mason, D.V., et. al. (1969) "Sources and Air Pollutant Emission Patterns in Major Metropolitan Areas", APCA 69-101.

16. Roberts, P.J.W., et. al. (1971) "Extensions and Modifications of a Contaminant Emissions Model and Inventory for Los Angeles", Appendix A of: "Further Development and Validation of a Simulation Model for Estimating Ground Level Concentrations of Photochemical Pollutants", Final Report, Contract CPA 70-148, Systems Applications, Inc., Beverly Hills, California, March.

17. Wendell, R.E., et. al. (1973) "Emission Prediction and Control Strategy: Evaluation of Pollution from Transportation Systems", JAPCA, Volume 23, Number 2, February.

18. Wolsko, T.D., et. al. (1972) "Transportation Air Pollutant Emissions Handbook" NTIS #ANL/ES-15.