MESOSCALE MODELING: A TRANSPORTATION AGENCY'S EXPERIENCE

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In recent years the resources applied to air quality model development have increased rapidly. Users are faced with a multiplicity of models more complex and difficult to use. Often a transportation agency lacks the technical skills required to use the models properly, and so model application is growing more slowly than model development. Evidently, the users need help, primarily in the area of input data. The user is told too little about how the data can be obtained, because the model maker is either not qualified to advise on such matters or considers his or her mandate to be only developing the model and fitting it into the planning process. There is a great need for unification.

Admittedly, achievement of a synthesis in which the models become unified in the transportation planning process is difficult, but the potential for model synthesis is no less exciting than that for model development. The state of the art of computer science today with respect to hardware vis-à-vis software is reversed from the situation of only 10 or 15 years ago. Machines then placed severe restrictions on the model maker and the model user. The machines of today, however, defy us to use them fully, and this gap between hardware and software will probably continue into the foreseeable future. I will examine some of the mesoscale models and describe the experiences of using them in Alabama.

DIFFUSION MODELING: APRAC-1A

The APRAC-1A urban diffusion model computer program, developed by the Stanford Research Institute, estimates concentrations of carbon monoxide resulting from the emissions from a traffic network at specified receptor locations under specified weather conditions. Required input for the model includes emission factors, traffic distribution, and meteorological data. Estimates can be made for any time of the day and any day of the year. An option of the model allows estimates of the street canyon effect. Use of the model for developing isopleth contour maps is made possible by means of the grid point mode in which estimates for a given hour of the day are made at a large number of receptor locations (1).

Receptor Spacing

For developing isopleth contour maps, receptor spacing must be sufficiently close for high resolution of the resulting concentrations. To determine just how close this spacing should be, a number of test runs were made with the APRAC in which St. Louis network data were used as input under synthetic worst case conditions (164-ft or 50-m mixing depth, 1-knot or 0.5-m/s wind speed). Results indicated that spacing should be no greater than 328 ft (100 m), and 164 ft (50 m) is preferred. The automatic receptor generator was used, and for this study spacing down to 10 m was used; a maximum of

25 ppm resulted with 1972 emission factors. In general, the greater the spacing is, the lower is the probability of generating concentrations close to the maximum. Obviously, for high resolution isopleths, very large numbers of receptors must be generated and automatic generation is essential. Random spacing was investigated and, based on limited results, appears to have no advantage over fixed spacing. Conceivably, however, a Monte Carlo approach could be devised and incorporated in the model by using a search algorithm, thus reducing the output substantially.

The automatic receptor generator has been incorporated as a modification of the APRAC. In its original form, the program requires 1 card per receptor. When the objective is to develop isopleth contours, the number of receptor cards may be large, requiring a prohibitive amount of work even for the smaller urbanized areas. The modification is available as an option and should be used only if the receptors are to be spaced evenly and the area containing the receptors is a square or a rectangle. The option should not be used for the street model mode. The A card specifies whether the option is to be used. The B card provides information required for the automatic generation of receptors, i.e., the minimum and maximum x and y values and the desired x and y spacing of receptor locations. The modification also includes a change in subroutine PPDATA (the output subroutine), such that the receptor coordinates are printed out along with the other information. This change applies to all options of the program. In addition, the model was modified so that receptor locations are specified in metric units.

Traffic Input Data

Obviously, no model can be more accurate than the traffic used for input. Machine counts or manual counts are used for those systems for which counts are available. For forecast years, traffic density is estimated by using those techniques that are a part of the transportation planning process. To reduce the manual effort required to develop the network data, the state developed a utility program that reads from the magnetic files containing the raw network data, performs the required conversions, and punches network cards (the N cards used as input to the APRAC-1A).

Speed-delay studies have been made in the city of Montgomery. Speeds on every link of the network were measured, both during peak-hour travel and off-peak. If resources allow, these studies will be extended to the other cities of Alabama; and if the results appear to be valid, then these speeds will be used in air quality studies rather than the synthetic speeds resulting from the assignment process.

Weather

Weather is, of course, an indispensable consideration in developing and using diffusion models, and it is well that models have the capability of considering any type of weather. However, those who develop and use air quality reports and those who must devise control strategies from them are primarily interested in worst case conditions—weather, traffic, or otherwise—since such a set of conditions will determine whether the air quality standards will be met or violated. The model maker should consider the ease or difficulty required in obtaining weather data. The state has developed a modification of the APRAC that improves ease of operation without degrading the power and sophistication of the model. Following is a description of the modification.

A required input to the APRAC in its original form is upper air (radiosonde) data [the temperature and pressure up through the 500-millibar (100-kPa) level]. Such data are difficult to obtain for most users, and forecasting these data for the future would be impossible without professional meteorological advice (difficult to obtain, to say the least). In 1973 the Alabama Air Pollution Control Commission recommended that the program be modified so that the need for the upper air data could be eliminated and the minimum and maximum mixing heights be input instead. This proved to be a feasible and rather easy modification to make. In the original program, the upper air data, from the Q cards, are used (in SUBROUTINE RAOBHM) to compute the minimum and maximum mixing heights HMIN and HMAX. Then HMIN and HMAX are used to compute the hourly mixing heights. The modification consists of bypassing that part of SUBROUTINE RAOBHM that reads in the upper air data and computes the HMIN and HMAX. Then HMIN and HMAX are added to the read statement for the P cards. To use the modification requires that Q cards be eliminated and HMIN and HMAX be added to the P cards. The output of the modified program is unchanged from that of the unmodified version except that the number of RAOB levels is not included. Mixing heights for specified areas can be obtained from the literature (2, 3).

Since the intent has been to use worst case conditions and since wind direction is an important factor in determining these conditions, a method was developed to rotate the wind vector at 30-deg intervals around the compass so that a total of 12 runs is required for the study. This method was used for a 3 × 3-mile (4.8 × 4.8-km) area of the central part of Mobile, where receptors were placed 0.1 mile (0.16 km) apart and the highest concentrations at each receptor of all 12 runs were recorded and then contoured (Figures 1 and 2). The importance of wind direction is indicated by the fact that the highest level estimated is 20 ppm with the prevailing southerly wind and 34 ppm with

Figure 1. Contours of highest CO concentrations of 12 receptors with south wind.

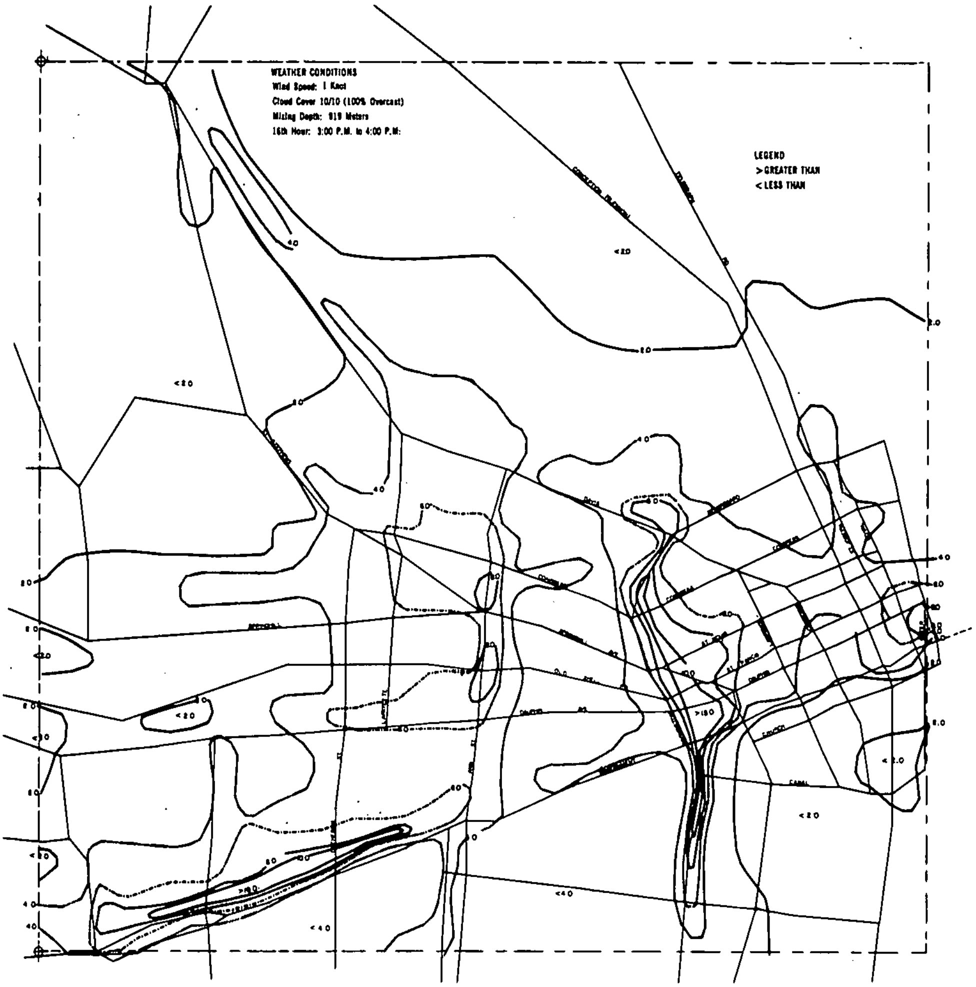


Figure 2. Contours of highest CO concentrations of 12 receptors with rotated wind.

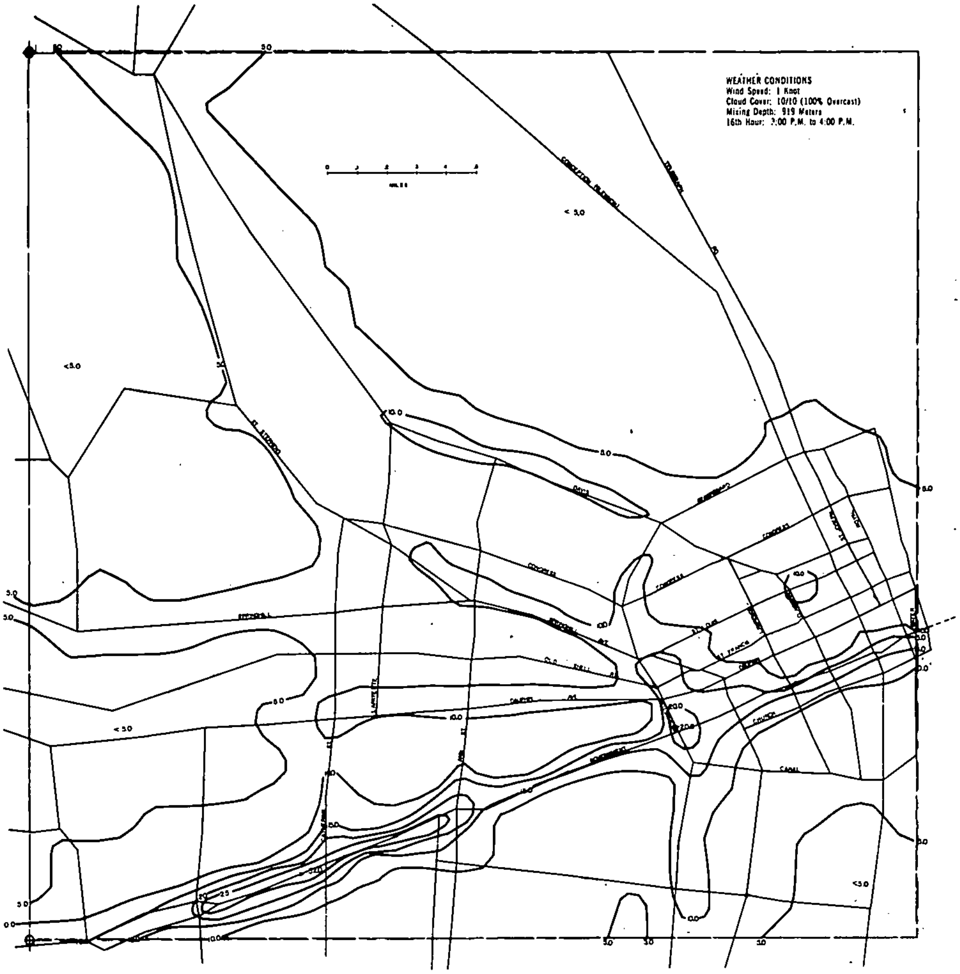
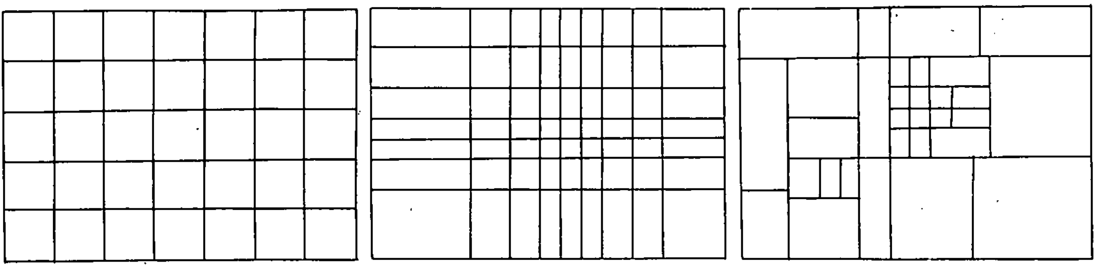


Figure 3. Emission inventory grid systems program (GRIDSUM).



In its simpliest form, grid squares of constant size are used.

For varying degrees of resolution, a grid system such as this is appropriate.

The most flexible form of the model permits selections such as this.

the rotated procedure. The use of the rotated wind, together with worst case traffic and stable air conditions, will probably yield levels higher than actual monitored levels and is therefore of value in determining the potential that high concentrations will occur in an area rather than the probability that they might occur. An unexpected result of the studies was that highest concentrations were estimated for Mobile, not Birmingham. This phenomenon occurs because the Mobile street system is more congested than the Birmingham street system, resulting in significantly lower speeds.

Application of the Model

The APRAC-1A has been run for 6 urbanized areas in Alabama and will be used as additional areas are added. It was used in air quality studies that were issued first in 1974 as a part of the certification of the transportation planning process. In general, the state plans to update its air quality studies only when there are significant changes in any of the factors affecting the studies, such as emission factors, traffic projections, or improvements in air quality modeling. Each air quality report has been reviewed by the Alabama Air Pollution Control Commission to determine the consistency of the report with the state's Air Quality Implementation Plan, and the letter of review has been included as a part of the report.

Figures 1 and 2 show examples of isopleth contour maps of Mobile that were developed by using outputs of the APRAC-1A. The APRAC-1A was run in the street canyon mode for 1 street in Mobile and 9 streets in Birmingham. Since the ratio of building height to street width is less than one, the estimates probably tend to be high. Highest concentrations were found to be virtually independent of wind direction and were about 10 ppm in Mobile and 30 ppm in Birmingham.

Data Processing Considerations

For the benefit of anyone who anticipates using the APRAC model, some information relating to the actual processing follows. In its original form, the program is dimensioned for 625 receptors (grid point mode) and 1,200 network links. It is fairly easy to redimension the program to increase its capability by changing the number of receptors and links at all places where they occur in the appropriate COMMON statements of the main program and the subroutines. XPT, YPT, and CCAL must be dimensioned for the number of receptors and ISK, X1, X2, Y1, Y2, and E must be dimensioned for the number of links. Also, in SUBROUTINE SFCOB2, 1200 must be changed in the initializing DO statement just before statement 40 if the number of receptors is to be changed. Execution of the program on the Alabama Highway Department IBM 370, as originally dimensioned, required 125 K bytes of storage, not including system overhead requirement (8 K to 12 K for the IBM 370 machine). Some typical program execution times on the IBM 370 are as follows (times do not include compilation):

Mode	Period (days)	Receptors	Links	CPU Time (min, sec)
Synoptic	30	6	1,371	35, 14
Synoptic	1	9	445	1, 5
Grid point	1	328	834	2, 10
Grid point	1	622	834	3, 18
Grid point	1	328	1,316	3, 34
Grid point	1	622	1,316	5, 12
Grid point	1	1,288	856	7, 13
Grid point	1	884	454	3, 13
Grid point	1	1,219	3,330	24, 50

Obviously, to reduce computer time, runs involving many days of input data should be avoided. For the grid point runs summarized above, times varied from 367 to 496 μsec/receptor/link.

For those using machines that are operating in a multiprogramming environment, simultaneous runs can be made with different wind directions. To do this, one should have all the weather cards ready in advance (one set of R cards for each wind direction) and then change the R cards on each successive pass into the card reader. Each run corresponding to one wind direction drops into a separate partition and runs independently of the others. In this way, as many as 6 wind directions have been run simultaneously, and jobs run for 12 wind directions as described above even with large numbers of receptor points have been completed in less than 90 min clock time. By comparison, more than 6 hours would be required for sequential runs using the same input data.

Part of the data input for the APRAC is the network card deck, which can be quite large for large networks. A fairly simple modification to the APRAC allows the model to read the network data from a disk file, thus eliminating the physical problem of manipulating the N cards. The state has incorporated such a modification as an option. A few changes in subroutine INDAT are all that is required.

Critique

The most serious shortcoming in using the APRAC-1A is that the emission factors used are not the same as those required for other models, but rather are curve-fitting constants alpha and beta. If the model is to be widely used, it should be modified so that emission factors such as those in Publication AP-42 can be used.

The extraurban contribution should be removed from the model since determining the input data is difficult and subject to error. The technique used in the model for calculating this contribution does not contain a provision for changes in emission factors. Therefore, it would be better to use local measurements or estimates for this component.

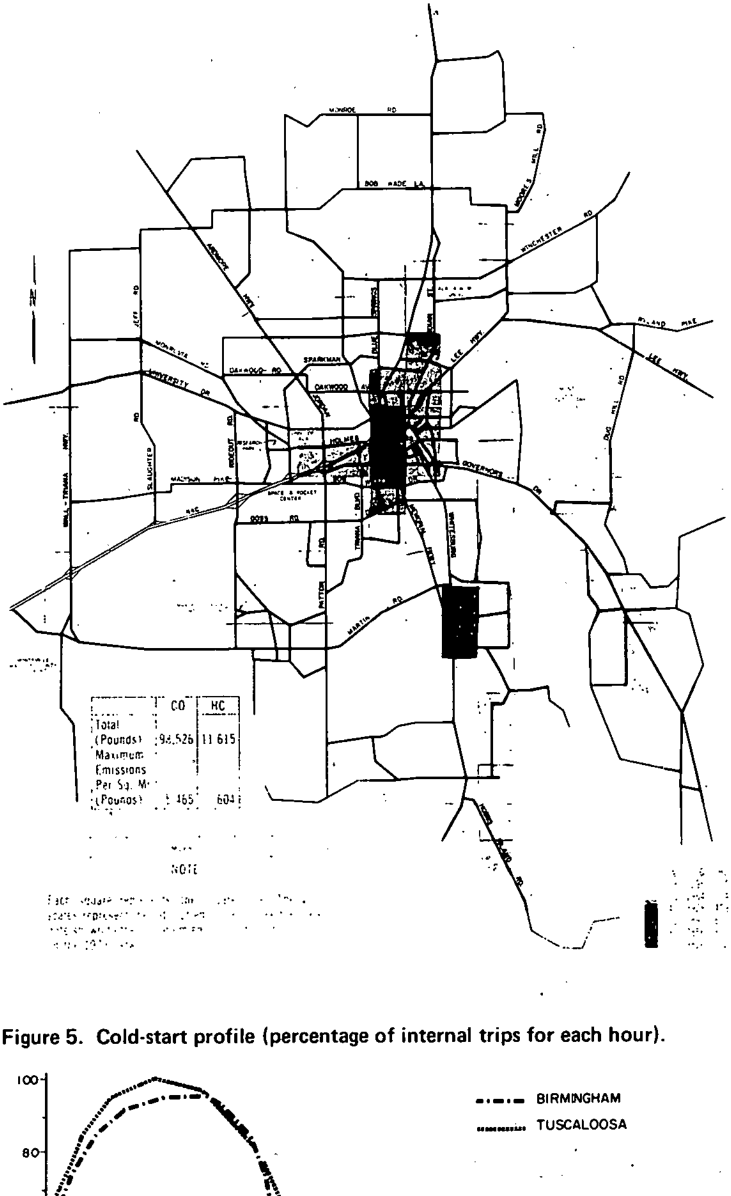
The APRAC-1A is inherently difficult and costly to use. However, the potential user should realize that after experience with the model, as with any model, he or she will find it is progressively less difficult. Also, further efforts to automate the use of the model should bear fruit. It need not be used often for any given area; every 3 to 5 years would probably be sufficient after thorough initial air quality studies have been made. The model is the most sophisticated of its type available. It would be advisable, therefore, to develop it further and improve its documentation rather than turn to less comprehensive alternatives.

EMISSION INVENTORY MODEL

For spatial resolution of emissions, emissions must be estimated for subdivided portions of an urban area. Alabama has developed a mobile emission inventory model that integrates traffic emissions and other traffic information in a highly flexible technique whose grid systems are shown in Figure 3. The model has been developed as a computer program called GRIDSUM and uses the same traffic input as the APRAC-1A. It estimates daily emissions of carbon monoxide, exhaust hydrocarbons, crankcase and evaporative hydrocarbons, and nitrogen oxides. It also provides a summary of area-wide totals for each pollutant type, vehicle miles traveled, network miles, and capacity miles and has 2 additional options that provide for processing of traffic data for isolating areas of roadway capacity deficiencies.

Figure 4 shows how the output of the model was used to estimate 24-hour emissions for Huntsville, Alabama, using 1-mile^2 (1.6-km^2) grid squares. Square kilometer grids will be used in future reports unless specific occasions require otherwise. Although this model was developed to integrate mobile emissions, a fairly simple modification would add point and area sources to it in order to get an output that would represent

Figure 4. Calculated emission patterns of CO and HC for Huntsville with 1980 street system including I-565.

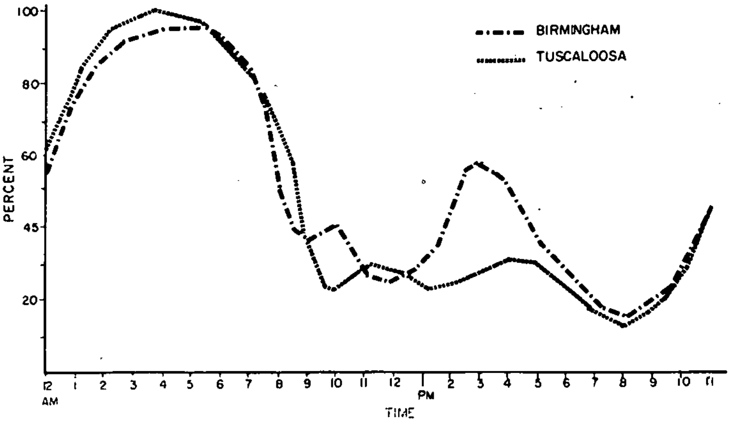


	CO	HC
Total (Pounds)	94,526	11 615
Maximum Emissions Per Sq. Mi (Pounds)	[illegible] 465	604

NOTE

[illegible]

Figure 5. Cold-start profile (percentage of internal trips for each hour).



total (mobile and stationary) emissions. The 3 options available in the program are as follows:

1. Option 1 outputs the emissions of carbon monoxide, exhaust and nonexhaust hydrocarbons, nitrogen oxides, network miles, and vehicle miles for each grid area. In addition, an areawide total of each quantity is output at the end of the report.
2. Option 2 outputs vehicle miles, network miles, capacity miles, and a volume to capacity ratio (V/C ratio) for each grid area. The summary page provides network totals and a percentage breakdown of the grid squares by V/C ratio.
3. Option 3 is similar to option 2 in that both aid in studying street system capacity deficiency. However, in option 3, each link is categorized according to generalized north-south or east-west direction breakdown of traffic flow. The output of each grid area is a separate listing of north-south and east-west vehicle miles and capacity miles and a V/C ratio for each directional category.

The program was developed in FORTRAN IV on the IBM 370/145 with the virtual storage operating system and requires approximately 128 K bytes of storage, not including system overhead. Execution time depends on the number of network links and the number of grid areas selected for summing. For a network of 3,100 links and 900 grid areas (Birmingham), an execution (CPU) time of 1 min and 40 sec was required.

A potentially valuable use for the output of GRIDSUM would be as an input for a dispersion model such as the climatological dispersion model (CDM), which is designed to accept point and area sources. Although GRIDSUM was intended to apply to CO, HC, and NO_x, it can be used for any mobile pollutant for which emission factors are available.

TRIP-MAKING ANALYSIS

According to the EPA equations (4) for carbon monoxide, the 100 percent cold-start correction factor for 1971 and 1972 automobiles at 19.6 mph (31.4 km/h) average route speed is 2.52 and 2.06 for 50 and 75 F (10 and 24 C) respectively. It follows, therefore, that to ignore cold starts is to introduce large uncertainties into our model. (The cold operating mode is defined as the first 505 sec of operation of an automobile that has been in a motor-off condition for 4 hours or more.) To make an accurate assessment of the cold-hot condition, it is essential to study the trip-making process from trip generation and trip distribution to traffic assignment. EPA suggests that 20 percent cold operation be used as an average. However, it is necessary to know what the hourly variation is in urban centers. Accordingly, a study was made of the home interview data taken during the origin-destination surveys in 2 Alabama urban centers: Tuscaloosa and Birmingham. Tuscaloosa is a small city (about 91,000 persons) with substantial light industry and little heavy industry; it is the home of the University of Alabama. Birmingham is a medium-large city (about 615,000 persons), is heavily industrialized, and has a large blue-collar population. The trip data were studied to determine the history of individual vehicles through the day. Results for the 2 cities are shown in Figure 5. The first trip of each day was assumed to be a cold start. Cold starts for all subsequent trips were recorded only when 4 hours or more elapsed from the end of one trip to the beginning of the next. The analysis showed that before 9:00 a.m. about 71 percent of the cold starts occurred in Tuscaloosa and about 40 percent in Birmingham. Note that the profiles for the 2 cities are generally rather similar, particularly with respect to activity during the early and latter portions of each day. However, between 9:00 a.m. and 8:00 p.m., Birmingham is somewhat different; the peaks are higher, and they occur earlier. Cold starts were about 46 percent of the total in Birmingham and 35 percent of the total in Tuscaloosa.

These profiles were derived from a limited amount of data: for Tuscaloosa, about 1,000 trips representing 212 vehicles and 176 households; for Birmingham, about 1,100 trips representing 291 vehicles and 233 households. The state is developing a computer program that will read all the origin-destination survey data for all urban areas in Alabama.

Given sufficient data, one might find that each city would exhibit a distinct signature with respect to its cold-start profile, and it might be possible to generalize these profiles as a function of city size and type. It would be interesting to compare profiles for a large white-collar metropolitan area such as the District of Columbia with a highly industrialized area of comparable size.

Households with more than 1 automobile were studied separately to determine to what extent, if any, socioeconomics affect the cold-start profile. No great difference was apparent. In Birmingham, the multiple-car households exhibited a slightly higher (about 1.5 percent) overall percentage compared with single-car households, and the morning and afternoon peaks were slightly lower. However, the sample size precludes drawing any conclusions. When the computer program is completed, the state plans to study the socioeconomics of trip making in greater detail.

The profiles discussed above are derived only from the condition of a given vehicle at the beginning of each trip and do not consider the vehicle condition during the trip. A complete analysis must consider the length of the trip, for the length will determine how much of the trip will operate in the hot mode. To do this, we must study trip distribution. For example, the effect of the higher cold-start percentage in Birmingham will be offset by the fact that the average trip length is much greater in Birmingham. Therefore, a higher percentage of Birmingham trips that started cold will reach the hot condition. Average trip duration is about 22 min in Birmingham and only about 12 min in Tuscaloosa. Work trips average 31.27 min in Birmingham and 13.13 min in Tuscaloosa. Nonwork trips average 20.92 min in Birmingham and 10.88 min in Tuscaloosa. From the above, we can calculate that about 27 percent of the travel time of the Birmingham work trips that start cold will be in the cold mode and 73 percent in the hot mode (505 sec = 8.42 min ÷ 31.27 = 26.9 percent). Using the same technique, one can calculate that the cold-mode percentages for Birmingham nonwork trips, Tuscaloosa work trips, and Tuscaloosa nonwork trips are 40, 64, and 77 percent respectively. Since these percentages apply only to those trips that started cold, cold-mode percentage for all trips can be obtained by multiplying the above cold-mode percentages by the percentage of all trips that started cold. The percentages are as follows for the cold-mode trips:

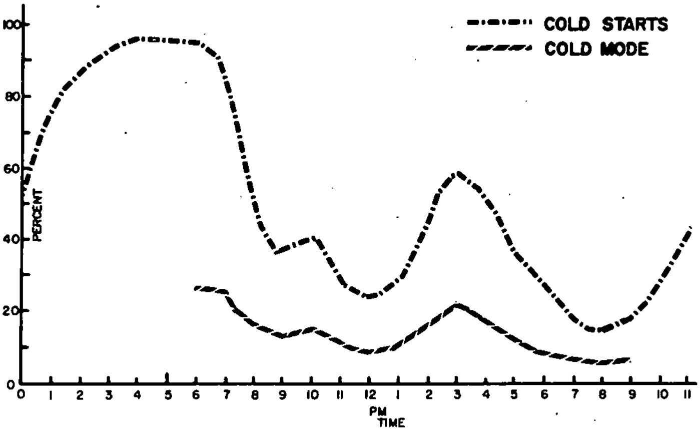
City	Work Trips	Nonwork Trips
Tuscaloosa	64 × 35 = 22	77 × 35 = 27
Birmingham	27 × 46 = 12	40 × 46 = 18

It is apparent that in the smaller city a higher percentage of trips will operate in the cold mode than in the larger city. These results apply to daily trip totals and will contain large uncertainties because of hourly changes in trip distribution, cold-start percentages, and temperatures. Therefore, such percentages can be considered only as gross approximations. A more accurate analysis will require that these variables be considered on an hourly basis as follows.

Suppose that, between 7 and 8 a.m. in Tuscaloosa, the typical January temperature is 35 F (1.7 C), the cold-start percentage is 78 percent, and 54 percent of all trips are work trips. The average trip duration is calculated as (0.54 × 13.13) + (0.46 × 10.88) = 12.10 min. All trips that start cold will operate 69.6 percent (8.42 ÷ 12.10) of the time in the cold mode. Therefore, all trips at this hour will operate 54 percent (0.78 × 0.696) of the time in the cold mode. Figure 6 shows the results of applying this technique to Birmingham between the hour beginning at 6 a.m. and the hour beginning at 9 p.m. The percentages of work trips and nonwork trips were obtained from analyses of screen-line checks made between 6 a.m. and 10 p.m. Trip duration data were taken from trip distribution reports.

The above analysis is not intended to be an estimate of real-world conditions but to illustrate the importance of the cold-start correction, in particular, and of the trip-making process in general. Furthermore, it is important to study the cold-hot condi-

Figure 6. Cold mode profile for Birmingham.



tion not only in temporal detail but in spatial detail also. This spatial detail can be obtained by deriving the cold-hot profile from the origin-destination survey data on a zonal basis. The temporal distribution of trip purposes also needs to be studied. The origin-destination data contain a wealth of information that can and should be applied to air quality modeling.

AUTOMATING COMPUTATIONS IN PUBLICATION AP-42

The latest revision of the EPA emissions manual (4) is much more involved than earlier revisions. In general, it follows other revisions in its approach to the problem of calculating emissions, i.e., emission ratings for the various model years and the various vehicle types are combined to yield calendar year emission factors that can be applied to traffic on a roadway segment or network. However, a number of matters are considered either for the first time or in more detail than before. Such considerations include cold starts, ambient temperature, speed correction, and deterioration factors. Procedures for calculation of model-year mix are the same as before. The effect of these considerations is to greatly reduce the uncertainties inherent in the estimation of emission factors, but at the expense of the time involved, to say nothing of the multiple opportunities for errors. The reaction of the typical conscientious user will probably take one of two paths: He or she will either make a laborious effort to follow the procedures outlined or throw up his or her hands in despair and fall back on the average emission factors listed at the end of Publication AP-42. However, a third alternative is automating the computations recommended in Publication AP-42; this is the path that Alabama is investigating. The procedures of the document are so involved that the development of such a program requires a major effort, although one that we believe will pay for itself many times over in time saved. Alabama plans to release a preliminary review version of its documentation so that a thorough review can be made by EPA, the Federal Highway Administration, the Transportation Research Board, and any others who are interested. Wherever possible, the program will contain default values for those who do not have local data, such as national model-year mix data. (We plan to derive model-year mix for each county in Alabama and for the state as a whole from a program now under development using license plate registration data.)

In the automation, a technique for manipulating hourly variations in traffic is as follows. On a given roadway at a particular hour of the day, the contribution of traffic in grams per mile is a function of the emission factor representing that traffic corrected for all factors subject to hourly variations. Such hourly variations are traffic, ambient temperature, cold-hot operation correction, and speed correction. If all these variable quantities are known, then all the corrections can be calculated and combined (multiplied) at each hour to yield a total correction for that hour. Next, the correction factors for all 24 hours can be added, then multiplied by the uncorrected emission factor. The end result represents a daily (24-hour) emission factor for a particular roadway type or segment. This daily emission factor, after appropriate correction for model-year mix, can be used in a daily emission inventory model such as GRIDSUM and will implicitly contain the hourly variations noted. For an hourly emission factor, the product of all correction factors for that hour is multiplied by the uncorrected emission factor.

CONCLUSIONS AND RECOMMENDATIONS

1. Coordination between model developers and model users should be improved.
2. Additional automation is required to facilitate the use of models, particularly with respect to generating input for the models.
3. The APRAC-1A model needs to be revised, with particular attention given to emission factors.
4. The trip-making process requires additional analysis to determine the effects of cold starts on emissions, and these effects need to be incorporated into the models.

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