Airport Air Pollutant Inventories: Pitfalls and Tools

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This paper presents a description of common problems (pitfalls) and their solutions that occur during assessment of total air pollutant load from airport operations. Available computer tools are briefly discussed. Discussed in detail is the use and development of a microcomputer spreadsheet for conducting efficient emission inventories and the use of this spreadsheet as an effective planning tool.

Airports can be a significant local air pollution source and should be included in any local emission inventory. The requirements brought about by State Implementation Plans (SIPs) and federal environmental assessments (*1*) also make emission reporting a necessity. To prepare an emission inventory the air quality analyst must have adequate tools and methods to accomplish an accurate, comprehensive study.

Until recently, these tools and methodologies were confined to AP-42 (*2*) and a series of individual reports (*3,4,5,6*). Mobile sources accessing the airport required further references. The six major source types at airports (aircraft, support vehicles, stationary sources, fueling operations, fuel storage, and motor vehicles) had no overall documentation or methodology. This has led to certain problem areas. Accordingly, the authors' experiences showed that evaluation from airport to airport varied greatly in method and accuracy. In addition, outdated emission factors and incorrectly estimated times-in-mode led to inaccurate analysis.

This paper will report on the use of a microcomputer spreadsheet as an effective tool and provide methodologies to help the airport and air-quality analysts to avoid "falling into the common pitfalls" associated with airport air pollutant emission inventories.

THE EMISSION INVENTORY CONCEPT

The inventory of emissions permits a review of the total amount of pollutants emitted from a facility for a particular unit of time. To be consistent with local methodologies, usually the number of tons per year for most of the "criteria" pollutants listed in the National Ambient Air Quality Standards (NAAQS) are reported. These criteria pollutants include carbon monoxide, nitrogen oxides, sulfur oxides, hydrocarbons, and particulate matter. Notably, this list excludes lead (emitted in such small quantities from airport sources because of the use of low-lead or lead-free fuel that the results may be considered insignificant) and ozone (a secondary pollutant).

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The emission inventory may be sufficient to substantiate that there will be no significant impact. Accordingly, many airport air quality environmental assessments may not require an impact analysis, the next step beyond the emission inventory. Although an emission inventory cannot be used to directly demonstrate compliance with the NAAQS, the Federal Aviation Administration (FAA) requires the inventory as a first step to determine whether dispersion modeling is needed (*1*). Also, emission inventories are used to demonstrate consistency with the SIP by showing that the total pollutant load for an airport will not exceed the amounts planned for in the SIP. A direct comparison of emission inventories, present to future, is also usually adequate to evaluate the future scenarios for compliance with the SIP and the impact on the SIP of future scenarios, assuming that the SIP does not change.

The inventory permits trend assessment of any proposed project in three distinct ways. First, the inventory can be used to compare future project alternatives. The relative merits of each scenario, including the existing case and the do-nothing alternative, can be assessed. Second, the inventory can be used to compare future emissions to existing totals, to help analyze the effects of planned changes. Third, a comparison of project emissions to the total county inventory can be made. This permits an assessment of the relation between the proposed project and other major sources in the area, a very useful planning tool.

Airport sources may be separated into six distinct groups: (a) aircraft; (b) ground support equipment; (c) stationary sources (i.e., boilers, heating plants, etc.); (d) motor vehicles; (e) fuel storage; and, (f) fueling operations. Most large airports will have all of the six groups listed above. Stationary sources do not exist at all airports, however, and some airports may have other types of sources. Therefore, care should be taken to identify all sources at the start of the evaluation.

COMMON PITFALLS

Associated with each of the six source areas are problems or "pitfalls" that the air quality analyst must overcome. The following discussions, for each source, are methodologies that may be used to overcome the common pitfalls.

Aircraft

Large Commercial Aircraft

Data on the number of aircraft operations, aircraft type, and runway use must be accurately known. The collection of this data may involve consulting several sources. One complication that may be encountered is that each aircraft type may be equipped with several different engines, according to year of manufacture, retrofitting, and customer preference. It is not apparent which engine is in use, and most often a review of published sources and discussions with the aircraft manufacturers, airlines, airport, and the FAA are required to determine engine types for each aircraft model. (A starting point for engine type for each model of aircraft may be found in the periodical, *Aviation Week and Space Technology* (*7*). If several engines are used by airlines for a particular model of aircraft, efforts should be made to find percentages of each engine type. If this information cannot be quantified, the predominant type should be selected. When no one type dominates, the engine with the greatest amount of emissions should be assumed. In this way, the analysis is conservative and may overpredict, but not underpredict, emissions.

Selection of the wrong engine type can lead to large errors in the emission inventory. The common DC9 aircraft illustrates this point. Many engine types are possible for this aircraft (including the stretch design, DC9-80, commonly referred to as the MD80). Table 1 shows the emissions, by mode, for four common engine types used in the DC9 series. A review of this table shows the large differences that may occur in estimations from the various engine types. For example, for the crucial idle mode at airports, NO_x could be overestimated by a factor of 5.6 if the older JT8D-7 engine were assumed rather than the JT8D-9 or by 4.9 if selected over the JT8D-209. Figure 1 graphically shows the difference in carbon monoxide emissions for the four types of engines commonly used in DC9s. The new DC9-80 series shows marked improvement.

After the engine type for each aircraft is determined, emission rates for each are required. Emission rates for each engine type are a function of aircraft mode (idle, approach, climbout, and takeoff), time-in-mode, and fuel use. Each variable must be quantified. The EPA lists emission factors, per mode, for many types of aircraft in its publication AP-42 (*2*).

Unfortunately, AP-42 has not been updated for aircraft since February 1980. Since that time, manufacturers have made large strides in producing more efficient, cleaner engines. To overcome this difficulty, the FAA staff in Washington (Nicholas Krull, AEE-30) offers assistance by providing results from engine certification testing. The staff encourages the use of these factors where appropriate. FAA certification data, however, are only available for fuel use rates, hydrocarbons, carbon monoxide and nitrogen oxides, as well as a smoke number. Particulate and sulfur oxide data are not included.

Sulfur oxides may be estimated because sulfur oxides emissions from aircraft are a direct function of the sulfur content of the fuel. Jet fuel is highly refined and contains very small amounts of sulfur. The method used by the EPA in AP-42 is to multiply fuel usage rates by 0.001 (0.1 percent) to determine a conservative SO_x emission factor. This method may be used to supplement the certification data.

Particulate emission factors are not so easily predicted. Particulate emissions are not only a function of fuel type but also of engine efficiency, mode, and combustion chamber design. Particulate emissions are thus very difficult to quantify without extensive testing. As a first approximation, AP-42 values may be used for similar engine types with similar smoke numbers when only certification data are available.

Table 2 summarizes newer aircraft emission factors developed from FAA certification data for large commercial aircraft. This list may be used to supplement the values found in AP-42. It also should be noted that the certification data are in g/kg, but the AP-42 data are in lbs/hr or k/hr.

Time-in-mode data also need to be determined. Specifically, the landing/takeoff (LTO) cycle methodology within AP-42 may lead to large errors because of the differences that occur at individual airports. Indeed, the authors found a very significant overprediction of emissions during initial investigations of the Nashville and Los Angeles airports when LTO cycle data was used. For example, the LTO cycle given by AP-42 contains 26 min for taxi/idle (in and out) for commercial aircraft. Measurements made over many days at Nashville International Airport showed that the idle/taxi time was typically only 17 min. Accordingly, if the LTO cycle from AP-42 had been used at the Nashville airport, the idle/taxi time error could have resulted in an overprediction by a factor of greater than 1.5 while the aircraft was on the ground. It is important that the time-in-mode for idle/taxi be determined on a case-by-case basis for each airport, because these times change considerably from airport to airport. From a combination of the taxi and push-back times and the given runway use scheme, weighted average idle/taxi times can be derived for operations on each runway for individual airports. These times can then be combined on the basis of the annual percentage of use of each runway strategy. Care should be taken during peak periods to allow for additional time caused by queue lines. After all times-in-mode are determined, a new LTO cycle could be defined for each runway usage, or individual times-in-mode could be used and the results summed. For example, each aircraft type and different concourse use could have different times.

To determine times-in-mode when an aircraft is in the air, a 3,000-ft (912 m) inversion height and average mixing height above the ground is usually a good assumption (all emissions

TABLE 1 COMPARISON OF ENGINE TYPES: DC9 AIRCRAFT

MODE	DC9-50 JT8D-17	DC9-30 JT8D-9	DC9-10/20 JT8D-7	DC9-80 JT8D-209
IDLE				
FUEL USE	521.6	475.2	464.8	469.1
CO	17.7	16.4	16.5	6.6
NOX	1.8	1.4	7.9	1.6
HC	4.6	4.8	4.9	1.9
SOX	0.5	0.5	0.5	0.5
TAKEOFF				
FUEL USE	4527.0	3744.0	3528.7	4287.6
CO	3.2	4.6	5.3	4.4
NOX	91.9	67.1	9.5	97.8
HC	0.2	1.8	1.4	1.5
SOX	4.5	3.7	3.5	4.3
CLIMBOUT				
FUEL USE	3588.0	3056.4	2920.7	3538.1
CO	3.6	5.1	5.8	5.0
NOX	56.0	43.4	16.2	67.2
HC	0.2	1.4	1.5	1.8
SOX	3.6	3.1	2.9	3.5
APPROACH				
FUEL USE	1275.0	1072.8	1030.0	1293.1
CO	9.2	10.1	10.8	5.7
NOX	8.8	6.1	13.9	11.4
HC	0.6	1.9	1.6	2.2
SOX	1.3	1.1	1.0	1.3

SOURCE: JT8D-17 data from AP42; all others from FAA certification data.
NOTE: Values are shown in kg/hr.

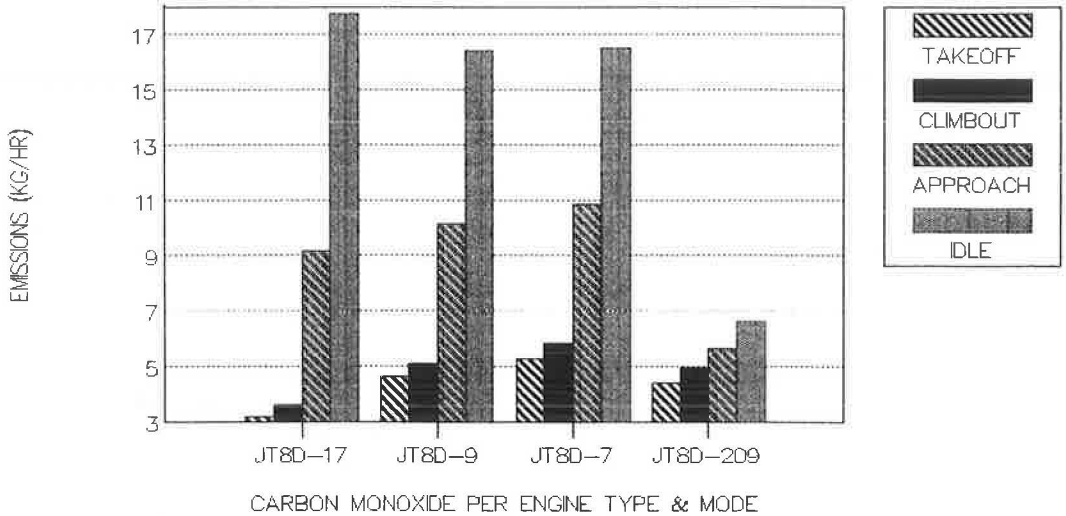

FIGURE 1 DC9-Type aircraft emissions compared—carbon monoxide only.

TABLE 2 FAA EMISSION INDEX[a]

Engine	Mode	Fuel Flow (kg/sec)	Emissions (g/kg) HC	CO	NO_x	Smoke No.[b]
PW 2037	Idle	0.1450	2.20	22.37	4.50	11.40
	Takeoff	1.5970	0.06	0.43	32.90	
	Climbout	1.3200	0.07	0.44	26.50	
	Approach	0.4080	0.20	2.23	10.60	
CF6-80A	Idle	0.1500	6.29	38.20	3.40	[c]
	Takeoff	2.1450	0.29	1.00	29.80	
	Climbout	1.7950	0.29	1.10	25.60	
	Approach	0.6150	0.47	3.10	10.30	
JT8D-209	Idle	0.1303	4.03	14.10	3.50	
	Takeoff	1.1910	0.35	1.03	22.80	11.10
	Climbout	0.9828	0.50	1.40	19.00	
	Approach	0.3592	1.69	4.37	8.80	
RB211-535C	Idle	0.2000	4.54	30.40	3.30	
	Takeoff	1.8040	0.27	1.37	31.79	
	Climbout	1.4740	0.23	1.00	26.59	14.87
	Approach	0.5440	0.15	2.26	9.85	
CFM56-3-B1	Idle	0.1210	1.83	31.00	3.90	
	Takeoff	1.0200	0.04	0.90	18.50	
	Climbout	0.8010	0.05	0.90	16.00	4.00
	Approach	0.3380	0.10	3.50	8.40	
JT8D-217R	Idle	0.1550	0.95	9.43	3.30	
	Takeoff	1.4170	0.21	0.95	25.30	
	Climbout	1.1030	0.27	1.03	17.60	19.60
	Approach	0.3755	0.53	2.54	8.40	
JT8D-7	Idle	0.1291	10.60	35.50	17.10	
	Takeoff	0.9802	0.40	1.50	2.70	
	Climbout	0.8113	0.50	2.00	5.55	22.20
	Approach	0.2861	1.60	10.50	13.50	
JT8D-9	Idle	0.1320	10.00	34.50	2.90	
	Takeoff	1.0400	0.47	1.24	17.92	
	Climbout	0.849	0.47	1.66	14.21	23.00
	Approach	0.2980	1.73	9.43	5.64	
ALF502R5	Idle	0.0408	5.39	40.93	3.78	
	Takeoff	0.3581	0.06	0.30	13.53	16.90
	Climbout	0.2955	0.05	0.25	10.56	
	Approach	0.1034	0.22	7.10	13.53	

[a]From FAA certification data.
[b]Maximum.
[c]Not given.

released within 3,000 ft (912 m) of ground level are considered). This assumption is consistent with AP-42, and airborne times shown by AP-42 may be used.

Smaller Aircraft and Military Operations

Emissions for general aviation aircraft, commuters, and military aircraft may be computed by assuming that the AP-42 landing/takeoff/cycles are applicable for generalized types. This approach is suggested because of the large differences in idle times that could occur because of irregular operations and the usually large number of different types of general aviation aircraft. This assumption may or may not be appropriate for all airports. The selection of these aircraft should follow the conservative procedure of selecting "dirty" engines when one type of aircraft does not dominate.

It should be noted that small aircraft emissions may be a significant contributor to the overall emissions depending on the airport operating characteristics. Accordingly, generalization of small aircraft could lead to errors in the predicted emissions. Each analyst should decide if a generalization of small aircraft is adequate or if a more detailed survey of small aircraft is required. Once again AP-42 emission factors will need to be supplemented with certification data because AP-42 lists only four general aviation piston aircraft types, four smaller turboprop types and five business jets.

Ground Support Equipment Emissions

If no detailed information on ground support equipment used at an airport is readily available, a methodology presented by FAA (*3*) may be used. The FAA report lists usage times for each service vehicle per aircraft type. Aircraft may need to be generalized into sizes to estimate support vehicle needs because no list of aircraft is available (*3*). The time per aircraft can be multiplied by the total number of operations during the time period under consideration, to estimate the total time for all operations. Next, the rate of fuel consumption may be used to determine total fuel use. From the total fuel use it is possible, using the given emission factors (*3*), to calculate the emissions for each ground service vehicle.

For this analysis, it is important to determine whether the service vehicles use gasoline or diesel fuel. Selection of the wrong fuel type can cause a significant error (pollutants other than the criteria pollutants may also be a concern here). For example, if gasoline vehicles are assumed, when in fact most are diesel, carbon monoxide will be overestimated by a factor of 6.7, hydrocarbons by a factor of 7.5, and nitrogen oxides, particulates, and sulfur oxides underestimated by factors of 2.7, 6.3, and 4.8 respectively.

Central Utility Plant (Boiler or Heat Generation Plant Emissions)

Stationary sources occur at many airports but are often overlooked in emission inventories. Care should be taken to assess the stationary sources that are present, their full use and any expected future changes.

AP-42 provides procedures for estimating stationary source emissions. The analyst, however, must determine future requirements and be careful when estimating future emissions to ensure: (a) that an unreal future demand is not put on existing facilities (if new facilities will be required these sources should be included); and, (b) that future fuel use and controls on emissions are considered.

Motor Vehicles

When predicting emissions from motor vehicles accessing an airport, two philosophies exist:

1. Emissions from motor vehicles should only be considered when the vehicles enter airport property and become part of the airport sources; or,
2. Emissions from motor vehicles should be considered when the vehicles start their journey to the airport because the entire trip is airport related.

For county inventories, coordination is needed to select a strategy to ensure that emissions are not counted twice.

If the entire vehicle trip to the airport is considered, two methodologies are available to the analyst. The first method is to conduct surveys of vehicles arriving at the airport to collect sufficient data so that total trip emissions can be determined. The other methodology would involve using one of several available trip generation models to determine zonal attractions for airport traffic, and from this calculate vehicle miles traveled and total emissions.

If only on-airport operations are considered, motor vehicle emissions will generally be smaller than aircraft emissions. This is an important consideration for the analyst during any planning process.

The data for on-airport vehicle operation are usually available for parking lots and loop road use from the local airport authority. Again, AP-42 values may be used or, if more accuracy is needed, available computer programs such as MOBILE-3 (*8*) should be used.

If specific statistical data of vehicle types using the airport are lacking, then national average emission factors should be used. According to an EPA document (*9*) for large urban areas, the national average specific percentages of vehicle types is 80.3 percent automobiles, 11.6 percent light trucks, 4.5 percent heavy gasoline trucks, 3.1 percent heavy diesel trucks, and 0.5 percent motorcycles. The national averages also assume 20.6 percent of the motor vehicles are operating in a cold condition and that 79.4 percent of the motor vehicles are operating in a stabilized condition with 27.3 percent having started hot.

These percentages may overpredict the amount of heavy trucks using the airport, which may cause a slight overprediction of emissions. Overprediction, however, is desirable for a first stage environmental assessment because if no problem exists when overestimations are used, then none would exist in a more precisely modeled situation. If problems do occur because of motor vehicle emissions, the analyst should strive to better define the motor vehicle traffic and mix.

Another pitfall that may occur at airports involves the method used to predict emissions from idling motor vehicles accessing the airport. This problem becomes more complex when predicting future emissions. The weighted average of vehicle types (i.e., taxi, limo, private auto) may be used to provide a representative idle time for passenger arrival and departure. This allows an efficient analysis because the weighted idle time may be multiplied by the number of vehicles for a total idle time at the terminal. This makes the effects of changes in passenger usage on total pollutant load easily quantifiable. The analyst should also be careful, however, to consider idle times in parking lots, at toll gates, etc. The equation used for weighted idle time would be:

$$t_{mv} = V_y[X_t(t_t) + X_a(t_a) + X_l(t_l) + \cdots X_n(t_n)] \quad (1)$$

where

t_{mv} = total idle time for motor vehicles in minutes
V_y = number of arriving vehicles/year,
X_t = proportion of taxis,
t_t = average taxi idle times in minutes,
X_a = proportion of private autos,
t_a = average private auto idle times in minutes,
X_l = proportion of limos,
T_l = average limo idle time in minutes,
X_n = proportion of nth vehicle type,
t_n = average idle time of nth vehicle type, and

$$X + X_a + X_l + \cdots + X_n = 1.0.$$

This produces total idle times for the analyzed situation in min/year. Of course to use this method, composite emission factors must also be determined in the same way mathematically:

$$EF_{mv} = X_t(EF_t) + X_a(EF_a) + X_l(EF_l) + \cdots X_n(EF_n) \quad (2)$$

where

EF_{mv} = composite emission factor, all vehicle types,
EF_t = average emission factor for idling taxis,
EF_a = average emission factor for idling autos,
EF_l = average emission factor for idling limos, and
EF_n = average emission factor for 11th vehicle type.

Then the product of t_{mv} will yield the total yearly pollutant load. In this form, planning and estimating future emissions becomes a simple task.

Fuel Storage

When liquid fuel is stored, releases of hydrocarbons to the atmosphere are inevitable. At any airport, the fuel storage methods must be determined.

The EPA has developed complex equations to estimate the hydrocarbon releases associated with breathing losses (L_B) and working losses (L_W) for several tank types and includes them in AP-42. Each variable in these equations must be determined on the basis of data provided by the airport or estimated from existing information.

Breathing loss emissions are caused by vapor expansion and contraction from changes in temperature and barometric pressure. The AP-42 report does not provide a clear methodology to be used at airports when the tanks are underground.

The average ambient diurnal temperature change (ΔT) for underground tanks is a direct function of the change in soil temperature. It can be assumed that the fuel temperature is approximately at ground temperature (except when fuel is first added to the tank). Temperature information may be found in the U.S. Department of Agriculture (USDA) Soil Conservation Service soil survey reports. The mean annual soil temperature for much of the United States may be estimated by adding 1.8°F (1°C) to the mean annual air temperature. Also, for soil depths greater than 39.4 in. (100 cm), diurnal changes are very small. Therefore, it can be assumed that the fuel temperature in underground tanks is equal to the average ground temperature, and remains relatively stable throughout the day (assumed 0.01°F change). This technique may be used at most sites.

Working losses are caused by filling and emptying the tanks. Vapors are expelled when the liquid level is increased; emissions also occur when the liquid level is drawn down, because air is drawn into the tank and gaseous expansion occurs.

The average space height must be estimated to predict working losses. If accurate data are not available, this can be done by the simplifying assumption that tanks are nearly drained before the delivery of new fuel. This conservative assumption could then be extended to the corollary that on the average, the tanks are one-half full and the average vapor space height is one-half the tank depth.

The paint factor allows for additional heating of darker tanks. For underground tanks this factor is inappropriate and should be set to 1.0.

The turnover factor can be estimated by assuming all tanks receive equal use. Then the turnovers per year could be estimated by:

$$\text{Turnovers per year} = (\text{annual throughput})/(\text{tank capacity}) \quad (3)$$

The total annual throughput for each fuel type is usually accurately known.

For future scenarios, fuel use must be estimated. A conservative estimation can be determined by multiplying the ratio of the number of fuel-specific operations in the future compared to the existing case. For example, if aircraft operations are estimated to double by some future date, then it can be assumed that fuel use will also double. A better estimation can be made if the future fleet mix is known with some degree of certainty, and if the number of operations are known. Projected fuel loadings could then be multiplied by the number of expected future operations to determine total airport fueling operations. Each of these methods allows the turnovers per year to be estimated for the future case. From the estimated turnovers for each study year, a table provided in AP-42 is used to determine the turnover factor.

Once all the variables are quantified, the equations could be simplified for general use. Only selected variables need be changed (i.e., tank quantity or diameter) to determine the effects on emissions. This permits a very quick reestimation to examine various scenarios. The analyst should also be aware of tank age and the method of fuel transfer. Tank age would be important if leaks occurred at the seals. The method of transfer could result in fugitive hydrocarbon releases and is discussed in the next section.

Vapor recovery systems are being used much more frequently than in the past, sometimes as a requirement. If used, the recovery efficiency should be determined and the final results corrected.

FUELING OPERATIONS

Fugitive hydrocarbons are also released during the transfer of fuel. The EPA has developed emission factors based on the total amount of fuel transferred and has published these factors in AP-42.

The number of transfers must be determined to estimate the emissions. The analyst should determine how fueling operations are done at the airport under study (i.e., by trucks, pit hydrants, or other methods) because this will affect the number of fuel transfers. For example, if truck fueling is used, fuel is transferred from tanks to the truck and then to the aircraft (three transfers); however, if pit hydrants are used, fuel is only transferred to the aircraft from a pipeline (one transfer). From the number of fuel transfers, total hydrocarbon releases from fueling operations may be estimated. Care should also be taken to determine how the tanks are filled.

To estimate the hydrocarbon emissions from fueling operations, the number of gallons transferred per year are multiplied by the AP-42 emission factor. Emission factors are available for JP-4, diesel fuel, gasoline, and 100 L.L. (low lead) aviation fuel. Hydrocarbon releases caused by automobile fueling are generally smaller in comparison to the other fueling operation releases for any large airport because of the smaller volume actually pumped. Accordingly, these are sometimes eliminated from the analysis. Care should be taken to ensure that this is a valid simplification by reviewing total service vehicle and automobile fueling amounts.

EMISSION INVENTORY TOOLS

Procedures and tools have existed for some time for the conduct of airport air quality studies. These procedures (*2,3,4,5,6*) are informative and very useful. Unfortunately, no overall, comprehensive guide has been published describing the entire emission inventory process at airports. Accordingly, all of the steps needed to carry a comprehensive emissions study through to completion are not exactly clear.

FAA MODELS

Adding to the confusion was a general lack of comprehensive computer tools specifically designed for emission inventories. The lack of computer tools forced manual calculations, adding further chance for errors. The Airport Vicinity Air Pollution Model (AVAP) (*10*) has been available since 1975 and did combine all the sources in a single model. However, AVAP was designed for dispersion modeling and so requires extensive data input in a tedious fixed-field format (main-frame based). An emission inventory could be prepared using the output file, but only after extensive manual computations, which leads to the manual method problems noted above. Additionally, AVAP does not have updated emission factors for newer aircraft. Hence, although AVAP is a useful dispersion modeling tool, it is not a useful emission inventory tool.

FAA released a model called the Emission and Dispersion Modeling System (EDMS) (*11*) in December 1985. This model is microcomputer based and has all components of airport emissions in a single model. FAA's close dealings with airports led to this responsive model, which eliminated most of the problems of AVAP and allowed access to most airport operators because of the microcomputer base. Further releases in 1988 provided refinements and a more extensive data base. The primary output of this model is an emission inventory in a directly usable form. Although the title implies that dispersion modeling is accomplished, at this time the model-output is a completed emission inventory and an input file for dispersion modeling.

Because EDMS is ultimately meant to be a dispersion model, however, it also requires extensive inputting of data (for example, the sample problem requires 125 steps). Fortunately, this data is requested in a user-friendly, screen-prompted format. Much of the input is required for the creation of the dispersion modeling input file. This input file is directly compatible with the dispersion models contained in the Users' Network for Applied Modeling of Air Pollution (UNAMAP) system: (Point-Area-Line) (PAL) (*12*); HIWAY-2 (*13*); and, CRSTER (*14*). Quick analyses, as for planning, are not easily accomplished with EDMS. As the manual suggests, "An experienced user should be able to process the example problem in less than 3 hr." The authors required a quick, efficient way to compare multiple strategies and operations at the airports. Ultimately, a methodology and series of microcomputer spreadsheets were developed to permit quick calculations of emissions and easy revision of emission input data (*15*). The ability to quickly revise and recalculate was especially useful for studying the various project alternatives under consideration.

DEVELOPMENT OF THE SPREADSHEET

To permit the calculation of emissions easily and quickly, LOTUS 1-2-3 spreadsheets were developed. Originally, separate spreadsheet files were created for each source. Each spreadsheet contained a series of templates that allowed easy, user-friendly screen input, easily changed calculation sheets, and a summary table as the last template. Manual calculations were performed to validate each spreadsheet.

The concept behind these templates was simple and efficient (detailed programming of the spreadsheet is not described and the reader is referred to the LOTUS user manual (*16*). An auto-execute macro command places the user at the input screen at the beginning of the program. The initial use of the spreadsheet begins with all data ranges zero or blank and are shown as unprotected fields. User-friendly prompts such as "enter title" would be shown, but protected. In this way, only data entry fields may be changed and they are highlighted by being shown in a different color (for PCs so equipped). If more than one page of data entry is required, the user is advised to use the "page down" key to advance to the next data input screen. When all required data is input, the program prompts the user to review the data by scrolling, to change the data as needed, or to calculate the answer. Calculation is controlled by invoking a hidden macro command that calculates, first by setting variables as needed (for example, the fact that the year of analysis causes a significant change in motor vehicle emission factors is accounted for by macro manipulation of the data in the spreadsheet). Next, calculations are performed based on appropriate equations. Figure 2 shows an example of an aircraft calculation template. The screen is then placed at the cells containing a summary sheet. Of course, if the user wishes, changes may be made to data manually and manual updates used to calculate. Screen location may also be accomplished manually. This procedure, however, would eliminate a key element of the spreadsheet process, manipulation of the data to insure proper calculations.

Once a complete series of initial spreadsheet files (for each source) was created, the entire series was combined and integrated into a single spreadsheet. Data input was prompted by three input screens. Figure 3 shows a typical input screen. Calculations for all sources are based on these input screens and tabulated in an overall summary table. Variables (input data) are shared as needed for each source calculation. Input data are also stored for review and/or changes by simply scrolling to the correct input screen. Accordingly, only the affected spreadsheet cells would need to be changed to study each project alternative. For example, to study the effects of changes to the fleet mix, only the aircraft operations need to be changed. The variables for other sources may also be easily changed, however, by simply scrolling to the desired input sheet. After the new data for different alternatives are entered, a simple "recalculate" macro command is used to revise the calculations for all pollutants and all aircraft in a matter of seconds, and place the screen at the summary table. Figure 4 shows a typical summary table.

The completed, overall spreadsheet was designed as the individual sheets in three stages; input templates, calculation templates and summary template. Figure 5 shows graphically the concept behind the programming of individual templates for each source. In the overall spreadsheet, subtotal summary templates were also included to allow the user to look at the changes in total emission load for planning of a single source. Also, macro commands were used for overall control as well as for data manipulations. For example, key stroke sequences were coded into a macro command that enabled the movement of data blocks in the motor vehicle section, which allowed correct emission factors to be used for year of analysis.

This technique used a vehicle age and mileage weighting distribution, based on the national averages. According to the selected year, vehicle usage factors could "slide" to the appropriate cells to allow calculation of an overall composite emission factor for each vehicle tape. This follows the methodology of AP-42 (*2*). This calculation technique was the same as shown in Equations 1 and 2.

Subsequent uses of the spreadsheet are very fast, because the user may store the results of previous calculation sections under different file names. Then, as changes occur, the user

AIRCRAFT: 727-200 ENGINE TYPE: JT8D-17 3 ENGINES A-11

YEAR: 1986

MODE	FUEL USE (LB/HR)	TIME/OPER. (MIN)	LTO PER YR.	TOT. TIME (HRS)	TOTAL FUEL USED (LB)
IDLE	1150	12.61	44421	9336	10736064.
TAKEOFF	9980	0.53	44421	392	3915963.2
CLIMBOUT	7910	2.20	44421	1629	12883425.
APPROACH	2810	4.00	44421	2961	8321440.3

POLLUTANT	MODE	EMISSION RATE (EPA)	EMISSIONS PER MODE	TOTAL EMISS.
CO	(IDLE)	39.10	1095079	1321682
	(TAKEOFF)	6.99	8228	
	(CLIMBOUT)	7.91	38650	
	(APPROACH)	20.23	179725	
NOX	(IDLE)	3.91	109508	1123224
	(TAKEOFF)	202.60	238489	
	(CLIMBOUT)	123.40	602964	
	(APPROACH)	19.39	172263	
HC (-CH4)	(IDLE)	10.10	282872	297942
	(TAKEOFF)	0.50	589	
	(CLIMBOUT)	0.40	1955	
	(APPROACH)	1.41	12527	
SOX	(IDLE)	1.15	32208	107571
	(TAKEOFF)	9.98	11748	
	(CLIMBOUT)	7.91	38650	
	(APPROACH)	2.81	24964	
SPM	(IDLE)	0.36	10083	40468
	(TAKEOFF)	3.70	4355	
	(CLIMBOUT)	2.60	12704	
	(APPROACH)	1.50	13326	

FIGURE 2 Aircraft emissions calculation spreadsheet based on AP-42 emission factors.

PLEASE ENTER YEAR OF ANALYSIS: 1986 PAGE A-2

**********COMMERCIAL AIRCRAFT INPUT**********

PLEASE ENTER THE LTO CYCLES AND TIME IN MODE FOR EACH AIRCRAFT TYPE

AIRCRAFT TYPES	# LTO'S PER DAY	*TIME IN MODE (AVG. EVENT IN MIN.)* TAXI/IDLE	TAKEOFF	CLIMBOUT	APPROACH
A300	8.9	16.22	0.63	2.20	4.00
B707	0.4	15.46	0.53	2.20	4.00
B727	121.7	12.61	0.53	2.20	4.00
B737	114.7	12.61	0.53	2.20	4.00
B737-300	14.4	12.61	0.53	2.20	4.00
B747-100	11.8	16.22	0.63	2.20	4.00
B747-200	27.3	16.22	0.63	2.20	4.00
B747-SP	3.6	16.22	0.63	2.20	4.00
B757-200	9.7	15.46	0.53	2.20	4.00
B767-200	18.6	16.22	0.63	2.20	4.00
BAe146	35.8	12.61	0.53	2.20	4.00

**********FUELING, STATIONARY, AND MOTOR-VEHICLES INPUT******PAGE A-5

	ENTER
FUELING DATA	
ENTER NUMBER OF JP-4 FUEL TANKS ON AIRPORT:	23
ENTER AVG. DIAMETER OF ALL TANKS (FT):	20
ENTER THE EFFECTIVENESS OF VAPOR RECOVERY (%):	85
STATIONARY SOURCE DATA (TWIN TURBINES)	
ENTER FT3/100 OF NATURAL GAS USED PER YEAR:	5137385
ENTER GALLONS OF DISTILLATE FUEL USED:	274086
ENTER THE PER CENT (BY WEIGHT) OF SULPHUR IN FUEL:	0.045

MOTOR-VEHICLE DATA

ENTER AADT (VEH/DAY): EMPLOYEE: 45167 ALL OTHER: 63000

FOR "ALL OTHER": ENTER % BUS: 3.3 % TRUCK: 0

ENTER TRIP LENGTH (MI.): EMPLOYEE: 20 ALL OTHER: 46

ENTER DAILY AVG. PARKING LOT USAGE (VEH/DAY): 34673

ENTER AVG. IDLE TIME AT TERMINAL (MIN): 2

TO COMPUTE RESULTS, PRESS ALT-A, TYPE ANALYSIS YEAR AND HIT ENTER.

FIGURE 3 Typical spreadsheet input screens.

*****SUMMARY OF RESULTS*****

SOURCE	POLLUTANTS (TONS/YR) CO	NOX	HC	SOX	SPM
AIRCRAFT	4,331.6	3,546.4	1,629.4	690.4	107.2
GRD VEHICLES	1,171.9	66.9	261.9	0.9	2.1
FUELING EVAP.	---	---	263.4	---	---
STAT. SOURCES	5.8	28.4	1.4	1.0	1.6
MTR-VEHICLES	28,475.2	2,582.2	2,740.3	351.5	916.8
TOTALS	33,984.5	6,223.9	4,896.3	1,043.8	1,027.7

FIGURE 4 Summary page from spreadsheet.

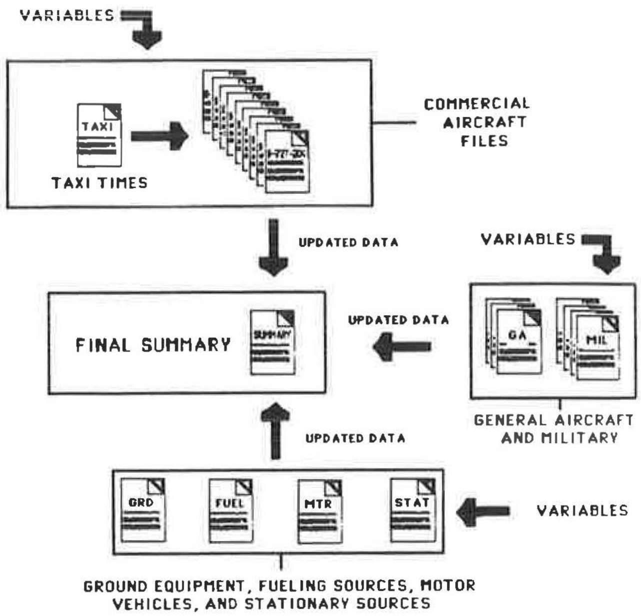

FIGURE 5 Conceptual design of airport emissions inventory spreadsheet methodology.

simply recalls the proper spreadsheet, makes the required changes, and recalculates. Many scenarios can thus be evaluated quickly.

SUMMARY

This paper presents suggestions to overcome common problems (pitfalls) and a computer methodology to estimate air pollution emissions from airports. The computer methodology presented may be used at any airport. Table 2 presents emission factors from FAA certification data that should save a great deal of time and increase accuracy in future studies. Methodologies for determining aircraft taxi time and automobile idle time have also been presented. This work should help other analysts by saving considerable time and effort in conducting similar analyses to allow quick efficient planning methods and emission inventories.

A conservative approach is suggested to ensure that any problem areas would be identified. For example, if the project alternatives had shown great differences or if noncompliance with the SIP had occurred, then a more detailed examination, and perhaps dispersion modeling, would be necessary.

A key factor in estimating emissions is the amount of taxi/idle time required for the aircraft. Accordingly, great effort should be made to quantify this factor. If the suggested AP-42 techniques are used alone, errors may occur because of (a) outdated emissions factors; and (b) excessive idle times based on a very large, congested airport. Accordingly, the methodology and emission factors of this paper are thought to give much more reasonable results.

FAA computer tools available to the analyst are not meant primarily for emission inventories and require extensive data input. The authors have found that the use of LOTUS 1-2-3 spreadsheet templates allows quick and efficient estimates of changing criteria through data storage in input templates.

Emission inventories may be completed quickly and efficiently. Emission inventories can be valuable planning tools. The computer methodology presented here for conducting an emission inventory allowed the future cases to be adequately analyzed and also allowed the inventories to be input for project decision making. Although the results should not be used to predict impacts (dispersion modeling is required for that), comparisons between project alternatives, changes from existing emissions, and changes in countywide emissions may all be studied. The time required for such an analysis in the future should be reduced by using the information collected by the authors and the microcomputer methodologies presented herein.

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