67

Environmental Considerations During Transportation Planning

Roger L. Wayson
University of Central Florida

Environmental considerations are required during the planning of all transportation projects to help ensure that mobility does not occur at the price of damaging our environment. Accordingly, transportation planners, land use planners, transportation engineers, and environmental specialists must consider environmental impacts when planning or designing a transportation project. It is important that these individuals understand *why* environmental planning is necessary, *how* the impact must be analyzed, and *what* must be done to mitigate environmental impacts. Evaluation of impacts requires a systematic, interdisciplinary approach due to the diversity of impacts that may occur. This chapter presents an overview of the environmental process with emphasis on the physical impacts, especially air quality and noise pollution.

67.1 The Environmental Process

The Federal Aid Highway Act of 1962 (FAHA62) required continuing, cooperative and comprehensive effort during project development and is often referred to as the 3-C process. FAHA62 is significant in that a public involvement process was begun, which is now ingrained in transportation planning.

The cornerstone of the present environmental legislation is the National Environmental Policy Act (NEPA). NEPA was passed in 1969 and became effective in 1970. In a very short and succinct piece of legislation, NEPA declares a national policy that each generation is the trustees of our environment and is charged with the responsibility of minimizing anthropogenic impacts to the environment to preserve our resources for future generations. To accomplish this charge, Section 102 required a systematic, interdisciplinary approach to ensure an integrated approach of natural and social sciences to allow informed planning and decision-making. Detailed documentation was also required which led to the birth of the environmental impact statement (EIS). The EIS evaluation required the analysis of:

1. Impacts
2. Unavoidable impacts

3. Alternatives
4. Short term use vs. long term productivity
5. Irretrievable use of resources

An EIS has to be prepared for any Federal project, policy or program implementation. The environmental assessment process is often called the NEPA process. Subsequent legislation, such as the Federal Aid Highway Act of 1970 (FAHA70) for highways, has implemented NEPA requirements for all major transportation projects participating in federal funding.

The NEPA process requires the impacts to be compared to accepted criteria and recommend mitigation where needed. This has led to a requirement for mathematical models, evaluation methodologies, and exact reporting procedures. Regulations have been promulgated to define these required processes as well as measures to be used to mitigate impacts, and guidelines for public participation.

In addition to the NEPA process, other formalized processes, such as conformity (air quality), 404 permitting (water), and 4f determination (land use), may be required during transportation planning. Various goals for each of these processes can make planning difficult.This myriad of laws and regulations acts to protect the environment and has formed our present system. A brief summary of the major federal laws and regulations are presented by environmental topic in the following sections.

67.2 Fundamental Concepts and Legal Requirements

Negative environmental externalities have occurred as humankind's mobility has increased. These undesirable impacts from transportation include physical impacts (noise, air pollution, water pollution, and effects on ecology) as well as sociological impacts (archeological impacts, displacements, monetary impacts, etc.). If transportation projects are to be completed, it is important to understand the nature of these impacts and the required analysis techniques. Physical impacts are primarily described in this chapter, with an emphasis on noise and air pollution.

Transportation Noise

Fundamental Concepts of Sound

The perception of sound by an individual — whether it is from a tuning fork producing a pure tone or the complicated spectra from traffic noise — is an amazing process. The individual evaluates the sound by at least four distinct criteria. These are loudness, frequency, duration, and subjectivity.

Loudness. The loudness or intensity of the noise is directly related to the amplitude of the pressure fluctuations transmitting through the air. The pressure fluctuations cause the ear drum to be flexed and create the sensation of sound. The ear can sense pressure fluctuations as low as 2×10^{-5} newtons per square meter (the threshold of hearing) and up to about 63 newtons per square meter, which is considered the threshold of pain. This represents a pressure change of over 10,000,000 units! Figure 67.1 shows typical sound pressure levels.

This large range of pressure fluctuations is clumsy to use in reporting. Also, as a protective mechanism, the auditory response is not linearly related to pressure fluctuations.[1] To overcome these two problems, a human-made unit to describe loudness is used — the decibel (dB) (see Fig. 67.1). The decibel is computed mathematically by:

$$\mathrm{SPL}\left(\mathrm{dB}\right) = 10\ \log_{10}\left(p^2/p_o^2\right)$$

where p_o = the reference pressure (2×10^{-5} newtons/m^2)
p = the sound pressure of concern

The use of dB indicates the loudness is measured as a sound pressure level (SPL) and no longer just the sound pressure.

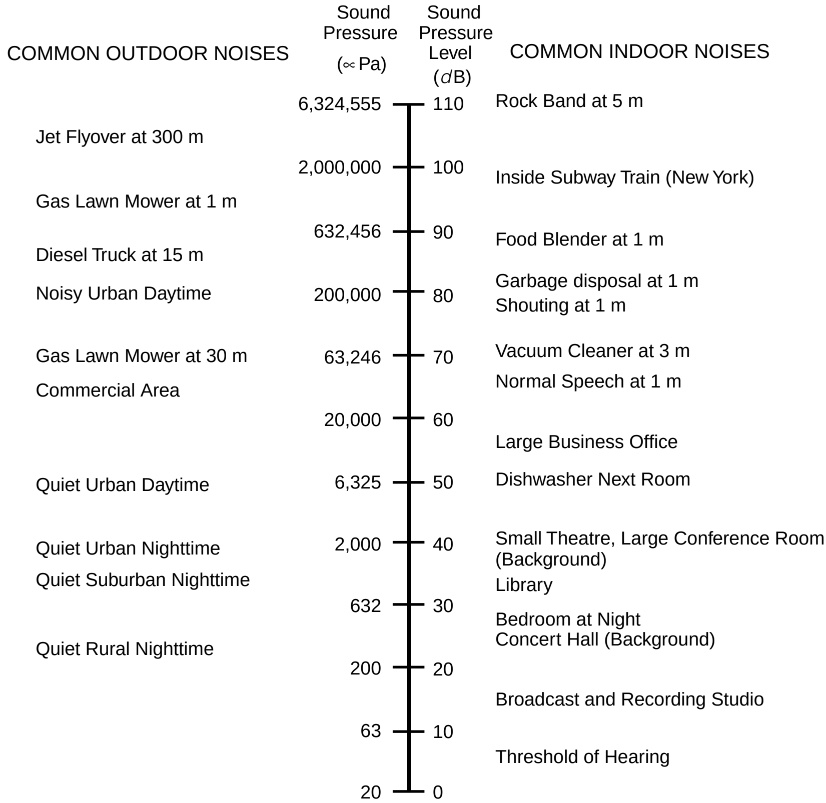

FIGURE 67.1 Typical noise levels. (*Source:* Ref. 2.)

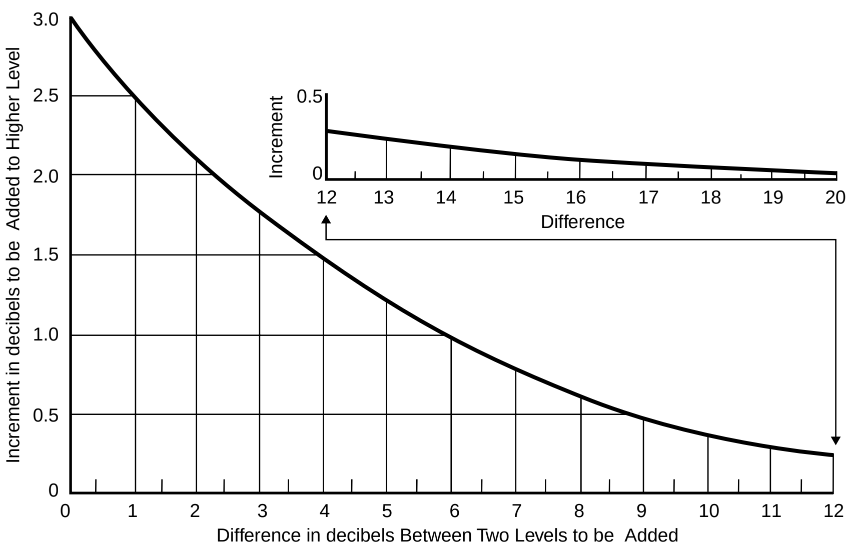

FIGURE 67.2 Chart for combining levels by decibel addition. (*Source:* Ref. 2.)

Decibels do not add in a linear fashion, but logarithmically. This means that if the sound pressure is increased by a factor of two, an increase in the sound pressure *level* would only be 3 dB. Adding dB may be accomplished using a simple chart (Fig. 67.2)[2] or, to be more exact, the equation:

$$SPL_{total} = 10 \log_{10} \sum_{i=1}^{n} 10^{SPl/10}$$

In outdoor situations, a change of greater than 3 dB is required to be noticeable. A change of 10 dB is generally perceived to be a doubling of the sound level. This means that a significant change in transportation patterns (vehicle volume, speed, mix, etc.) or alignment must occur for individuals to *objectively* determine a change in noise levels.

Frequency. The human ear can hear a large range of frequencies, or changes in the rate of pressure fluctuations in the air. The pressure changes per second, or oscillations per second, have the unit of Hertz (Hz). The ear can detect a range of frequencies extending from about 20 Hz to 20,000 Hz. It is these differences in the rate of the pressure fluctuations that provide the tonal quality of the sound and permit identification of the source. A flute has a much higher frequency than a bass guitar and we are adept enough to easily tell the difference, just as we can discern aircraft sounds from the blowing wind.

Frequency, the wavelength of the sound wave, and the speed of sound are all related. Mathematically:

$$f = c/\lambda$$

where f = frequency (Hz)
c = speed of sound (~343 m/s)
λ = wavelength (distance)

The human ear does not detect all frequencies equally well. Low frequencies (less than 500 Hz) and higher frequencies (greater than 10,000 Hz) are not heard very well. This requires a sound to be described by more than just loudness, by including some description of the frequency spectra. The loudness of each frequency could be reported and evaluated, but this is not practical. Groups of frequencies, called octave bands, are used to describe sounds and provide a detailed description of the frequency components (see Table 67.1). However, in regards to transportation sounds, a broader approach is most often used. In this approach, all frequency band contributions are first adjusted to approximate the way the ear hears each range, then the contributions are summed to a single number. Three common scales have been used. Figure 67.3 shows the A, B, and C weighting scales. The A scale is the way our ears respond to moderate sounds, the B scale is the response curve for more intense sound, and the C scale is the way our ears would respond to very loud sounds. The non-linear response of the ear at low and high frequencies is quite apparent from these graphs. Most regulations and evaluations applicable to transportation analysis use the A scale.

TABLE 67.1 Octave Band and Center Frequencies

Octave Frequency Range (Hz)	Geometric Mean (or Center) Frequency of Band (Hz)
22–44	31.5
44–88	63
88–177	125
177–355	250
355–710	500
710–1,420	1,000
1,420–2,840	2,000
2,840–5,680	4,000
5,680–11,360	8,000
11,360–22,720	16,000

Source: Reference 2.

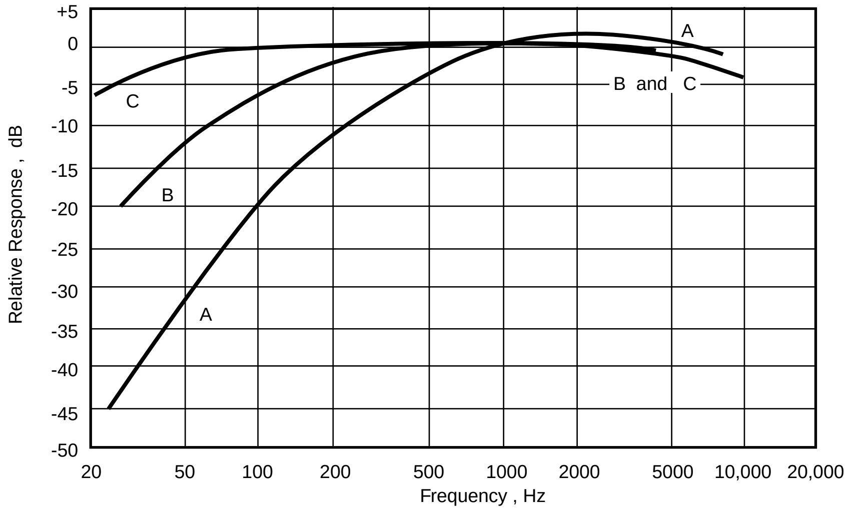

FIGURE 67.3 Frequency response curves. (*Source:* Ref. 2.)

Duration. A firecracker may be loud, but it lasts only a fraction of a second. Traffic noise may not be as intense, but it is continual. Effective descriptors of how sound varies with time have been developed. Some of the more important descriptors in regards to transportation noise are maximum sound level, $L_{max}(t)$; statistical sound levels, $L_{xx}(t)$; the equivalent sound level, $L_{eq}(t)$; and the day/night level, L_{dn}. In each of these descriptors the capital L represents that each is a sound pressure level with units of dB. The (t) indicates each is given for a specific period of time. By definition, L_{dn} is a 24-hour metric.

L_{max} represents the maximum noise level that occurs during a defined time period (see Fig. 67.4). This allows for a more complete description of the noise when combined with loudness and frequency description. For example, 60 dB (A-weight) L_{max} (1h) defines the overall sound level, frequency weighting, and an indication of the noise changes during a defined time period.

More description is possible with statistical descriptors (L_{xx}). The subscript xx indicates the percentage of time that the listed level is exceeded. For instance, a reported sound level of 60 dB (A-weight) L_{10} (1h) would mean that a sound pressure level of 60 dB on an A-weighted scale was exceeded 10% of the time in a 1-hour time period. The numeric value may be any fraction of the time, but L_{10}, L_{50}, and L_{90} are most commonly used (see Fig. 67.4). L_{90} is the sound pressure level exceeded 90% of the time and is commonly used as the background level.

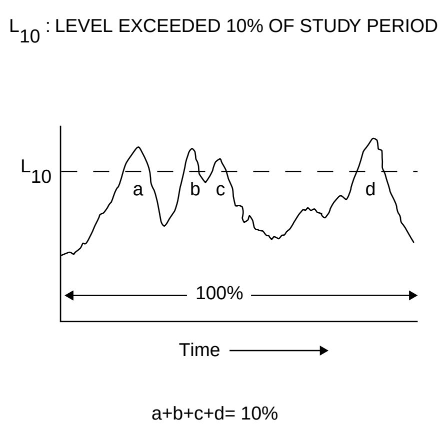

FIGURE 67.4 Graphical description of L_{10}.

L_{eq}, the equivalent sound pressure level, is a single number metric that represents the value of a non-varying tone that contains the same acoustic energy as a varying tone over the same time period. Other common nomenclature the reader may encounter for the L_{eq} value on an A-weighted scale is L_{Aeq}. One might think of L_{eq} as an average acoustic energy descriptor. It should be noted that the average energy is not an average of SPL over the time period because of the logarithmic nature of the dB. L_{eq} has the advantage of allowing different noises that occur during the same time period to be added. It has become the metric of choice in the U.S. for highway noise analysis.

The descriptor L_{dn}, the day/night level, is by definition a 24-hour metric. L_{dn} is sometimes shown as DNL. L_{dn} takes into account that not only is duration important, but the time of day the sound occurs is important as well. L_{dn} consists of hourly L_{eq} (A-weighted) values, energy averaged over the entire 24-hour period, with a 10-dB (A-weight) penalty added to each hour during the time period from 10 P.M. until 7 A.M. The 10-dB penalty in effect requires the sound pressure to be 10 times lower in the nighttime hours.

One other descriptor, primarily used in California, is the Community Noise Equivalent Level (CNEL). This descriptor, also sometimes refered to as L_{den}, is similar to L_{dn} with the early evening also being considered. A 5-dB(A) penalty is added to each hour from 7 P.M. until 10 P.M.

Effects and Subjectivity. Until now we have discussed characteristics of sound that may be mathematically quantified. However, individuals have different responses to various sounds and, as such, whether the sound is desirable or considered noise is quite subjective. Rock music to one listener may be a refreshing sound but to another listener, only noise. Unwanted sound is commonly referred to as *noise*. Transportation noise is a common problem in urban areas. The first three components of sound discussed (loudness, frequency, and duration) can be objectively described. Noise annoyance is subjective and criteria are usually based on attitudinal surveys.

It has been found that a single loud noise can result in an acute hearing loss, but this is not typically the case with transportation-related noise. Our mechanized societies tend to be more of a chronic problem, resulting in reduced hearing ability after long-term exposure. In the short-term, annoyance or irritation is of more importance. Transportation noise could lead to problems in our emotional well-being and cause increased tension by interfering with our sleep or causing disruption in our daily lives.[3] Studies have shown that noise prevents deep sleep cycles needed for complete refreshment, causes increased tension due to continual intrusion, inhibits communication ability, and reduces the learning abilities of students when excessive noise intrudes into the classroom.

Legislation and Regulations Affecting Transportation Noise

Federal legislation for noise pollution was passed in the 1960s and 1970s and is still in effect. The Housing and Urban Development Act of 1965, reinforced with the Noise Control Act of 1972, mandated the control of urban noise impact. The Control and Abatement of Aircraft Noise and Sonic Boom Act of 1968 led to noise standards being placed on aircraft. The Quiet Communities Act of 1978 better defined and added to the requirements of the Noise Control Act. This environmental legislation required noise pollution to be considered for all modes of transportation. Analysis methodologies and documentation requirements of noise impacts resulted.

To help ensure enforcement, the EPA created the short-lived Office of Noise Abatement and Control which contributed significantly to the determination of noise sources and the determination of regulations. A desirable neighborhood goal of 55 dB (A-weight) L_{dn} was identified.[4]

Many discussions have surrounded the appropriate noise level and descriptor most applicable to various forms of transportation and land use. In the U.S., the Federal Highway Administration (FHWA) has defined procedures (23CFR772) that must be followed to predict the worst hour noise levels where human activity normally occurs. Included in these detailed procedures are the Noise Abatement Criteria for various land uses as shown in Table 67.2. The legislation states that when the Noise Abatement Criteria are approached or exceeded, the noise mitigation must be considered. If abatement is considered feasible (possible) and reasonable (cost effective), then abatement measures must be implemented. Abatement may not occur if it is infeasible or unreasonable even though the criteria are exceeded. This leads to the requirement that each project be documented and considered individually. In addition to the Noise Abatement Criteria, substantial increases also trigger abatement analysis for projects on new alignment or drastic changes to existing highways, even though the Noise Abatement Criteria are not exceeded.

Aircraft noise is also controlled by federal legislation. The Control and Abatement of Aircraft Noise and Sonic Boom Act of 1968 mandated noise emission limits on aircraft beginning in 1970. The standards for new aircraft created classifications of aircraft based on noise emissions called Stage I, II, or III. The Stage I (noisier) aircraft have all but been phased out in the U.S. New regulations, in the form of 14CFR91 (*Transition to An All Stage III Fleet Operating in the 48 Contiguous United States and District of Columbia*) and 14CFR161 (*Notice and Approval of Airport Noise and Access Restrictions*) call for the fast phase-in of the quieter Stage III aircraft.

TABLE 67.2 FHWA Noise Abatement Criteria

Activity Category	$L_{eq}(h)^1$	$L_{10}(h)^1$	Description of Activity Category
A	57 (exterior)	60 (exterior)	Lands on which serenity and quiet are of extraordinary significance and serve an important public need and where the preservation of those qualities is required if the area is to continue to serve its intended purpose
B	67 (exterior)	70 (exterior)	Picnic areas, recreation areas, playgrounds, active sports areas, parks, residences, motels, hotels, schools, churches, libraries, and hospitals
C	72 (exterior)	75 (exterior)	Developed lands, properties, or activities not included in categories A and B table
D	—	—	Undeveloped lands
E	52 (interior)	55 (interior)	Residences, hotels, motels, public meeting rooms, schools, churches, libraries, hospitals, and auditoriums

Source: 23 CFR Part 772.

In 1979, the Aviation Safety and Noise Abatement Act placed more responsibility on local and regional airport authorities. The Airport Noise Control and Land Use Compatibility (ANCLUC) Planning process included in Part 150 of the Federal Aviation Regulations (FARs) allow federal funds to be allocated for noise abatement purposes. This process is often referred to as a "Part 150 study".

The FAA has also implemented a program that requires computer modeling for environmental analysis and documentation. Impacts are defined to occur if the L_{dn} is predicted to be above 65 dB (A-weighted).

In response to a lawsuit by the Association of American Railroads, the Federal Railroad Administration (FRA) has released standards as 40CFR Part 201. Figure 67.5 presents these standards. The lawsuit was necessary to circumvent hindrances to interstate commerce caused by inconsistent local ordinances.

In addition to administration regulations of U.S. DOT, other criteria or regulations may be applicable such as the guidelines established by the Department of Housing and Urban Development (HUD) to protect housing areas. The HUD Site Acceptability Standards use L_{dn} (A-weighted) and are "acceptable" if less than 65 dB, "normally unacceptable" from 66 to 75 dB, and "unacceptable" if above 75 dB. In addition, state and/or local governments have also issued guidelines. The analyst should carefully review all applicable requirements before beginning any study.

Estimating Transportation Noise Impacts

At the heart of transportation noise prediction is the use of reference emission levels that are averages of noise levels and frequency spectra that occur from defined transportation sources for a specified distance and test condition. This level is then corrected for distance, environmental variables, transportation volumes, and other related parameters during the noise prediction process.

Most highway vehicle modeling in the U.S. is based upon a single pass-by of the defined vehicle type at a distance of 15 m (50 ft) from the center of the vehicle track.[5] In Europe, 7.5 m (25 ft) is more typical. Defined vehicle types are generally broken into automobiles and trucks with subcategories of each. The U.S. Federal Highway Administration uses the categories of cars, medium trucks, heavy trucks, buses, and motorcycles. The various frequency spectra for each vehicle type is considered. An example of the Federal Highway Administration National reference emission levels is shown in Fig. 67.6.[6,7] Note that as speed increases, so do the emission levels. It should also be noted that the emission levels allow prediction from idle to 80 miles per hour. These levels were based on in situ measurements.[6,7]

The reference levels must then be adjusted to the modeling conditions. Among these are geometric spreading (effects of distance), traffic volume adjustments, source characteristics, diffraction, and environmental adjustments.

Noise reduction occurs with increased distance from a source and is usually referred to as geometric spreading. The attenuation due to geometric spreading may be characterized by the geometry of the source. If noise is emitted from a single location, the source is referred to as a *point source* (see Fig. 67.7). A boat whistle, a locomotive at idle, or a single aircraft could be identified as a point source. If the point

SUMMARY OF RAILROAD NOISE STANDARDS
40 CFR PART 201

Noise Source	Operating Condition		Noise Metric	Meter Response	Meas't Location	Standard dB(A)
Railroad Cars	Speed ″ 45 mph		L_{max}	Fast	100 Feet	88
	Speed > 45 mph		L_{max}	Fast	100 Feet	93
Active Retarders	Any		$L_{adj.ave.}$ max.	Fast Fast	Rec.Prop.	83
Car-Coupling	Any		$L_{adj.ave.}$ max.	Fast	Rec.Prop.	92
Locomotive Load Cell Test Stands	Any		L_{90}*	Fast	Rec.Prop.	65
	or	(a) Primary Standard	L_{max}	Slow	100 Feet	78
		(b) If (a) is Not Feasible	L_{90}*	Fast	Rec.Prop >400 Feet	65

* L_{90} measurement must be validated by showing that L_{10}(Fast) - L_{99}(Fast) ″ 4 dB(A).

SUMMARY OF RAILROAD NOISE STANDARDS
40 CFR PART 201
Locomotive Source Standards

Operating Condition	Noise Metric	Meter Response	Meas't Location	Locomotive Type	
				Non-Switchers Built On Or Before 31 Dec 79	All Switchers; * Non-Switchers Built After 31 Dec 79
Stationary, Idle	L_{max}	Slow	100 Feet	73 dB(A)	70 dB(A)
Stationary, Non Idle	L_{max}	Slow	100 Feet	93 dB(A)	87 dB(A)
Moving	L_{max}	Fast	100 Feet	96 dB(A)	90 dB(A)

* Switchers are in compliance if L_{90}(Fast) ″ 65 dB(A) on receiving property. L_{90} measurement must be validated by showing that L_{10}(Fast) - L_{99}(Fast) ″ 4 dB(A).

FIGURE 67.5 Railroad noise standards. (*Source:* 40 CFR Part 201.)

source is extruded in space, a line is formed and the source is referred to as a *line source* (see Fig. 67.7). Highway traffic may be modeled as either a moving point source or, for high volume highways, a line source.

For a point source the sound energy spreads as the surface of a sphere ($4\pi r^2$). The intensity and the root-mean-square pressure decreases proportionally to the inverse of the square root of the distance from the source (inverse-square law). A definite relationship in dB can be derived, resulting in:

$$\Delta \text{SPL}(\text{dB}) = 10 \log_{10} \left(r_1/r_2\right)^2$$

where ΔSPL (dB) = difference in SPL
r_1 = distance at point 2
r_2 = distance at point 1.

Consider when the distance — point source to receiver — is doubled. Then:

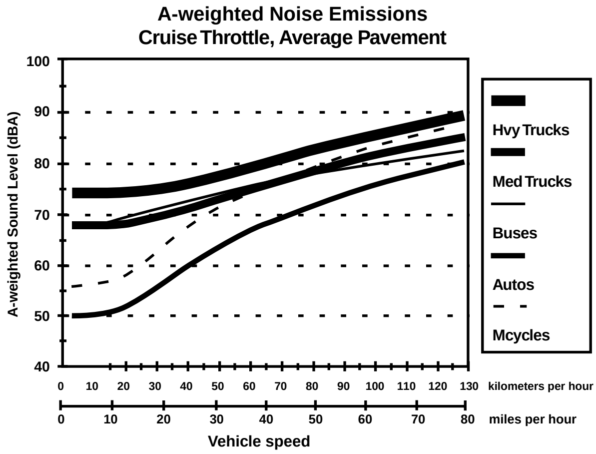

FIGURE 67.6 An example of the A-weighted reference energy mean emission level curves in TNM for average pavement and cruise conditions. (*Source:* FHWA Traffic Noise model Technical Manual.)

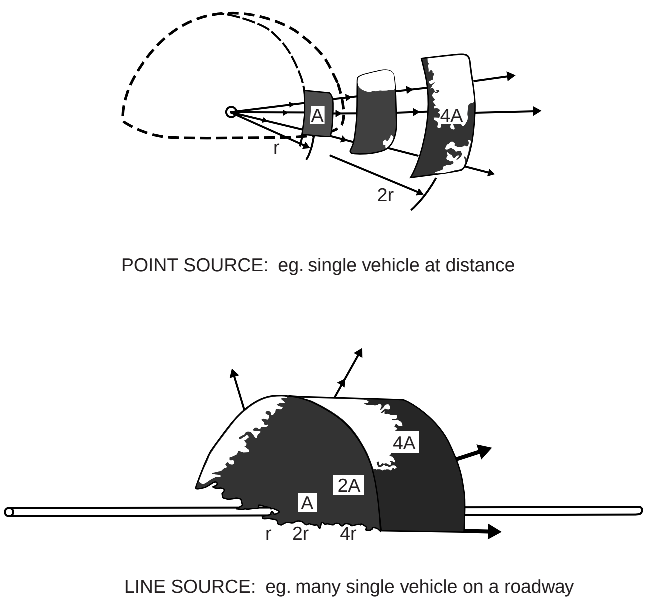

FIGURE 67.7 Point source and line source propagation geometries. (*Source:* Ref. 2.)

$$\begin{aligned}\Delta \text{SPL}(\text{dB}) &= 10 \log_{10} (1/2)^2 \\ &= 10 \log_{10} 1/4 \\ &= -6 \text{ dB.}\end{aligned}$$

Then, for a point source, every time we double the distance we reduce the noise levels by 6 dB. This is the way we might expect noise to decrease from a stationary vehicle.

Geometric spreading attenuation for a line source can be derived in a similar fashion to the point source. This time, the energy is spread over the surface area of a cylinder. In addition, the line consists of an infinite number of closely spaced point sources, so only the spreading away from the source in a single plane must be considered. This means that the sound energy spreading is proportional to the circumference of a circle. The circumference of a circle is equal to 2πr and using the same mathematical procedure as for a point source, a line source decreases as:

$$\Delta \text{SPL}(\text{dB}) = 10 \log_{10} \left(r_1 / r_2 \right).$$

For line sources, the sound level decrease is proportional to the distance from the source, not the square of the distance. Solving as before for a doubling of distance, a decrease of 3 dB occurs with each doubling of distance. Accordingly, it could be expected that the sound level would decrease by 3 dB for each doubling of distance from a highway. However, the highway is not actually in free space but close to the earth's surface. As a result, the interaction of the sound wave with the surface causes excess attenuation above what would be expected from just geometric spreading. The excess attenuation effects are related to the type of soil, ground cover, and surface topography. An acoustically hard surface abutting the highway (e.g., water or pavement) will result in a lower falloff rate (noise levels change less with distance from the roadway) than for an acoustically soft surface (e.g., vegetative coverings). Recent advances in modeling have significantly improved the prediction process for ground effects.

Since the reference levels are usually developed for a single motor vehicle (e.g., locomotive, rail car, or aircraft), additional vehicles, the number of vehicles by type, the duration of each different vehicle event, and the noise contribution of each vehicle allowing for vehicle path must be considered. Inclusion of these parameters permits a correct estimation of the overall noise for a defined transportation system.

The spatial relationship of the transportation source to the receiver not only determines the attenuation due to geometric spreading, but also determines characteristics of the noise path, such as obstructions to the sound path. Spacial relationships are usually accounted for by using an *x*,*y*,*z* Cartesian coordinate system. This permits distances — such as source to receiver, source to obstruction, obstruction to receiver — and other geometric relationships to be determined.

Obstructions in the noise path may cause diffraction or reflection of the sound (see Fig. 67.8). Diffraction, or the blocking of the sound, causes noise levels to be reduced. This area of decreased sound is called the *shadow zone*. Sound is attenuated the most immediately behind the object and the attenuation decreases with distance behind the object as the wave reforms. Diffraction is the reason properly designed highway noise barriers are effective. Obstructions may also reflect sound. This causes a redirection of the sound energy. The angle of incidence equals the angle of reflection.

Weather parameters may refract (bend) the sound waves causing reduced or increased noise levels according to the weather conditions. Figure 67.9 shows the effect of refraction that takes place when wind

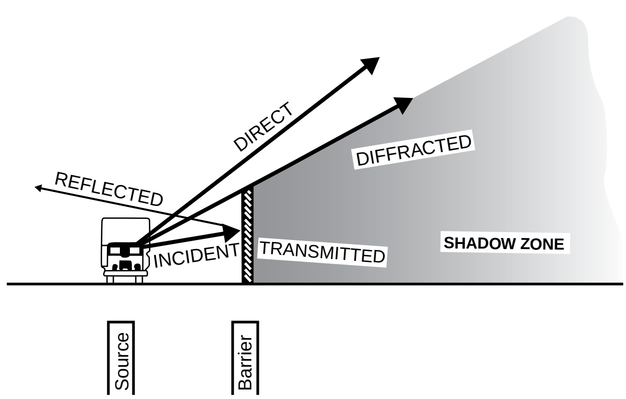

FIGURE 67.8 Effect of a barrier (shading indicates relative strength of sound energy). (*Source:* Ref. 2.)

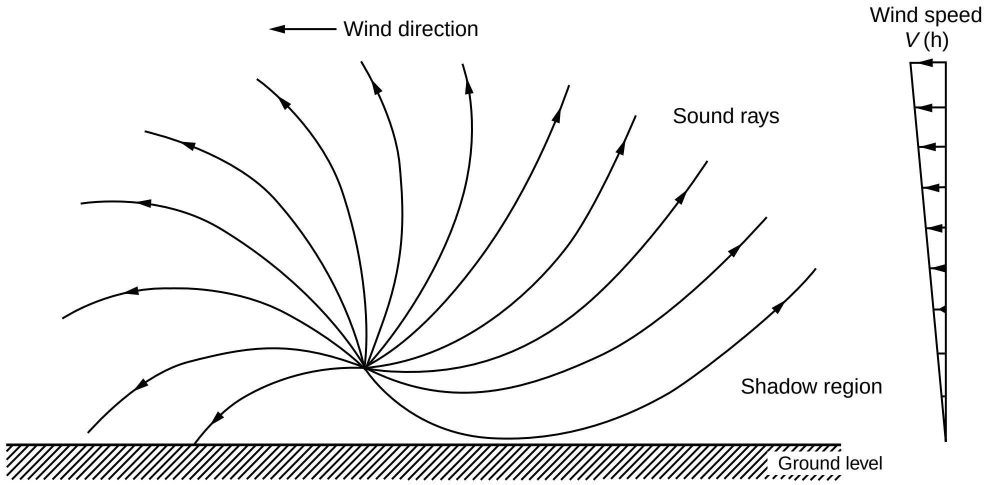

FIGURE 67.9 Refraction of Sound waves due to wind speed changes with height.

shear exists. Similar refraction is caused by temperature lapse rates (thermal vertical gradients). The upwind case occurs during normal lapse conditions (temperature decreases with height) and the downwind case would be expected when an inversion (temperature increase with height) occurs.

The refraction that occurs due to weather effects can be very significant but has been greatly ignored in many past models. It should be noted that since atmospherical effects cause refraction of the sound wave, negative excess attenuation (amplification) may also occur (downwind and during inversions). New model development will most certainly contain adjustments for these effects.

These overall developed methodologies have led to regulatory models by various governmental entities for transportation noise specific to area of jurisdiction. Each model usually begins with a reference sound level that has been established from in situ measurements at a defined distance for a single vehicle. Then adjustments are made and may include total number of vehicles, distance if not at the reference distance, end effects if near the end of a facility, ground effects, speed, and shielding (diffraction). Weather parameters are also included in some models.

For highway vehicles, the Federal Highway Administration (FHWA) has promulgated noise models for quite some time.[5] The FHWA is now in a transition between computer models, from STAMINA 2.0[8] to the new Traffic Noise Model (TNM).[9] Many state Departments of Transportation (DOT) have already begun the transition. The latest computer model, TNM, includes many improvements over STAMINA 2.0 including a Windows-based graphical user interface, graphical input, more theoretically based propagation algorithms, new reference levels, and dynamic linking of data (graphical and text). The output of the model is selectable and can be L_{eq}, Community Noise Equivalent Level (CNEL), or L_{dn} for user defined locations. The L_{eq} values can then be compared to the FHWA Noise Abatement Criteria (previously discussed) as well as other state and/or local criteria. CNEL is primarily used in California and L_{dn} is used by other agencies such as HUD and FAA.

The older FHWA computer model STAMINA 2.0 was meant to be run in conjunction with a “sister” program named OPTIMA[8] to allow design of highway noise barriers. OPTIMA reads an input file developed by STAMINA and allows the user to design effective noise barriers by changing barrier heights, eliminating barrier segments, and reviewing the effects on the overall noise levels at the specified receiver locations. In addition, a cost file is included to permit the user to determine the relative cost of the designed barrier scenarios, permitting consideration of both effectiveness and cost. All of this, plus graphical manipulation of the noise barrier during design, is in the TNM model. Figure 67.10 shows a typical design window for TNM. The latest version of TNM at the time of this writing is 1.1, with Version 2.0 in beta form.

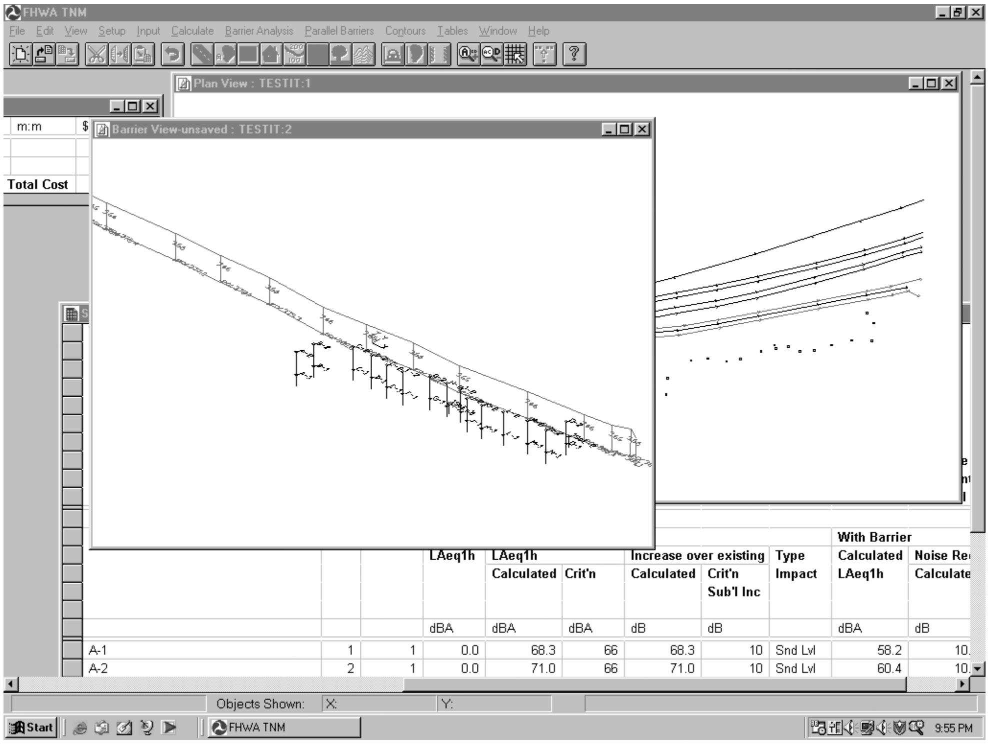

FIGURE 67.10 Screen capture of the TNM interface showing both graphical and text windows open.

Although the noise analysis procedures for aircraft are similar to those for highways, noise usually only occurs when the aircraft is near the ground. As with highway noise, expected increases and comparison to criteria are required. A level of 65 dB (A-weighted) L_{dn} is the established impact criteria and is based on yearly average operations at the airport.

Airport noise is usually predicted using the computer models NOISEMAP[10] or the Integrated Noise Model[11] (INM). Adjustments to reference levels are made as with highway models. While noise levels at user defined locations can be predicted as with the FHWA model, the primary output of these models are noise contours as shown in Fig. 67.11. Contours may be plotted for a specified level, typically the 65 dB L_{dn} FAA criteria, to determine areas defined to be impacted near the airport.

No detailed computer models have been released by the Federal Railroad Administration, but it is generally agreed that rail noise can be predicted based upon a strong logarithmic relationship to speed:[12]

$$L_{max} = 30 \log(V) + C$$

where V = speed of train
C = a constant

In this situation, L_{max} is at a defined location for a single pass-by. Adjustments for sight specific conditions (e.g., distance) must be calculated as for highway vehicles. For the newer high speed rail, a 40 log V relationship appears to be appropriate.[13] Measurements at yards may be used for future predictions by "scaling" the levels according to expected future use.

In addition, FRA[14] and FTA[15] (previously UMTA) have published noise and vibration guidance for passenger rail projects. The FRA method is especially applicable for high-speed fixed guideway systems, while the FTA includes all vehicles for transit, including urban rail and buses. Spreadsheet procedures have also been promulgated for these predictive methodology by both FRA and FTA.

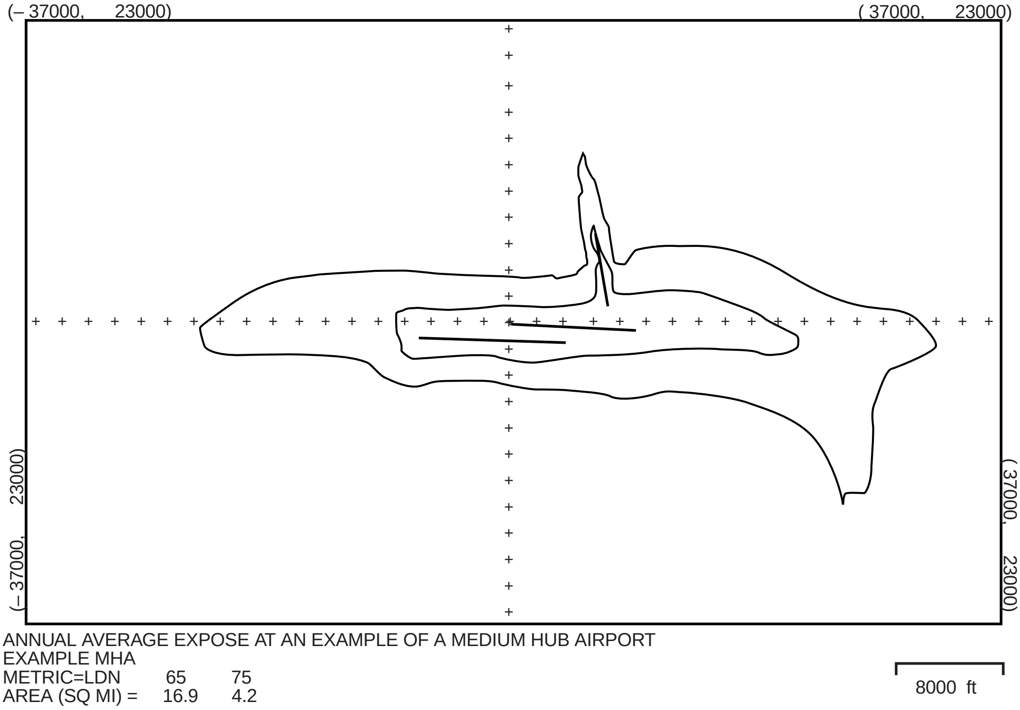

FIGURE 67.11 Typical noise contour plot from INM. (*Source:* Ref. 11.)

Mitigation of Transportation Noise

Mitigation of transportation noise may occur at the source, in the propagation path, or at the receiver. Each has benefits and problems. Abatement of noise from highways has proven to be successful in all these locations.

Traffic noise is emitted from the tire/pavement interaction, the exhaust, and from the engine. At higher speeds, the automobile noise is almost all from the tire/pavement interaction. For heavy trucks, the noise from the exhaust and engine during acceleration is much more dominant than the tire noise. Accordingly, reduction of noise from various sources is needed to reduced noise impacts on the highway neighbor. Insulation in the engine compartment is used to reduce engine noise, mufflers are used for exhaust noise, and pavement type selection may reduce tire/pavement interaction and lessen the noise impact.

Noise abatement techniques at the vehicle are still being developed. Two of these methods of control are the use of contra-noise and open-graded asphalt for tire noise control. Contra-noise involves generating a wave-form of equal amplitude but opposite phase to the cancel engine or exhaust noise. Implementation could consist of speakers used in engine compartments to cancel engine noise or electronic mufflers for exhaust noise.

The tire/pavement noise generation is a direct result of the friction and small impacts that occur as the tire rolls along the surface. Intuitively, it would seem that smoother pavement would create less noise. And while this is true, it leads to unsafe conditions due to reduced skid resistance. In addition, recent studies, particularly in Europe, have shown that open graded asphalt ("popcorn" asphalt) can also result in a significant noise reduction. This is thought to occur because although more noise is generated, the rough surface diffuses the normally reflected wave and, hence, less pressure fluctuations are transmitted. Highway traffic noise reduction may also occur at the source by using traffic management (e.g., reduce speeds or ban trucks). Near airports, noise may also be controlled at the source. FAR, Part 36, along with the regulations discussed earlier, has greatly reduced the aircraft engine noise and is the most effective aircraft noise abatement measure.

FIGURE 67.12 Typical noise barrier for highway.

The path may also be altered to reduce noise. As discussed earlier, increased distance between the source (motor vehicle) and the receiver (uses of land near or abutting the highway) results in reduced sound levels due to geometric spreading. It then follows that increased path distance results in traffic noise abatement. This abatement measure is possible if sufficient right-of-way widths are available. A green-belt is established and the noise levels are reduced at the receiver locations. This option is very costly in large urban areas because of the many typical relocations required and the cost of land. As such, it is a costly option for highways or railways in urban areas, but may be the only feasible method for airports.

A more cost-effective abatement method for highways and railways may be achieved by requiring changes in the vertical or horizontal alignment. Another more cost-effective abatement measure that has been used extensively in North America, Europe, Japan, and Australia is the diffraction of the sound wave by noise barriers. A typical traffic noise barrier is shown by Fig. 67.12. The difference in noise levels with and without the wall is referred to as insertion loss. Insertion loss is typically calculated using Fresnel diffraction techniques that depend on the angle the sound wave must make to go from source to the receiver with a barrier in the path. This angle is usually approximated by using the path length distance (difference between direct path and path over the obstacle). As the path length distance increases, so does the angle and the sound level reduction. Often highway neighbors request vegetative plantings instead of noise barriers. Some work has been done to determine the insertion loss due to vegetation,[16] but most often this method is not very effective except on a subjective basis. The new International Organization for Standardization (ISO) standard for vegetation would seem to provide the best results and is the most accepted procedure.[17]

Sometimes it is not practical or feasible to mitigate traffic noise in the path, such as near airports. In these cases, it may be possible to protect individuals by insulating buildings. A typical wood frame house, with the windows closed, attenuates the noise roughly 10 to 20 dB on an A-weighted scale. With increased insulation in the walls and roof, double-paned or thicker pane windows, acoustic vents, storm doors, and possible other changes, the house may provide a reduction of more than 40 dB (A-weighted). Many homes near airports are insulated in this manner using Part 150 funding. Public buildings, such as schools, have been insulated near highways using FHWA funding.

Other abatement measures have been defined by various agencies. The FAA has listed 37 abatement measures and are shown in Table 67.3. In regards to rail noise abatement, diffraction, reduction of rail squeal, dampening of track noise, and increased separation distance have all been applied. Noise barriers (diffraction) are quite efficient because of possible placement very near the guided path.

Cost may vary widely according to the mitigation method selected, materials available, location, and amount of abatement required. In April 2000, the Federal Highway Administration reported that the average noise barrier cost in the U.S. from 1972 to the report year, in 1998 dollars, was $179 per square meter ($16.63 per square foot).[18]

Buying or insulation of homes near airports is also quite costly. Accordingly, abatement may be somewhat costly, but it is usually only a small part of the overall project costs. It should be noted that a

TABLE 67.3 FAA Noise Control Strategy Categories

Category Number	Description
1	State noise law
2	Local noise law or ordinance
3	Airport master plan
4	ANCLUC plan
5	Part 150 noise exposure map approved
6	Part 150 noise compatibility plan approved
7	Development of an EIS
8	Noise monitoring equipment: temporary or permanent
9	Restriction on ground runup
10	Limit on the number of operations by hour, day, month, year, or noise capacity
11	Preferential runway system
12	Runway restrictions imposed for specific aircraft type
13	Use restriction by aircraft type or class
14	Use restriction based on noise levels
15	Use restriction based on Part 36
16	Use restriction based on AC 36-3
17	Complete curfew
18	Arrivals and/or departures over a body of water
19	Displaced runway threshold
20	Rotational runway system
21	Maximum safe climb on takeoff
22	Takeoff thrust reduction
23	Reverse thrust limits
24	Flight training restriction
25	Weight or thrust limit
26	Informal flight operation restriction
27	Zoning
28	Purchase land for noise control
29	Use of capital improvements to direct development
30	Building codes and permits to control noise
31	Noise easements
32	Purchase assurance
33	Soundproofing programs
34	Noise use fees
35	Shift operations to a reliever airport
36	Local pattern restrictions
37	Navigational aid assisted departure

Source: FAA.

liveable environment is the goal and not implementing mitigation measures may lead to drastic changes or cancellation of the project. As such, properly designed abatement would seem to be well worthwhile.

Transportation and Air Quality

Fundamental Concepts

General Considerations

Transportation sources are typically called mobile sources. Airports, parking lots, and other collectors of mobile sources are often referred to as indirect sources. From each source, various amounts and types of air pollutants are emitted according to fuel type, vehicle mode, vehicle volumes, and various other vehicle specific factors. An air pollutant can be defined as a gas, liquid droplet, or solid particle dispersed in the air with sufficient concentration to cause an adverse impact on public health or welfare. Combustion exhaust gases from transportation sources include carbon monoxide (CO), nitrogen oxides (NO_x), volatile organic compounds (VOCs), and sulfur oxides (SO_x). The emitted VOCs are sometimes simply referred to as hydrocarbons (HC), and are emitted not only from the combustion process but from evaporated fuels as well.

Particulate matter (PM) is also created during combustion and includes small solids or liquid droplets (0.01 to 100 μm). Standards are now written in terms of particulate matter less than 2.5 and 10 μm in aerodynamic diameter, designated as $PM_{2.5}$ and PM_{10}, respectively.

Other pollutants, not directly emitted from the source, may form in the atmosphere using the directly emitted pollutants as precursors. These include nitrates, sulfates, and photochemical oxidants (ozone).

Common units of measurement for air pollutants include parts per million (ppm) and micrograms per cubic meter ($\mu g/m^3$). The units ppm are a measure of very small ratios of volume (or moles) of pollutant per volume (or moles) of air. One ppm represents one-millionth of the total volume. One $\mu g/m^3$ is a small amount of mass in a defined volume of air.

Although significant reductions of mobile source emissions have occurred, the EPA still reported that in the year 2000 mobile sources were the primary anthropogenic source of CO (56% on-road, 22% off-road for a total of 78% of the total) and also contributed about 49% of the total NO_x and 48% of the total non-methane volatile organic compounds.[19] Research is currently being conducted by FHWA to determine the overall contribution of diesel vehicles on urban $PM_{2.5}$ and PM_{10} concentrations. The FAA is also very active in trying to determine the particulate matter emissions from aircraft. Lead emissions have been drastically reduced from mobile sources through the use of unleaded gasoline. Fuels in the U.S. are highly refined and sulfur is significantly removed. Accordingly, most SO_x emissions are attributed to non-mobile sources in the U.S.

Typically, efforts have been concentrated on a few regulated pollutants during transportation analysis. These include CO, HC, NO_x, and PM_{10}. It should be noted that HCs have no NAAQS but are precursors of ozone and often predicted as VOCs. Similarly, regional analysis are now being done for all ozone precursors and for toxic compounds emitted by transportation. These types of analysis will become more important in the future as will the particulate matter analysis, especially $PM_{2.5}$.

The reader is encouraged to consult a general air pollution text for particular pollutant characteristics. Due to space limitation, a complete description cannot be included here.

Health and Public Welfare Effects

Air pollution is generally associated with respiratory damage (bronchitis, emphysema, pneumonia, and lung cancer) as well as irritation of the eyes, nose, and throat. Public welfare effects include damage to structures and materials, damage to crops and animal life, and atmospheric haze. Global effects from acid rain, global warming, and ozone depletion are also of concern. Standards are usually written as primary standards to protect human health and secondary standards to protect public welfare.

Air Quality Legislation and Regulations

Federal legislation relating to air quality and transportation began in the mid-1950s when the Air Pollution Control Act of 1955 was passed. This law gave authority to the Public Health Service and was amended in 1962 to include health effects of auto exhaust. In 1963 the original Clean Air Act (CAA) was passed and subsequently amended in 1965. The Act authorized the Secretary of Health, Education and Welfare (HEW) to promulgate and enforce federal emission standards for new motor vehicles. The 1965 Motor Vehicle Control Act was passed in an effort to improve national vehicle emission standards to California standards by 1968. It is interesting that this legislation forced development of automotive emission controls and resulted in common use of such items as the positive crankcase ventilation (PCV) valve.

The Air Quality Control Act of 1967 charged the Secretary of HEW to publish air quality criteria. Unfortunately, criteria do not require compliance as do standards. This made the federal legislation good in theory but unenforceable in practice. Major responsibilities were still at the state and local level and evaluation methodologies varied widely.

In 1970, all federal air pollution control functions were transferred from HEW to the newly established Environmental Protection Agency (EPA). This gave direct authority for determining guidelines, methods, and standards to the EPA and forced state and local governments to look to the EPA for guidance.

TABLE 67.4 National Ambient Air Quality Standards

Pollutant	Primary (health std.) Averaging Time	Concentration	Secondary (welfar std.) Averaging Time	Concentration
Particulate (PM10)	Annual arithmetic mean	50 μg/m³	Same as primary	—
	24-hour	150 μg/m³		
Particulate (PM2.5*)	Annual arithmetic mean	15 μg/m³	Same as primary	—
	24-hour	65 μg/m³		
Sulfur dioxide	Annual arithmetic mean	.03 PPM	3-hour	.5 PPM
	24-hour	.14 PPM		
Carbon monoxide	8-hour	9 PPM	No secondary	—
	1-hour	35 PPM	Standard	
Ozone*	Max. daily 8-hour average	.08 PPM	Same as primary	—
	1-hour average	.12 PPM		
Nitrogen dioxide	Annual arithmetic mean	0.53 PPM	Same as primary	—
Lead	Maximum quarterly average	1.5 μg/m³	Same as primary	—

Source: 40 CFR Part 50.

The Clean Air Act Amendments of 1970 (CAAA70) permitted federal intervention if state and local governments did not meet their responsibilities. This was the first air quality law that provided strong federal controls in the individual states. Section 110 led to the establishment of State Implementation Plans (SIPs) first released as 40CFR51 and 52. The SIP is a state-prepared document that completely outlines how the state will deal with air pollution problems. Section 202 led to the promulgation of the National Ambient Air Quality Standards (NAAQS). The dose an individual receives depends on the toxicity of a particular pollutant, the concentration of exposure, and the time of exposure. The NAAQS were determined based on these three factors. Table 67.4 lists the NAAQS promulgated by the U.S. EPA. The NAAQS are used during air quality evaluations to determine if the project is in compliance, including transportation projects. Other pollutants may also be evaluated as previously mentioned for VOCs, a direct precursor of the secondary pollutant ozone.

Section 202 of the CAAA70 led to motor vehicle and aircraft emission standards, released as 40CFR85. A 90% reduction in CO and HC were originally required by 1975, with a similar reduction in nitrogen oxides (NO_x) required by 1976. This law directly led to the development of the catalytic oxidizer which was included on cars manufactured after 1974. Unfortunately, events such as the Arab oil embargo of 1973 led to delays in implementation of emission standards. As a result, the emission standards originally intended for the mid-1970s were not fully realized until the mid-to-late 1980s.

Another strong piece of environmental legislation passed in 1970, in regards to transportation, was the Federal Aid Highway Act of 1970 (FAHA70). This act required the Secretary of the U.S. Department of Transportation (DOT), guided by discussions with the EPA administrator, to develop and issue guidelines governing the air quality impacts of highways. A strong planning process was implemented and transportation plans were required to be consistent with the SIP. To ensure consistency, transportation control plans (TCPs) and transportation control measures (TCMs) were required to improve air quality.

The CAA was amended again in 1977. In this law, regions were classified as nonattainment areas (NAAs) if the NAAQS were exceeded. With the NAA designations came the concept of sanctions (loss of federal funds if a good faith effort was not given to meet the NAAQS) and states hurried to ensure their SIP was acceptable. The SIP had become a strong tool that allowed the EPA to review and concur with state air quality policy. In June 1978, in direct response to Section 108(e) of the CAAA77, the EPA and the U.S. DOT issued joint Transportation–Air Quality Planning Guidelines.[20] These ambitious guidelines were issued with a national goal of attainment of the NAAQSs by 1982, with some extensions until 1987 (e.g., for O_3 and CO). SIP requirements, various agency coordination, and analysis/abatement methodologies were included in the guidelines.

Unfortunately, the attainment dates were not met, which partially resulted in the CAAA90.The CAAA90, signed by the President on November 12, 1990, contains strong transportation provisions. In fact, one entire title of the act is related to mobile sources and other titles may have far-reaching effects on transportation issues.

Title I approaches NAAs in a new way. Categories of non-attainment have been developed for O_3, CO, and PM_{10}. For example, ozone NAAs are rated from *transitional* to *extreme*. Each category allows different time schedules and levels of air pollution control measures to help ensure the NAAQS will be attained. More heavily polluted areas have a greater amount of time to come into attainment, but must implement greater emission controls.

Title II (mobile sources) requires more strict emission controls, use of alternative fuels, off-road source (e.g., tractors and construction equipment) emission controls, and implementation of TCMs according to the severity of the air pollution problem in the area. Title II also requires more strict tailpipe emission controls. The Stage I requirements included: (1) phasing in tighter HC, CO, and NO_x tailpipe emission standards for cars and trucks beginning with 1994 models (HC 0.25 g/mi, CO 3.4 g/mi, NO_x 0.4 g/mi); (2) requiring vehicle manufacturers to design for reducing evaporative HC emissions during refueling; (3) controlling fuel quality (e.g., volatility and sulfur content); (4) re-formulated gasoline beginning in 1995 for most severely polluted ozone NAAs; (5) mandating oxygenated fuels during winter months for 41 moderate and serious carbon monoxide NAAs; and (6) establishing a clean fuel pilot program in Los Angeles, affecting 150,000 vehicles in 1996 and 300,000 in 1999, with stricter standards imposed in 2001. In addition, Tier II controls, even more stringent tailpipe standards, may be implemented at a later date as needed. Tier II is just being considered for implementation at the time of this writing (2002).

Title III (toxics) and Title IV (acid rain) may also have long-reaching effects on mobile sources as interpretation of the CAAA90 continues.

The CAAA90 directed the administrator of the EPA to

> "update the 1978 Transportation-Air Quality Planning Guidelines and publish guidance on the development and implementation of transportation and other measures necessary to demonstrate and maintain attainment of national ambient air quality standards (NAAQS)."

This resulted in the issuance of the updated Transportation and Air Quality Planning Guidelines,[21] which provide guidance to state and local government officials to assist them in planning for transportation-related emissions reductions that will contribute to the attainment and maintenance of NAAQS. Also in 1992, guidelines were released by the EPA for evaluating "hot spot" intersections[22] for carbon monoxide concentrations.

The complex determination of when projects achieved SIP conformity led to a series of EPA and U.S. DOT conformity guidelines and memorandums.[23–30] The purpose of these documents was to provide guidance regarding the criteria and procedures to be followed by MPOs, other recipients of funds designated under Title 23 of the U.S. Code or the Federal Transit Act, and the U.S. DOT in making conformity determinations. The Final Conformity Rule was finally released in November 1993 by FHWA and EPA as 40CFR Parts 51 and 93. This 169-page document is still confusing to many air quality analysts and has resulted in controversy, including lawsuits. Conformity requires not exceeding established emission budgets base on 1990 levels. Transportation projects generally are also required to show emission benefits.

The Intermodal Surface Transportation Efficiency ACT (ISTEA) was signed by the President on December 18, 1991. The Act included increased funding, flexibility for local projects, and additional metropolitan and statewide planning requirements. Multiple environmental concerns were formalized in this act. Emphasis was required on multi-modal considerations, land use considerations, development decisions, and transportation-related air quality problem solving. As such, projects to increase single-occupancy-vehicle (SOV) capacity will not be easily approved in NAAs. In fact, for transportation management areas (TMAs) in NAAs, it may be extremely difficult to use federal funds for any highway or transit project that will result in a significant increase in capacity for SOVs unless it is part of a congestion management system (CMS). This has led states to consider many non-traditional highway projects, such as high-occupancy-vehicle (HOV) lanes, across the country.

ISTEA also reinforced the CAAA90 requirements that transportation plans conform to the SIP. MPOs must also coordinate the development of long-range TIPs to be in conformity with the SIPS and the TIP must have had an opportunity for public comment. Also, regardless of funding source, MPOs must now consider the emissions from *all* transportation projects. Consistency with the long-range transportation plan is required. This has provided MPOs with more flexibility, but at a price of more planning requirements.

ISTEA was updated, corrected, and reauthorized by the Transportation Equity Act for the 21st Century (TEA21) on June 9, 1998. The strong air quality requirements and other environmental impacts, just as in ISTEA, are still in the act. In fact, TEA21 has strengthened the environmental requirements for all modes of transportation. One such is example is the requirements to address new air quality concerns such as a new monitoring network for $PM_{2.5}$.

Modeling of Air Pollutants from Transportation

Dispersion of air pollutants is due to molecular diffusion, eddy diffusion, and random shifts in the instantaneous direction of the wind. Eddies are small, random swirls of air that transport parcels of air from one location to another, resulting in the dilution of pollutants much more rapidly than would occur from just diffusion.The end result is that after emissions have been released, atmospheric dispersion determines the resulting concentrations. Because of the random nature of eddies and wind shifts, dispersion must be considered on a time-averaged rather than an instantaneous basis. The wind also provides bulk transport of pollutants downwind. In general, the higher the wind speed, the greater the mechanical mixing and the lower the concentrations as distance increases from the source.

In addition to the wind, solar insolation results in energy being absorbed by the ground, heating the surface. A temperature gradient (lapse rate) is formed and temperature decreases with height as the heat is transferred to the layer of air in contact with the ground. This causes the air to rise and mixing occurs. This thermal mixing may be dominant during the daytime and results in an "unstable" atmosphere. Unstable air tends to disperse air pollution vertically, promoting mixing of pollutants, and results in lower concentrations. It has been found that unstable conditions generally exist when the temperature gradient, or lapse rate, is greater than 5.4°F for each 1000-foot change in elevation (0.98°C for every 100 meters of height change). Near this lapse rate, neutral conditions exist (mixing is neither hindered nor helped), and atmospheric conditions with a lower lapse rate result in a stable atmosphere and mixing is hindered. When temperature increases with height, an inversion is formed and results in the greatest concentrations. These ideas are summarized in Fig. 67.13.

Based on this mechanical (due to the wind) and thermal mixing, atmospheric stability has been classified from A (very unstable) to F (very stable). The D stability class is considered neutral. This classification is called the Pasquill-Gifford atmospheric classification scheme and is shown in Fig. 67.14.

As the pollution is dispersed, the peak concentrations decline. However, the vertical and horizontal (perpendicular to the wind direction) distributions remain somewhat normally distributed or Gaussian.[31] The Gaussian model is one way to estimate dispersion for a non-reactive pollutant released steadily from a source at a defined downwind location. As such, modifications of this approach have been used extensively for modeling CO which has a half-life of over 40 days in the atmosphere. The general form of the equation for a point source is:

$$C = \left[Q/2\pi u \tau_y \tau_z\right]\left[0.5\left(y/\tau\right)^2\right]\left[0.5\left\{\left(z+H\right)/\tau_z\right\}^2 + 0.5\left\{\left(z-H\right)/\tau_z\right\}^2\right]$$

where C = concentration (mass/volume)
Q = emission rate (mass/time)
u = wind speed
τ_y, τ_z = standard deviation of dispersion in the y and z directions
y = distance receiver is removed from the x axis
z = receptor height
H = source height.

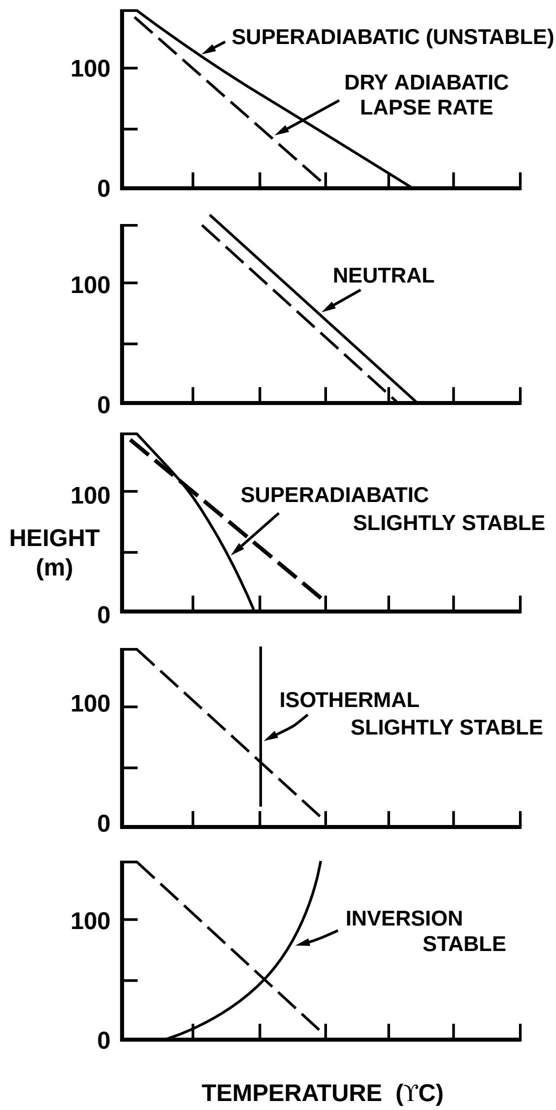

FIGURE 67.13 Graphical descriptions of lapse rates.

If it is assumed that line sources (for example heavily traveled roadways) can be modeled as short segments, then this model is still valid and can be applied in a repetitive fashion to calculate the sum of the contributions from each segment at a receptor location. The sum of all plumes at the receptor location provides the overall impact from the project. Other modifications to this basic equation have been used to approximate mobile sources as moving point sources, line sources, and area sources.

As the experience with these models increases, more advances are being made. The most recent EPA promulgated model is called AERMOD and uses a bivariate Gaussian distribution in the vertical plane to better approximate vertical mixing.[32] Some transportation models are making use of this more advanced model.

Use of the Gaussian model requires knowledge of the atmospheric mixing and the Pasquill-Gifford classes are commonly used. A good knowledge of the emission rate is also crucial to obtaining good performance of the dispersion model. With point sources, emission rates are relatively easy to obtain because of the consistent operational parameters. With mobile sources, getting a good estimate of the average emission rate is much more difficult.

A - Extremely unstable conditions
B - Moderately unstable conditions
C - Slightlt unstable conditions
D - Neutral conditions[a]
E - Slightly stable conditions
F - Moderatly stable conditions

Surface Wind Speed (at 10m)	*Daytime Conditions*			*Nighttime Conditions*[b]	
	Incoming Solar Radiation[d]				
m/sec	*Strong*	*Moderate*	*Slight*	*Thin Overcast or ≥4/8 Cloudiness*[c]	*″3/8 Cloudiness*
<2	A	A-B	B	-	-
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
>6	C	D	D	D	D

[a]Applicable to heavy overcast, day or night.

[b]Nighttime conditions refers to the period one hour before sunset to one hour after sunrise.

[c]The degree of cloudiness is defined as that fraction of the sky above the local apparent horizon which is covered by clouds.

[d]"Strong" incoming solar radiation corresponds to a solar altitude greater than 60ϒ with clear skies; "moderate" insolation corresponds to a solar altitude of 35ϒ to 60ϒ with clear skies; and "slight" insolation corresponds to a solar altitude of 15ϒ to 35ϒ with clear skies.

FIGURE 67.14 Pasquill–Gifford stability classes. (*Source:* EPA, Pub. AP-26.)

Standardized emission databases for mobile sources are available. In the U.S., EPA efforts have assembled major databases for both on- and off-road vehicles, locomotives, aircraft, and large ships, as well as other related sources. The emission factors are listed in the EPA document, *Compilation of Air Pollutant Emission Factors, 4th ed., Volume 2, Mobile Sources*[33] and the California specific emission factors. The national emission factors in the EPA document are commonly referred to as AP-42 from an abbreviation of the document number.

Due to the complexity of predicting emission factors for highway vehicles, a special computer program has been developed. The computerized database allows for numerous adjustments (mode, speed, facility type, etc.). The computer program is called MOBILE and currently the latest version is called MOBILE6.[34] California has chosen to develop even more state-specific factors to allow better modeling of their fleet. This model is called EMFAC with the versions now being used called EMFAC2000 and EMFAC2001.

Emissions factors are a measure of the source strength per unit of activity. As such, the units from the MOBILE model are mass emitted per distance (grams/mile). Idle emissions are obtained by using a user input speed of 2.5 mph and multiplying the computed answer by a factor of 2.5 (grams/mile × mph = grams/hour). It should be noted that in MOBILE, cruise is really a trip-generated model containing all four modes: (1) cruise, (2) idle, (3) acceleration, and (4) deceleration.

The EPA- and FAA-approved aircraft emission factors are those listed in the International Civil Aviation Organization (ICAO) database.[35] These factors are also listed in the FAA promulgated computer model, the Emission and Dispersion Modeling System (EDMS), along with emission factors for associated vehicles such as ground support equipment.[36]

After emission data have been determined, two analyses are typically accomplished. The NEPA process usually requires the Gaussian dispersion modeling methodology to be used so the pollutant concentrations may be predicted and compared to the NAAQS, the existing concentrations, and various future alternative predictions (including the no-build alternative). Multiplication of emission factors times activity rates determines the total pollutant load (total mass emitted) and is compared to the emission budget, area wide emissions, and the alternatives during the conformity determination process. Because of the complexity of the analysis procedure, many state agencies have written guidelines. Some examples have been included in the references.[37–40]

Because of the importance of weather on pollutant levels, historical meteorological data are used to evaluate dispersion. This data usually comes from airports or other weather stations. For analysis at airports, this historic data is often used during dispersion analysis to determine hourly pollutant concentration trends for multiple years to determine compliance with the NAAQS.

For other types of transportation projects removed from the immediate airport area, and because airports and weather stations are often on the outskirts of the urban area, a so-called worst case analysis is usually done. The approach is to use a set of "worst-case" meteorological conditions. This results in using the lowest realistic wind speed (1 m/sec), worst reasonable stability class, lowest (or highest) reasonable temperature, highest expected traffic and emissions, and closest reasonable receptor locations in the air quality models. This approach will result in the worst-case concentration that can reasonably be expected. If the predicted worst-case concentration does not violate the NAAQS, then it is safe to assume the project is not likely to exceed the standards under typical conditions.

Several computer models have been developed for highway projects. For uninterrupted flow, these include CALINE,[41] HIWAY,[42] and PAL.[43] For interrupted flow TEXIN 2,[44] CALINE 4,[45] and CAL3QHC[46] are available.CALINE (California Line Source Model) has been updated several times and uses the Gaussian approximation of many small line sources as previously described. CALINE 4 is the latest version, but the EPA maintains CALINE 3 as the approved model.HIWAY2 is another derivation of the Gaussian model as is PAL2.0 (Point, Area, and Line). HIWAY2 was too simplistic and as such is not commonly used. PAL2.0 was routinely applied in transportation projects such as parking lots or with the many considerations of different sources such as at airports. However, with the advent of AERMOD, with its area source algorithms, the use of PAL2.0 is greatly diminishing.

CALINE, HIWAY2, and PAL2.0 are used in free-flow conditions. At intersections, they lack the needed considerations for interrupted flows. At intersections, other models are currently used. Recent EPA testing has identified three models that perform well: TEXIN 2, CALINE 4, and CAL3QHC. Each uses the Gaussian dispersion algorithms but also accounts for queuing, delays, excess emission due to modes, and cruise. CAL3QHC, based on the Highway Capacity Manual,[47] is the EPA preferred model.

New models for highway air quality analysis are also on the horizon. This includes FLINT and HYROAD. These models, after validation, could replace the existing models now being used in the near future. Also, simulation techniques are being developed now that computer speeds are faster and puff models instead of plume models could be used in the future to better simulate the dynamic nature of highway vehicles.

For times greater than 1 hour (e.g., 8 hours) the error would be too great using dispersion models based on non-varying volumes and weather conditions. In these cases, persistence factors are used. Persistence factors are a number — less than one — that represents the ratio of the longer-term concentration to the short-term concentration based on changes in traffic and meteorology over the extended time period. Mathematically:

$$\text{Persistence factor} = \frac{Ct_2}{Ct_1}$$

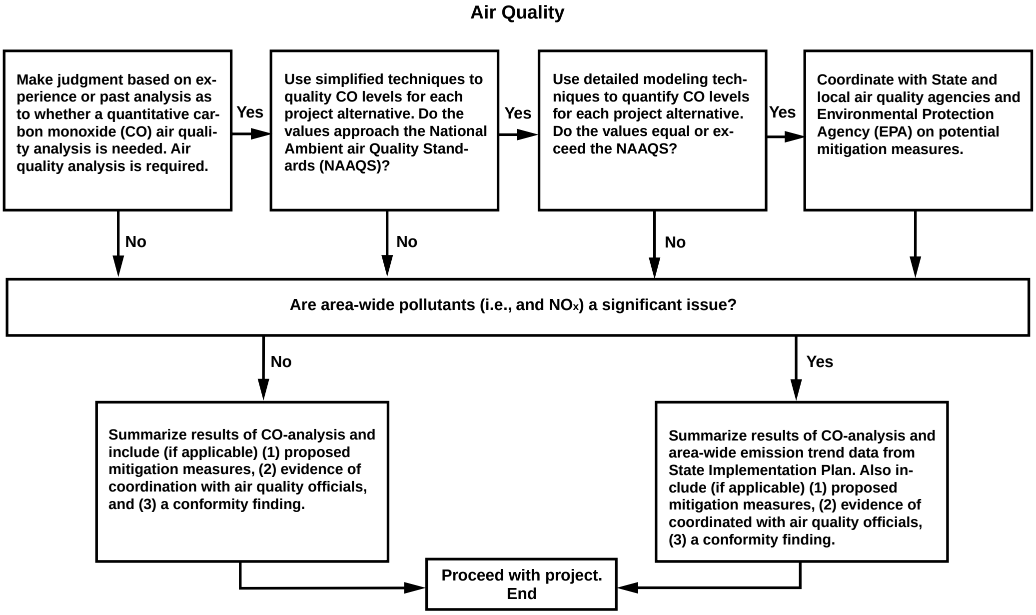

FIGURE 67.15 Generalized air quality evaluation flowchart. (*Source:* FHWA.)

where Ct_2 = long-term concentration and Ct_1 = short-term concentraiton. Typical persistence factors for carbon monoxide near intersections, when predicting the 8-hour concentration based on the 1-hour concentration, are in the range of 0.4 to 0.7.

Using these dispersion models, the first row of homes along a highway will be predicted to have greater concentrations than the second row of homes and so on. During modeling, care must be taken to model those receptors close to the roadway where normal human activity occurs and where the greatest concentrations of modeled pollutants (generally CO) will occur. If a violation of criteria or a standard occur at these receptors, sites farther away must be modeled to determine the extent of the problem. Figure 67.15 shows a typical flow chart of events for this project level, or microscale modeling. It should be noted that judgment for simple non-polluting projects may be used (usually called categorical exclusions) and simplified techniques (screening models) are often applied in the first analysis to reduce analysis time. If a screening model predicts an exceedance of the NAAQS, more extensive modeling using those previously discussed must be done.

Evaluation of air pollution from airports is similar to that of highways and is described in a series of documents.[48–51] As a first step, FAA Order 5050.4 uses an emission inventory to determine impacts.[48] If impacts are considered to occur, dispersion modeling is then required, again typically just for CO. Computer modeling is now quite common for airports. Originally, the Airport Vicinity Air Pollution Model was used[52] on mainframe computers. This model has been replaced by the PC-based Emission and Dispersion Modeling System (EDMS).[36]

No specific model has been issued for evaluating rail lines or yards. However, the Gaussian approach, coupled with AP-42 emission factors, would allow predictions to be made. Both rail systems and airports are compared with the NAAQS during NEPA evaluations and are considered during conformity determinations.

Of course, secondary pollutants such as ozone form in the atmosphere. These pollutants reach maximum concentrations at long distances from the source and Gaussian modeling is not applicable. For example, ozone forms from nitrogen dioxide in about 2 to 3 hours in an urban area. If the average wind speed is just 5 mph, the peak ozone concentrations due to the highway would be 10 to 15 miles away. As such, and because of the numerous contributions and reactions from other emissions, large-scale regional models are used for these predictions and are not project specific. A simple approach to regional

TABLE 67.5 Section 108(f) Transportation Control Measures

1.	Trip-reduction ordinances
2.	Vehicle use limitations/restrictions
3.	Employer-based transportation management
4.	Improved public transit
5.	Parking management
6.	Park and ride/fringe parking
7.	Flexible work schedules
8.	Traffic flow improvements
9.	Areawide rideshare incentives
10.	High-occupancy vehicles facilities
11.	Major activity centers
12.	Special events
13.	Bicycling and pedestrian programs
14.	Extended vehicle idling
15.	Extreme cold starts
16.	Voluntary removal of pre-1980 vehicles

Source: CAAA90.

modeling assumes that a defined volume (a "box") has complete mixing. Using this assumption, a simple mass balance can be used to predict concentrations in the box. The large regional model termed the Urban Airshed Model (UAM)[53] uses small, connected "boxes" to better define an entire area. Another area model now being used is the Community Modeling Air Quality Model.[54] This multiscale model (up to mesoscale considerations) allows simulation of chemical and physical interactions in the atmosphere as well.

Abatement

At the Source

The most effective abatement for air pollution occurs at the source. In the U.S., emissions standards and test procedures have changed significantly since the first automobile emission standards were imposed in California in 1966. Standards for mobile sources were discussed earlier in this chapter. Control of fuel storage is also very significant. Stage I vapor recovery is accomplished if fueling vapors are collected during delivery of fuel by tanker truck, while Stage II vapor recovery is defined to occur during the dispensing of fuel to the individual vehicles.

During Project Development

The CAAA90 required EPA to publish guidance on Transportation Control Measures (TCMs). Table 67.5 shows a listing of the defined TCMS for highway projects. While no such list exists for aircraft or rail operations, similar ideas can be applied. Problems at airports generally occur due to motor vehicle access. Problems for rail operations generally occur near the classification yards.

Water Quality as Related to Transportation

General Information

Transportation systems may affect water quality or can interfere with the desirable use of a waterway. For example, highway, airport, or railroad runoff adds pollutants to the surrounding bodies of water and may cause flooding. Bridges may affect navigable waters. Construction may cause erosion.

Runoff refers to the volume and discharge rate of water occurring as overland flow from a highway, airport, or rail line immediately after a precipitation event. Hydrologic variables that affect runoff are precipitation amount, evaporation, transpiration, infiltration, and storage.

Approximately 7% of the land in the U.S. is classified as floodplain. Floodplains are low areas adjacent to streams, oceans, and lakes which are subject to flooding at least once in 100 years.[55] In the U.S. in the early 1980s, about 90% of all losses from natural disasters were caused by floods. In addition to economic impacts, health and safety problems are evident. In the U.S., there are approximately 200 flood-related deaths per year. Transportation systems can exacerbate flooding conditions if the facility is not properly designed.

Construction, operation, and maintenance of transportation systems also contribute a variety of pollutants to runoff such as solids, nutrients, heavy metals, oil and grease, pesticides and bacteria. The extent to which the runoff affects the quality of the surrounding water requires adequate knowledge of quantity and quality of pollutants, their origin, and movement reactions within the system.

Water Quality Legislation and Regulations

Federal legislation for water-related activities in regard to transportation has been around since 1899 when the Rivers and Harbors Act was passed (Title 23 of the U.S. Code). This law, amended by the Department of Transportation Act of 1966, requires the U.S. Coast Guard to approve the plans for construction of any bridge over navigable waters. Accordingly, the required process, generally referred to as a Section 9 Permit from the applicable portion of the act, protects navigation activities from being affected by other transportation modes.

In 1972, Section 404 was added to the Federal Water Pollution Control Act. This required a permit (called a 404 permit) from the U.S. Army Corps of Engineers for any filling, dredging, or realignment of a waterway. For smaller projects that do not pass established threshold limits, a general permit may be issued.

The Federal Water Pollution Act was changed in 1977 and issued as the Clean Water Act. This act reflected the desire to protect water quality and regulated the discharge of storm water from transportation facilities. Also included in this law was the option for the Corps of Engineers to transfer 404 permitting to the states.

The 404 permitting process also includes required assessments of potential wetland impacts. The amount of wetlands affected, the productivity (especially as related to endangered or protected species), overall relationship to regional ecosystems, and potential enhancements during the design of the project must all be considered. Executive Order 11990, "Protection of Wetlands," issued in 1977, required a public-oriented process to mitigate losses or damage to wetlands as well as to preserve and enhance natural or beneficial values. This has led to a policy of wetlands being avoided and replacement required if destruction occurs. The Federal Highway Administration has released guidelines to help during this phase of the project.[56] In addition, FHWA has also released a memorandum entitled "Funding for Establishment of Wetland Mitigation Banks" on October 24, 1994, to help state DOTs meet requirements when wetlands must be taken and replaced.

Modeling of Water Impacts

The rational formula has been used since 1851 to calculate the peak discharge flow rate and can be derived using a mass balance for precipitation rate and runoff rate. The rational equation is:

$$Q_p = C\ i\ A$$

where Q_P = peak discharge
C = runoff coefficient
i = precipitation rate
A = watershed area

Typical units are used with conversion factors as required. Use of the equation must consider the following assumptions:

1. Rainfall intensity is constant over the time it takes to drain the watershed.
2. The runoff coefficient remains constant during the time of concentration.
3. The watershed area does not change.

These assumptions are reasonable for watersheds with short time of concentration (about 20 min) since the intensity is relatively constant for travel time below 20 min.

A detailed manual for flood analysis was developed by Davis[57] and is used by the U.S. Army Corps of Engineers. From basic hydrologic relationships between flow rates and frequency, and depth (stage) vs. flow rates, damages can be calculated as a function of flow rate.

Runoff water from transportation corridors, yards, parking lots, or airports has the potential to cause a pollution problem depending on the type and amount of pollutant present in runoff water and the ambient water quality characteristics of the receiving water it enters.[58] Suspended solids and associated pollutants in runoff discharges accumulate in localized areas close to the input sources, causing bioaccumulation of toxic materials in benthic organisms. Studies conducted in retention/detention ponds receiving highway runoff by Yousef et al.[59] indicate a decline in the number of benthic species present and the number of organisms in each specie. Also, species tolerant of pollutional loads dominated the bottom sediments in these ponds. Concentrations of dissolved pollutants may cause water quality criteria established for a particular receiving stream to be exceeded. The increased levels can produce visible impacts, fish kills, taste and odor problems, or alterations in the aquatic biological community.

Contaminants accumulate on roadway surfaces, median from moving vehicles, highway construction and maintenance, natural contributions, and atmospheric fallout. The magnitude and pattern of accumulation varies with many factors including dry periods between rainfall events, sweeping practices, scour by wind and/or rainfall, type of pavement and grade, traffic volume, and adjacent land use. For example, Gupta et al.[60] identified the variables affecting the quality of highway runoff as follows:

(a) Traffic (volume, speed, braking, type and age, etc.)
(b) Climate (precipitation, wind, temperature, dust fall)
(c) Maintenance (sweeping, mowing, repair, etc.)
(d) Land use (residential, commercial, industrial, rural)
(e) Percent impervious areas
(f) Regulations (air emissions, littering laws etc.)
(g) Vegetation
(h) Accidental spills

Particulate matter and other associated pollutants are generally attributed to atmospheric deposition, degradation, and traffic activities. Dustfall is a measure of the particulate matter in the range of 20 to 40 μm range, that falls out of the atmosphere due to gravity. The quantity and quality of particulates vary greatly with land use and geographic location. Smith et al.[61] reported dust fall loads in the U.S. to approximate 0.23 g/m^2-d in the northern region, 0.16 to 1.53 in the central region, 0.07 to 0.18 in the southern region, and 0.06 to 0.16 in the eastern region. He concluded that the dry areas of mid-U.S. are dustier than the wet areas to the east. During the period of 1975–1981, emissions of particles from automobiles were estimated to have decreased about 20%.[62]

Predictive models for accumulation of particulate matter and associated pollutants have been developed with emphasis on that fraction of pollutant load which is available for wash-off. A simplified equation of a predictive model for highways can be expressed as follows by Gupta et al.:[60]

$$P = P_0 + K_1 \; H_L \; T$$

where P = pollutant load after buildup
P_0 = initial surface pollutant load
K_1 = pollutant accumulation rate
H_L = highway length
T = time of accumulation

Wide variations were found to occur for K_1. Gupta reported K_1 could be estimated using:

$$K_1 = 0.007 \left(\mathrm{ADT}\right)^{0.89}$$

where ADT = average daily traffic.

Structured techniques have also been developed to evaluate wetlands. A methodology called WET[63] (Wetlands Evaluation Technique) has been promulgated by the FHWA and allows a comprehensive review of wetland impacts and mitigation.

Abatement of Water Related Impacts

Storage of highway runoff water on highway right-of-way can provide both flood control and contaminant discharge abatement by permitting settling. To reduce flooding potential, the volume of storage is determined to be consistent with downstream flow rates for a specified return period and the available on-site land area for ponding of the runoff.

Stringent controls and regulations have been placed on point source discharges such as sewage treatment plants and industrial wastewater outlets in most of the industrialized countries of the world. However, a corresponding improvement in the receiving water quality of surface waters has not always been noticeable. During the last 20 years, research into non-point sources has zeroed in on urban storm water runoff as a major pollution source and authors have reported that concentrations of certain constituents, such as heavy metals and nutrients, greatly exceed those found in secondary effluent discharges.[64–66] To mitigate these discharges, runoff from transportation systems can be transported in separate sewer systems, combined sewer systems, or held on site before allowing drainage directly into lakes, streams, rivers, and other surface water. Direct runoff discharge adversely impacts the water quality and prior treatment is required by many regulatory agencies.[67] On-site treatment can add significant costs to a transportation project but may be extremely necessary in cases such as aircraft fuels spillage.

Erosion and sedimentation often occur during the construction phase of a transportation project and may also occur during operation. Silt fences, minimizing clearing, increased vegetative cover, embankments, rounding of slopes, water flow control, and on-site ponding have been used to mitigate erosion. FHWA has issued a water quality action plan to protect the water resources.[68] This guidance, along with the legal requirements in 23CFRPart650 and an erosion/sediment control memorandum from FHWA,[69] helps to provide an effective policy to control erosion and sediment transport.

Energy Use

Fossil fuels are the primary source of energy for transportation. The automobile is the number one consumer. These fuels are becoming short in supply and are being used much faster than they are being formed.[70] The conservation of these fossil fuels is of extreme importance for many reasons (monetary, social, national defense, etc.). Unfortunately, transportation use of these fuels continues to increase and it is expected that there will be more than 1 billion vehicles in use by the year 2030.[71] Many conservation techniques are possible including vehicle technology improvements, ride sharing, traffic flow improvements, transportation systems management, and improved goods movement.[72] During project development, these techniques may be evaluated based on energy consumption. These estimates can be done directly by identifying vehicle movements and applying fuel consumption factors. However, many factors are difficult to determine and in many cases surrogates must be used such as "scaling" future values based on recorded fuel consumption or approximations using population or vehicle-miles-traveled (VMT). Each of these estimation procedures provides a method to determine which alternatives may result in a significant fuel savings.

It is also important to consider the fuel used during project construction. Fossil fuels are used in the materials (e.g., asphalt) for needed machinery (e.g., graders), and for transportation of supplies, equipment, and labor. The overall fuel savings of a project is related to the construction and operational fuel use.

During project development, estimates may be required of the total fuel use. This will require fuel use rates as a minimum. Many such documents are available.

Ecological Impacts

Transportation projects can have major impacts on ecological systems. During construction, physical removal of vegetation, compaction of soils, paving of surfaces, draining, and construction vehicle operation can all destroy needed habitats. During operations, mowing, application of herbicides, accidental spills, vehicle operations, and human activity can interrupt the normal ecosystem cycle. Accordingly, these impacts must be considered during transportation planning. Transportation agencies such as FHWA will participate in funding for ecological mitigation.[73]

The U.S. Fish and Wildlife Service has become quite involved during transportation planning since the Fish and Wildlife Coordination Act of 1958 (16USC 661-667(d)) required the U.S. Fish and Wildlife Service to be consulted when bodies of water are to be modified. In addition to this charge, the Fish and Wildlife Service is involved if coastal barrier resources are involved (P.L. 97-348), endangered species are present (50CFR Part 402, Endangered Species Act), during wetland evaluations discussed earlier, and/or if wild or scenic rivers are involved. The Endangered Species Act has caused many projects to be modified or stopped. Early coordination is required to avoid such problems.

In addition to these considerations, there are other ecological considerations that are required during the transportation planning process. Coastal zone management must be considered if the project is located near the coast line (15CFR part 930) and requires involvement of the National Oceanic and Atmospheric Administration. The Farmland Protection Policy Act (7CFR Part 658) requires justification of taking such land and involvement by the Department of Agriculture. If the project is in a floodplain, the Federal Emergency Management Agency may become involved. If the project will affect hazardous waste areas, the EPA must be brought in.

It becomes apparent that ecological impacts are very important considerations and they require involvement of many "players" during the transportation planning process. All of these impacts and the related analysis cannot be discussed here. The reader is encouraged to consult other references on these topics.

Sociological Concerns

NEPA required conservation of our resources. Our well-being and preservation of our heritage certainly qualifies. During transportation planning, Section 106 of the Historic Preservation Act (36CFR Part 800) requires that historic properties be identified and protected. This requires coordination with the State Historic Preservation Officer (SHPO), and sometimes with the Department of Interior and Advisory Council on Historic Preservation. Complete documentation is required by the SHPO to allow a determination of impact.

Socio-economic impacts must also be considered. Generally these impacts include disruption of community cohesion, preventing access to community facilities, general overall social or economic disruption, discrimination, and/or relocation. During planning these items must be assessed and measures taken to mitigate any such impacts. Again the reader should consult other references as needed.

Aesthetics

Many times the public judges the quality of a transportation project by the visual impact. It is important to evaluate aesthetics from both the point of view of the traveler and the transportation neighbor. The FHWA has released a document to help during the planning process entitled "FHWA Visual Assessment Methodology." Listed are common mitigation measures which include changes in horizontal and vertical alignment, landscaping, use of vegetation, litter pickup, and maintenance practices. To help with these considerations, another good guide has been issued by the American Association of State Highway Officials.[74] This document is also helpful in that it lists the many applicable laws related to project development.

67.3 Summation

This chapter was intended to present an overview to the environmental process and provide an adequate starting point for professionals. Emphasis was placed on noise and air quality evaluations. Information on basic principles, legislation/regulation, analysis, and abatement was presented for general impacts. A complete description would require much more discussion and, indeed, several volumes of text. Other laws and regulations not mentioned here may be required for a particular project. The practicing professional will find the environmental requirements for a transportation project to be both dynamic and evolving. As such, analysis methodologies for each project should be reviewed and coordination with local, state, and federal reviewers should occur to help ensure the methodology used meets all requirements.

References

1. Martin, F.N., 1991. *Introduction to Audiology*, 4th Ed., Prentice Hall, Inc., Englewood Cliffs, NJ.
2. Federal Highway Administration, 1980. *Fundamentals and Abatement of Highway Traffic Noise - Textbook and Training Course*, Washington, D.C.
3. Bronzaft, A.L., 1989. "Public Health Effects of Noise," Paper No. 89-101.3, Proceedings of the 82nd Annual Meeting of the Air & Waste Management Assn., Anaheim, California.
4. U.S. Environmental Protection Agency, 1974. *Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety*, EPA-550/9-74-004, U.S. Environmental Protection Agency, Washington, D.C.
5. Barry, T.M. and J.A. Reagan, 1978. *FHWA Highway Traffic Noise Prediction Model*, FHWA-RD-77-108, Federal Highway Administration, Washington, D.C.
6. Fleming, G.G., A. Rapoza, and C. Lee, 1995. *Development of National Reference Energy Mean Emission Levels for the FHWA Traffic Noise Model*, Report No. FHWA-PD-96-008 and DOT-VNTSC-96-2, John A. Volpe National Transportation Systems Center, Cambridge, MA.
7. Bowlby, W., R. Wayson, S. Chiguluri, M. Martin, and L. Herman, 1997. Interrupted Flow Reference Energy Mean Emission Levels for the FHWA Traffic Noise Model, Report No. FHWA-PD-97-019 and DOT-VNTSC-97-1, John A. Volpe National Transportation Systems Center, Cambridge, MA.
8. Bowlby, W., J. Higgins and J. Reagan, eds. 1983. *Noise Barrier Cost Reduction Procedure, STAMINA 2.0/OPTIMA User's Manual*, FHWA-DP-58-1, Federal Highway Administration, Washington, D.C.
9. Menge, C.W., C.F. Rossano, G.S. Anderson, and C.J. Bajdek, 1998. FHWA Traffic Noise Model, Version 1.0, Technical Manual, FHWA-PD-96-010 and DOT-VNTSC-FHWA-98-2, John A. Volpe National Transportation Systems Center, Cambridge, MA.
10. Moulton, H.T., 1990. *Air Force Procedure for Predicting Aircraft Noise around Airbases: Noise Exposure Model (NOISEMAP) User's Manual*, AAMRL-TR-90-011, Armstrong Laboratory, Wright-Patterson AFB, OH.
11. Gulding, J., et. al., 1999. Integrated Noise Model [INM], Version 6.0 User's Guide, FAA-AEE-99-03, Washington, D.C.
12. Hanson, C.E., 1976. "Environmental Noise Assessment of Railroad Electrification", Inter-Noise '76 Proceedings, Washington, D.C.
13. Wayson, R.L. and W. Bowlby, 1989. "Noise and Air Pollution of High Speed Rail Systems," Journal of Transportation Engineering, American Society of Civil Engineers, Vol. 115, No. 1, pgs. 20-36.
14. Federal Railroad Administration, 1998. *High-Speed Ground Transportation Noise and Vibration Impact Assessment, Final Draft*, Report No. 293630-1, Contract: DTFR53-94-A-00056, U.S.DOT, Washington, D.C.
15. Federal Transit Administration, 1995. *Transit Noise and Vibration Impact Assessment*, DOT-T-95-16, Office of Planning, Washington, D.C.
16. Harris, R.A. and L.F. Cohn, 1986. "Use of Vegetation for Abatement of Highway Traffic Noise," *Journal of Urban Planning and Development*, American Society of Civil Engineers, Vol. 111, No. 1, pgs. 34-38.
17. International Organization for Standardization, 1996. Acoustics - Attenuation of Sound During Propagation Outdoors - Part 2, ISO/DIS 9613-2, Geneva, Switzerland.
18. Federal Highway Administration, 2000. *Highway Traffic Noise Barrier Construction Trends*, U.S. Dept. of Transportation, Washington, D.C.

19. U.S. Environmental Protection Agency, 2001. .Latest Findings on National Air Quality: 2000 Status and Trends, http://www.epa.gov/oar/aqtrnd00/, Office of Air Quality Planning and Standards, Research Triangle Park, NC.
20. Chapter 23 of the Code of Federal Regulations Part 770 (23CFR770) *Air Quality Guidelines*. 1981. pp 8429–8431).
21. U.S. Environmental Protection Agency, 1992. *The 1992 Transportation and Air Quality Planning Guidelines*, EPA 420/R-92-001, Research Triangle Park, NC.
22. U.S. Environmental Protection Agency, 1992. *Guidelines for Modeling Carbon Monoxide from Roadway Intersections*, EPA Report No. EPA-454/R-92-005, USEPA Office of Air Quality Planning and Standards, Research Triangle Park, NC.
23. U.S. Environmental Protection Agency/U.S. Department of Transportation, 1991. USEPA and USDOT Guidance for Determining Conformity of Transportation Plans, Programs, and Projects with Clean Air Act Implementation Plans During Phase 1 of the Interim Period, Federal Highway Administration, Washington, D.C.
24. U.S. Department of Transportation, 1992. Further Guidance on Conformity Determinations, FHWA Memorandum, Office of Environment and Policy, July 27.
25. U.S. Department of Transportation, 1992. Clarification of FHWA July 27, 1992, Memorandum to Regional Administrators, Federal Highway Administration Office of Environment and Policy, Oct. 9.
26. U.S. Environmental Protection Agency, 1993. *Criteria and Procedures for Determining Conformity to State or Federal Implementation Plans, Program, and Projects Funded or Approved Under Title 23 U.S.C. or the Federal Transit Act*, Federal Register Vol. 58, No. 6, January, 11, 1993, pgs. 3768-3798.
27. U.S. Department of Transportation, 2000. *Designation of New 8-hour Ozone Nonattainment Areas*, FHWA Memorandum, March, 29, Washington, D.C.
28. U.S. Department of Transportation, 2000. *National MOU between DOT and EPA on Transportation Conformity*, FHWA Memorandum, April, 25, Washington, D.C.
29. Federal Highway Administration, 2001. *Transportation Conformity Reference Guide*, *http://www.fhwa.gov/environment/conform.htm,* July, 31.
30. U.S. Environmental Protection Agency, 2002. *Policy Guidance on the Use of MOBILE6 for SIP Development and Transportation Conformity*, Memorandum, January, 18, Washington, D.C.
31. Pasquill, F., 1974. *Atmospheric Diffusion*, John Wiley & Sons, New York, NY.
32. U.S. Environmental Protection Agency, 1998. *Revised Draft User's Guide for the AMS/EPA Regulatory Model - AERMOD*, Office of Air Quality Planning and Standards, Research Triangle Park, N.C.
33. *U.S. Environmental Protection Agency, 2000. Compilation of Air Pollutant Emission Factors, Volume 2: Mobile Sources, 5th Edition*, Final Draft, Ann Arbor, MI.
34. U.S. Environmental Protection Agency, 2002. *User's Guide to MOBILE 6.0 (Mobile Source Emission Factor Model)*, EPA420-R-02-001, Ann Arbor, MI.
35. International Civil Aviation Organization, 2000. *Annex 16 - Environmental Protection, Volume II - Aircraft Engine Emissions*, London, UK.
36. Federal Aviation Administration, 1997. *Emission and Dispersion Modeling System (EDMS) Reference Manual*, FAA-AEE-97-01, Washington, D.C.
37. California Department of Transportation, 1988. *Air Quality, Technical Analysis Notes*, California Department of Transportation, Office of Transportation Laboratory, Sacramento, CA.
38. Florida Department of Environmental Regulations, 1988. *Guidelines for Evaluating the Air Quality Impacts of Indirect Sources*; Final Draft, Florida Dept. of Environmental Regulation, Tallahassee, FL.
39 Florida Department of Transportation, 1999. *Project Development and Environmental Guidelines; Part 2: Analysis and Documentation*, Chapter 16, "Air Quality Analysis", Florida Dept. of Trans., Tallahassee, FL., August, 18.
40. New York State Department of Transportation, 1995. *Air Quality Interim Project Environmental Guidelines*,, Environmental Analysis Bureau, Albany, NY.

41. Benson, P., 1979. *CALINE - 3 - A Versatile Dispersion Model for Predicting Air Pollutant Levels Near Highways and Arterial Streets*, FHWA Report No. FHWA/CA/TL-79/23, Office of Transp. Lab., California Dept. of Trans., Sacramento, CA.
42. U.S. Environmental Protection Agency, 1980. *User's Guide to HIGHWAY-2: A Highway Air Pollution Model*, EPA 600/8-80-018, Research Triangle Park, NC.
43. Peterson, W.B. and E.D. Rumsey, 1987. *User's Guide for PAL 2.0 - A Gaussian-Plume Algorithm for Point, Area, and Line Sources*, EPA 600/4-78-013, U.S. Environ. Protection Agency, Research Triangle Park, NC.
44. Bullin, J.A., J.J. Korpics and M.W. Hlavinka, 1986. *User's Guide to the TEXIN-2 Model: A Model for Predicting Carbon Monoxide Concentrations Near Intersections*, FHWA Report No. FHWA/TX-86/283-2, College Station, TX.
45. Benson, P., 1984. *CALINE - 4 - A Dispersion Model for Predicting Air Pollutant Levels Near Roadways*, FHWA Report No. FHWA/CA/TL-84/15, Office of Transp. Lab., California Dept. of Trans., Sacramento, CA.
46. Schattanek, G. and T. Stranton, 1990. *CAL3QHC, A Modeling Methodology for Predicting Pollutant Concentrations Near Roadway Intersections*, User Guide, Parsons, Brinckerhoff Quade & Douglas, Inc., New York, NY.
47. Transportation Research Board, 1985. *The Highway Capacity Manual, Special Report 209*, Trans. Research Board, Washington, D.C.
48. Federal Aviation Administration, 1986. *Policies and Procedures for Considering Environmental Impacts*, FAA Order 1050.1D, Washington, D.C.
49. Federal Aviation Administration, 1997. *Air Quality Procedures for Civilian Airports and Air Force Bases*, FAA Report No. FAA-AEE-97-03, Washington, D.C.
50. U.S. Environmental Protection Agency, 1973. *An Air Pollution Impact Methodology for Airports; Phase I*, EPA Report No. APTD-1470, NTIS, Springfield, VA.
51. Wayson, R.L. and W. Bowlby, 1988. "Inventorying Airport Air Pollutant Emissions," *ASCE Journal of Transportation Engineering*, Vol. 114, No. 1, January, 1988, American Society of Civil Engineers, New York, NY.
52 Federal Aviation Administration, 1975. *Airport Vicinity Air Pollution Model User's Guide*, Report FAA-RD-75-230, Washington, D.C.
53. U.S. Environmental Protection Agency, 1995, *Users Guide for the Urban Airshed Model, Volume I–VIII*, EPA-450/4-90-007a-g, Research Triangle Park, NC.
54. U.S. Environmental Protection Agency, 2002. CMAQ (Community Modeling Air Quality), *http://www.epa.gov/asmdnerl/models3/*, last visited May, 4.
55. Water Resources Council, Hydrology Committee. 1981. "Guidelines for Determining Flood Frequencies", *Bulletin 17B*, U.S. Water Resources Council, Washington, D.C.
56. Federal Highway Administration, 1986. *Highways and Wetlands: Compensating Wetland Losses*, Report No. FHWA-IP-86-22, Washington, D.C.
57. Davis, S., 1988. *National Economic Development Procedures Manual: Urban Flood Damage*, U.S. Army Corps of Engineers, IWR Report 88-R-2, Fort Belvoir, VA.
58. Driscoll, E.D., P.E. Shelly and E.W. Strecker, 1988. *Evaluation of Pollutant Impacts from Highway Stormwater Runoff: Analysis Procedure*, FHWA/RD-08/006, Federal Highway Administration, McLean, VA.
59. Yousef, Y.A., L'Yu Lin, J.V. Sloat and K. Kaye, 1991. *Maintenance Guidelines for Accumulated Sediments in Retention/Detention Ponds Receiving Highway Runoff*, FL-ER-47-91, Florida Dept. of Transportation, Tallahassee, FL.
60. Gupta, M.K., R.W. Agnew, D. Gruber and W.A. Kreutzberger, 1981. *Constituents of Highway Runoff: Volume IV — Characteristics of Runoff from Operating Highways — Research Report*, FHWA/RD-81/045, Federal Highway Administration, Office of Research and Development, Washington, D.C.

61. Smith, R.M., P.C. Twiss, R.K. Krauss and M.J. Brown, 1970. “Dust Deposition in Relation to Site, Season and Climatic Variables,” *Proceedings of Soil Sciences Soc. Am.*, 34:112-117.
62. Cooper, C.D. and F.C. Alley, 1994. *Air Pollution Control: A Design Approach*, 2nd Edition, Waveland Press, Inc., Prospect Heights, IL.
63. Adamus, P.R., E.J. Clairain, R.D. Smith and R.E. Young, 1987. *Wetland Evaluation Techniques (WET)*, Report No. FHWA-IP-88-029, Federal Highway Administration, McLean, VA.
64. Rimer, A.E.; Nissen, J.A.; and Reynolds, D.E., 1978. “Characterization and Impact of Stormwater Runoff from Various Land Cover types.” *Journal of the Water Pollution Control Federation*. 50:252.
65. Helsel, D.R., J. Kim, T.J. Grizzard, C. Randall, and R.C. Hoehn, 1979. “Land Use Influences on Metals Storm Drainage.” *Journal of the Water Pollution Control Federation.* 51:709.
66. Sartor, J.D., G.B. Boyd and F.J. Agardy, 1974. “Water Pollution Aspects of Street Surface Contaminants.” *Journal of the Water Pollution Control Federation.* 46:458-167.
67. Wanielista, M.P., Y.A. Yousef and J.E. Christopher, 1980. *Management of Runoff from Highway Bridges*, Florida Dept. of Transportation, Contract No. 99700-7198, Tallahassee, FL.
68. U.S. Department of Transportation, 1996. *Guidance on Developing Water Quality Action Plans*, FHWA Memorandum, May 28. Washington, D.C.
69. U.S. Department of Transportation, 1994. *Erosion and Sediment Control, Final Rule*, FHWA Memorandum, September, 2, Washington, D.C.
70. Davis, G.R., 1990. “Energy for the Planet Earth,” *Scientific American*, Vol. 263, No. 3, 1990, pgs. 55-62.
71. Bleviss, D.L. and P. Walzer, 1990. “Energy for Motor Vehicles,” Scientific American, Vol. 263, No. 3, pgs. 103-109.
72. Institute of Transportation Engineers, 1992. *Transportation Planning Handbook*, Prentice Hall, Inc., Englewood Cliffs, NJ.
73. U.S. Department of Transportation, 1995. *Participation in Funding for Ecological Mitigation,* FHWA Memorandum, July, 25, Washington, D.C.
74. American Association of State Highway Officials, 1991. *A Guide for Transportation Landscape and Environmental Design*, Washington, D.C.

Further Information

References have purposely been used quite heavily in this chapter and the interested reader should obtain these references as needed. In addition, extensive literature in the form of preprints, proceedings, and journal articles is available through the U.S. DOT Administrations, the U.S. EPA, the Air and Waste Management Association, the American Society of Civil Engineers, the Society of Automotive Engineers, and the Transportation Research Board. Discussion of most topics of interest can be obtained from these sources. In addition, the FHWA has recently released a computer disk called the Environmental Guidebook. Many of the documents mentioned in this text and more are included on the disk.