EVALUATION OF AIR AND NOISE POLLUTION IMPACTS DURING THE HIGHWAY SYSTEM PLANNING STAGE

George A. Bonina, Pennsylvania Department of Transportation

The Pennsylvania Department of Transportation, in response to an increasing interest in the protection of the quality of the human environment, has undertaken the evaluation of environmental impacts during the highway system planning stage. This paper considers air and noise pollutants. The relationship between system planning and project planning is discussed, a framework for analysis is presented, and types of studies conducted by the system planning staff are defined. A macroscale study estimates the impact of an entire highway system on air quality and traffic noise levels in an urban area. A mesoscale study estimates the impact of an individual project on air quality in an urban area. Data needed to effectively evaluate air and noise pollution impacts at the system planning stage are discussed. Types of air quality models and their limitations and application to macroscale and mesoscale studies are considered. A highway noise model and its adaptation to system planning requirements and strategies for abatement of air and noise impacts are discussed.

•THE purpose of this paper is to describe the technical procedures that the Pennsylvania Department of Transportation is following during the system planning stage to analyze the impacts of transportation systems and individual projects on air quality and noise pollution. Figure 1 shows the relationship among the various analyses and reports that are required for urban transportation study areas. The first report is the environmental overview statement (EOS), whose purpose is to define the current environment of an urban area or region. The EOS is used as a data base for future studies; input to it consists of economic, sociological, and cultural factors; growth patterns; air and water quality; noise; environmental hazards; and environmental resources.

Alternate transportation systems within an urban area are developed through analysis at the system planning stage. Input to this analysis includes the proposed transportation plan itself, community goals and objectives, policy decisions, and the data base from the EOS. The output is the level of economic, social, and environmental impacts of the proposed plan and secondary impacts such as increased population growth caused by increased accessibility. These impacts for various alternate plans are reported in an economic, social, and environmental (ESE) evaluation statement.

The project planning stage tests alternative transportation corridors and alignments. Output from this analysis are the economic, social, environmental, and secondary impacts of each alternate. The impacts are included in the project environmental impact statement (EIS), which identifies potential problems and benefits of each alternate. The ESE evaluation statement is used as input to the project EIS.

An important aspect of the analysis procedure is the relationship between the system and project planning stage. Figure 1 shows that a proposed project can be evaluated at the system planning level as well as at the project planning level. The system planning evaluation will permit the testing of alternatives to the project, such as improving public transit service, car pooling, or not building the project at all. This paper deals with an air and noise pollution analysis at the system planning stage. The procedures are intended to be used in conjunction with urban transportation planning techniques.

FRAMEWORK FOR ANALYSIS

There are three general guidelines for evaluating air and noise pollution impacts of transportation systems. First, the analysis should be receptor oriented. Although overall indications of the change of air or noise pollution in the region are important to obtain, the final determination of the acceptability of the system should be based on the impact of the system on individual receptors in the region. For example, air quality in the region may be generally improved at the expense of seriously degrading the air quality at one or more specific receptors. Such conditions must be clearly identified during the system planning stage. At the start of a study, a set of sensitive receptors should be identified in the region. These receptors can include schools, churches, hospitals, residential developments, and outdoor recreation areas. They may also be natural receptors such as breeding and nesting grounds and shorelines. Existing as well as proposed future land use should be considered. The set of receptors can serve as a benchmark for comparing alternative transportation plans.

Second, air pollution concentrations and noise levels from a proposed highway system should be compared with base year conditions and target year do-nothing conditions as well as with absolute standards [for noise (18); for air (22)]. Comparison with absolute standards will ensure that legal requirements are met. Comparison with base year existing conditions and target year do-nothing conditions will provide an estimate of the impact on receptors. Base year air pollution and noise levels can be measured or estimated by mathematical models. Target year air pollution and noise levels must be estimated by mathematical models.

Third, whenever changes are made to the transportation network, all economic, social, and environmental factors should be reevaluated. There is a law of ecology that states that everything is interconnected. This means that a small modification to one environmental system might result in significant changes in other environmental, social, or economic systems. For example, construction of a bypass to reduce central city pollution and congestion can induce more suburban growth and contribute further to center city decay and suburban sprawl that is costly in land and resource consumption. It might increase trip lengths and automobile dependency and might encroach on ecologically valuable space. System planning should be able to identify the secondary as well as primary impacts of the transportation system.

SCOPE OF ANALYSIS OF AIR AND NOISE POLLUTION IMPACTS

The system planning staff of the Pennsylvania Department of Transportation evaluates areawide air and noise pollution impacts of transportation systems during the system planning stage and air pollution impacts of individual projects during the project planning stage. The transportation system is composed of existing and proposed transportation facilities. A project is an individual highway facility or portion of a highway facility.

The type of study conducted during the system planning stage is known as a macroscale study. The purpose of a macroscale study is to evaluate the impact of an entire transportation system on a region. Input to the macroscale study consists of the data base from the EOS for the region, the transportation system plan, the community goals and objectives, and the policy decisions, as mentioned previously. The macroscale study does not emphasize the impacts of individual projects but considers the impact of the system as a whole. The macroscale study is used to test alternative highway and transit plans. Output from the macroscale study is used as input to the ESE evaluation statement.

During the project planning stage, a mesoscale air pollution analysis is performed, whose purpose is to determine the impact of the project on the region. Input to the mesoscale study is similar to that of macroscale. The project is analyzed in the context of the adopted transportation plan. Alternative corridors (including the alternative of not building the project at all) and policy decisions are tested, and their impact on air quality in the region is determined. Output from the mesoscale study along with the

ESE evaluation statement is used as input to the project EIS.

A third type of air and noise study used in the EIS is called a microscale study. The microscale study is performed after design alternatives are chosen. Its purpose is to determine the impact of the project within the project's immediate corridor.

AIR POLLUTION IMPACT ANALYSIS

Data Requirements and Availability

Five types of data are required to perform a macroscale and mesoscale air quality analysis: traffic data, land use, emission factors, meteorological data, and ambient air quality. Detailed highway design data are necessary only for the microscale study. Whenever any data item is unavailable it is best to assume the condition that will produce the highest air pollution emissions and concentrations.

Traffic Data

Traffic volume, average speed, and percentage of trucks are needed for each link of the highway network under analysis for each hour of the day. These values can be obtained by applying appropriate hourly factors to average daily values normally output from the traffic assignment process. The hourly factors are stratified by link class (e.g., freeway or arterial) and area type (e.g., CBD or rural). Capacity restraint techniques are used whenever possible in the traffic assignments because of the sensitivity of emissions to speed. The amount of traffic in the urban area that occurs on streets not on the network is also estimated.

Land Use Data

Land use data are required so that sensitive receptors can be chosen. Existing land use is determined from surveys normally performed for an urban transportation study; future land use is used to determine future sensitive receptors.

Emission Factors

Emission factors are computed for carbon monoxide, hydrocarbons, and oxides of nitrogen. Emission factors are expressed in units of grams per vehicle miles (kilometers) of travel and are a function of average speed, percentage of trucks, model year age distribution of vehicles, and expected performance of emission control devices. Average speed and percentage of trucks are obtained from the transportation network. Age distribution is obtained from vehicle registration data and is assumed to be constant in future years. Methods for computing emission factors are available in another report (10).

Meteorological Data

Meteorological data are used to characterize the transport and diffusion of pollutants. Meteorological parameters can be estimated for each urban area from records available from the National Climatic Center in Asheville, North Carolina. Most urban areas within Pennsylvania have some source of meteorological data (e.g., airport, U.S. Weather Service), for which the National Climatic Center keeps records.

The following raw data items are required to develop the basic meteorological parameters: wind direction, wind speed, surface temperature, cloud temperature, and morning vertical temperature profile. The first four items are usually recorded as hourly observations; the morning vertical temperature profile is used to estimate mixing depth. At least 5 years of observations are used. Summaries of wind direction, wind speed, stability class, and mixing depth are used to develop worst and most frequent meteorological conditions for the urban area under study.

Ambient Air Quality

Ambient air quality data are used for two main purposes:

1. To characterize existing air quality for use as a base for estimating future air quality, and
2. To calibrate mathematical air pollution diffusion models.

Ambient pollutant levels are the most difficult data to obtain. Within the larger urban areas of Pennsylvania (Philadelphia and Pittsburgh), some historical air quality data are available, and limited continuous sampling programs are underway. The available data in these areas must be supplemented with other sampling in most cases. Within other urban areas of Pennsylvania almost no ambient air quality data are available. The Pennsylvania Department of Environmental Resources is in the process of developing an extensive network of air-monitoring stations; however, several years are expected to elapse before the network is fully operational.

Air Quality Models

There are three types of models available for estimating air quality: emissions model, proportional or rollback model, and diffusion model. The model used in a particular urban area depends on availability of input data.

Emissions Model

Calculation of emissions of carbon monoxide, hydrocarbons, and oxides of nitrogen is required initially for all types of air quality studies. The summaries and graphs developed through use of the emission model can be used to indicate links in the highway network having high emissions. Output of emissions from individual links can be used as input to a diffusion model. It is important to note that emissions are expressed in units of mass of pollutants emitted (grams or kilograms) and are not directly comparable with air quality standards that are expressed as concentrations in units of mass per unit volume (grams per cubic meter) or parts per million.

The Pennsylvania DOT has developed a computer program to compute carbon monoxide, hydrocarbon, and nitrogen oxide emissions for each link of a highway network. This program is similar to the SAPOLLUT program developed by the Federal Highway Administration. Input to the program consists of the following:

1. Highway network,
2. Factors stratified by link class and area type to convert average daily traffic to hourly traffic volume for each hour of the day,
3. Factors stratified by link class and area type to convert average daily speed to average hourly speed for each hour of the day,
4. Percentage of trucks stratified by link class and area type for each hour of the day, and
5. Year for which pollutant emissions are to be calculated.

Emissions for a link are computed by multiplying the emission factor by the traffic volume and by the link length. Emissions for automobiles and trucks are computed separately and added together to obtain total link emissions. Output of the computer program consists of the following:

1. Magnetic tape containing total emissions of carbon monoxide, hydrocarbons, and oxides of nitrogen for each hour of the day for each link. This tape includes the X-Y coordinates of the endpoints of each link and can be used as input to an areawide diffusion model or used to make additional summaries not given below.
2. Listing of the emissions of each pollutant for each link for selected hour periods of the day. The worst hour of the day for emissions of each pollutant is indicated for each link. This listing can be used to determine links with high emissions.
3. Summary of emissions of each pollutant for selected hour periods cross-classified by link class and area type.
4. Listing of total emissions of each pollutant summarized by traffic analysis zone.
5. Total daily emissions of each pollutant for the entire network.

Figure 2 shows a typical graph that can be constructed from emissions output and that can be used to compare alternative networks. The two curves on the graph represent the range of emissions. The upper curve represents the maximum emissions and assumes that full growth will occur with no changes in the transportation network. The lower curve represents minimum emissions and assumes that no growth and no change will occur in the transportation network. The decrease of emissions from the base year for both curves is due to emission control devices on motor vehicles. The points on the graph represent emissions from alternative network configurations.

Rollback Model

A rollback or proportional model assumes that there is a direct linear relationship between pollutant emission and concentration. For example, if emissions of carbon monoxide are halved, the reference carbon monoxide concentration at a sampling site is also assumed to be halved. The rollback model is applicable only if ambient pollutant levels are available for use as reference concentrations. Concentrations from nonhighway sources of emissions must be added to those from highway sources. The major disadvantage of the rollback model is that the resultant concentration is assumed to be constant over a large area; it does not vary from receptor to receptor. The major advantages of the rollback model are that it is simple to apply (if ambient data are already available) and that it makes use of measured pollutant concentrations rather than simulated values. Computation of emissions is necessary before the rollback model can be applied.

The rollback model has three main uses. First it can be used to determine if ambient air quality standards will be exceeded in the future by a particular highway network. It is important to note that, eventhough the ambient concentration is not exceeded on an areawide basis, the concentration at individual receptors may be higher because of contributions from highways within their own corridors. The results of the rollback model, therefore, should be considered as a general guide in evaluating a highway network. Second, it can compare alternate highway network configurations. Since a direct relationship between concentration and emissions is assumed, the same results could be obtained by comparing emissions alone. Third, it can project base year ambient conditions to a future year and add them to the results of a line-source model for a particular highway. If used in this manner an additional assumption is that the ambient concentration is caused by emissions from all highways in the area except the highway under study. Within the highway, corridor concentrations estimated by a line-source model are added to the ambient concentrations predicted by the rollback model.

Diffusion Models

Diffusion models represent a higher level of sophistication in air quality modeling. A diffusion model is used to estimate the concentration of a pollutant at a receptor caused

Figure 1. Economic, social, and environmental impact analysis.

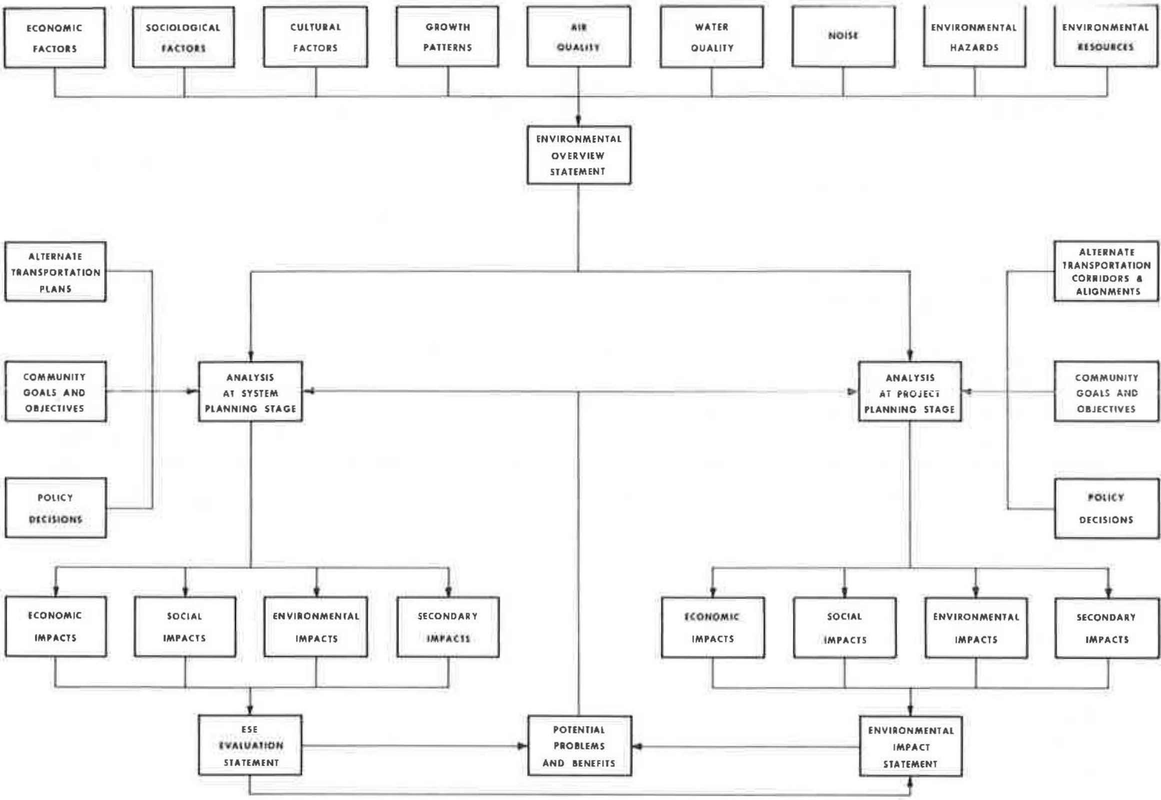
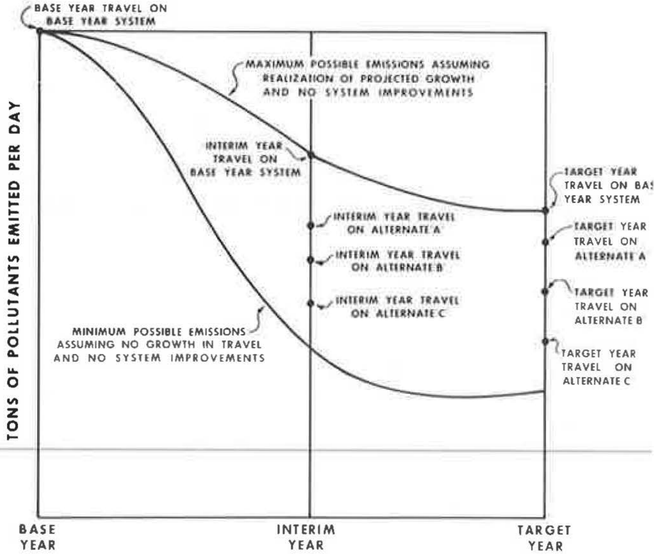


Figure 2. Comparison of alternative transportation systems based on annual variation of daily pollutant emissions.



by one or more sources. Input to a diffusion model generally consists of source emission rates, meteorological data, and the spatial relationship between sources and receptors.

The diffusion model adopted by Pennsylvania DOT for use in system planning is the APRAC-1A urban diffusion model developed by the Stanford Research Institute. This model can be used to estimate carbon monoxide concentrations only. The computer program for this model has been modified to directly accept output from the emissions model computer program. APRAC computes the concentration on carbon monoxide caused by emissions from the highway network at selected receptors in the urban area for selected hours of the day. Input to the APRAC model consists of the following:

1. Emissions model output, which includes the carbon monoxide emissions for each hour of the day for each link of the highway network and X-Y coordinates of the endpoints of each link;
2. Background carbon monoxide emissions, which account for emissions from traffic on streets not on the highway network and are usually assumed to be negligible;
3. X-Y coordinates of sensitive receptors in the urban area;
4. Average wind direction, wind speed, surface temperature, and cloud cover for each hour of the day; and
5. Morning vertical temperature profile.

Output consists of the carbon monoxide concentration at each receptor for selected hours of the day.

APRAC, as originally developed, is intended to be used in conjunction with the street canyon submodel to estimate carbon monoxide concentrations on downtown streets. Except for Philadelphia and Pittsburgh, no urban areas in Pennsylvania have street canyons as defined in the model. Pennsylvania DOT has been using APRAC without the street canyon submodel to estimate background concentrations in small urban areas. The background concentrations represent rooftop level, not street level, and are considerably lower than would be expected. Therefore, the department has been using APRAC as a guide to locate receptors having high concentrations. APRAC output is not compared with national ambient air quality standards.

Air Pollution Abatement Strategies

During system planning, there are numerous strategies and policies that can be tested. One important air pollution abatement measure is to increase transit ridership (19) by use of direct incentives, actions designed to increase high vehicle occupancy. These include

1. Use of public information program,
2. Improvement of transit system maintenance,
3. Improvement of transit customer service,
4. Encouragement of CBD businesses to provide voluntary rebate on transit fares for customers and employees,
5. Encouragement of CBD employers to stagger work hours,
6. Use of exclusive lanes for buses and high-occupancy vehicles,
7. Restructuring of bridge tolls to decrease cost for high-occupancy vehicles, and
8. Encouragement of car pools.

Automobile disincentives, measures that tend to discourage automobile use, can also be implemented to increase transit ridership. These include

1. On-street parking limits and cost increases for parking in private and commercial parking facilities, and
2. More effective enforcement of traffic and parking regulations.

Direct restraints, measures that prohibit or reduce vehicle use, can be implemented as well to increase transit ridership. These include

1. Prohibition of certain groups of vehicles from the CBD on given days,
2. Gasoline rationing,
3. Prohibition of vehicles from selected areas of the city, and
4. Monitoring of ramps to restrict vehicles entering freeways.

During location and design stages, the following measures can be taken to decrease air pollution concentrations due to a highway:

1. Design the facility to operate at a high level of service and thereby increase speeds and decrease emissions of carbon monoxide and hydrocarbons,
2. Purchase extra right-of-way where high concentrations are expected close to the highway,
3. Design the facility as an elevated section near sensitive receptors, and
4. Shift the highway location away from sensitive receptors.

Other methods of minimizing adverse effects of air pollution include

1. Requiring pre-1968 vehicles to be equipped with emission control devices,
2. Reevaluating land use plans to discourage sensitive receptors from locating near high-volume facilities,
3. Reducing or at least not increasing the density [highway miles (kilometers) per square mile (square kilometer) of land area] of the transportation network, and
4. Zoning.

The cost and technical and political feasibility to implement all recommendations should be computed and, if found to be reasonable, the system should be modified and tested. If the cost is not reasonable, new transportation plans and policies should be developed and tested to determine the impact on economic, social, and environmental systems.

NOISE POLLUTION IMPACT ANALYSIS

Data Requirements and Availability

The major items required for an impact analysis of noise pollution are traffic data, land use data, and ambient noise levels. The first two items are the same as those required for an air pollution impact analysis previously discussed. Ambient noise levels are used to estimate the impact of the highway system on a receptor. Table 1 gives some typical continuous background noise levels (dBA).

Highway Noise Model

The highway noise model adopted for use by Pennsylvania DOT is described elsewhere (14). The computer program has been modified to accept output from the traffic assignment process. Input to the noise model consists of the following for each receptor:

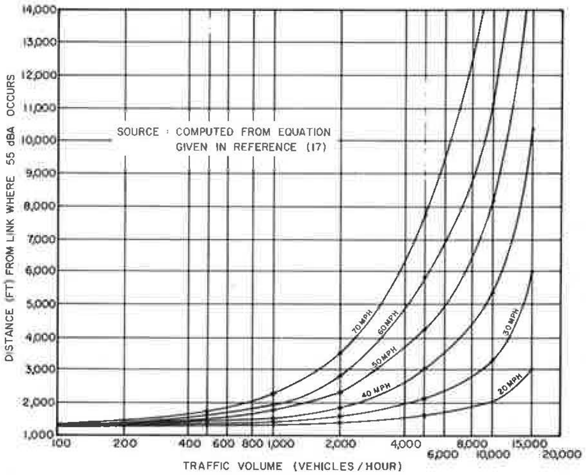
1. X-Y coordinates,
2. Ambient L_{10} and L_{50} noise levels,
3. Land use category, and
4. Building noise reduction (if interior noise standard applies).

Table 1. Typical continuous background noise levels.

Land Use	L_{10}	L_{50}
High-density residential	75	51
Medium-low-density residential	53	49
Industrial	60	55
Commercial	58	52
Central business district	73	67
Park and open space	51	46

Note: These data are based on readings taken during off-peak hours in York, Pennsylvania, where population in 1970 was 130,055.

Figure 3. Distances from highway link where 55 dBA occurs.



SOURCE : COMPUTED FROM EQUATION GIVEN IN REFERENCE (17)

Output from the air pollutant emission program includes the following:

1. X-Y coordinates of the endpoints of each link,
2. Automobile and truck volumes for the hour period of interest,
3. Automobile and truck speeds,
4. Number of lanes,
5. Elevated or depressed height of link,
6. Percentage of grade,
7. Type of traffic (free or interrupted), and
8. Type of roadway surface (smooth, normal, or rough).

Outputs of the program are the L_{10} and L_{50} noise levels caused by the highway network. A program option permits comparison of the outputs with Federal Highway Administration standards (18) and with estimates of the impact of a proposed highway and the expected community response based on criteria in the NCHRP report (14).

To use the program, the analyst must determine which links contribute to the noise level at each receptor. All links that may contribute 55 dBA or more are included. Figure 3 shows the distance from the link where 55 dBA will occur as a function of traffic volume and speed. The program uses X-Y coordinates to determine the spatial relationship between the receptor and links, element type, and angle necessary for the model. In addition, it is possible to input noise barriers and other structures that reduce noise.

Another version of the model, incorporated in the air pollutant emission program, is used to estimate the noise level at specific distances [e.g., 100, 200, and 500 ft (30, 61, and 152 m)] from each link of the highway network. This information is listed by hour period, and hours of highest noise are indicated. This can be used to identify links having the potential to exceed standards. This version of the model assumes that every link is an at-grade infinitely long section with grades less than 2 percent, free-flow traffic conditions, normal roadway surface, and no barriers. The output noise level is caused by the single link, not a combination of several links.

Macroscale Noise Pollution Analysis

A macroscale noise pollution analysis is conducted to determine the impact of the entire highway network on noise levels in the region. The first step in the analysis is to identify noise-sensitive receptors in the urban area. These include hospitals, schools, churches, residential developments, and outdoor recreation areas as specified in PPM-90-2 (18). Identifying every receptor in the study area is not necessary, but including only those receptors near facilities that have the potential to exceed standards or those near proposed facilities and existing facilities that will experience significant changes in traffic volume is necessary. Figure 3 can be used to determine whether the links cause significant noise at a receptor. Links with the potential to exceed standards and the hours of the day when highway noise is highest can be identified by using the computer program previously described. Links experiencing significant changes in traffic volumes can be identified from traffic assignment output.

To estimate the level of impact requires that an estimate of the ambient noise levels be available at each receptor. Ambient levels can be obtained from generalized values as a function of land use, or field measurements can be taken. Pennsylvania DOT is currently using generalized values as a function of land use for systems level evaluation. The computer program is used to estimate the noise level at each receptor caused by contributing links. If land use is input, the program will compare the highway noise level with the absolute standards (22) and will estimate the level of impact and expected community response to the highway. The results of the analysis are summarized, and potential problems and benefits are identified. This information is used as feedback to develop new alternative transportation plans. The results of the macroscale noise study are used as an input to the ESE evaluation statement for the adopted transportation plan.

Noise Abatement Strategies

Measures to reduce highway noise levels can be taken during system planning and during location and design. During system planning an attempt can be made to change travel patterns and demand for highway travel so that the need for highway links or the traffic volume on links with high noise output can be reduced by, for example, providing the alternative of public transit. The network configuration can be modified to reduce total traffic or truck traffic near sensitive receptors.

The land use plan can be modified so that less noise-sensitive land uses are located near links with high noise output.

During location and design the following steps can be taken to reduce highway noise:

1. Use noise barriers near sensitive receptors,
2. Shift highway alignment,
3. Elevate or depress the highway near sensitive receptors, and
4. Purchase additional right-of-way so that high noise levels are confined within the right-of-way.

All noise abatement measures should be analyzed to determine their effect on other economic, social, and environmental factors.

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