APTD-0937

A GUIDE FOR REDUCING AIR POLLUTION THROUGH URBAN PLANNING

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Water Programs
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

APTD-0937

A GUIDE FOR REDUCING AIR POLLUTION THROUGH URBAN PLANNING

by

Alan M. Voorhees & Associates, Inc.
Westgate Research Park
McLean, Virginia 22101

and

Ryckman, Edgerley, Tomlinson & Associates
12161 Lackland Road
St. Louis, Missouri 63141

Contract No. CPA 70-100

EPA Project Officer: John L. Robson

Prepared for

ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Water Programs
Office of Air Quality Planning and Standards
Research Triangle Park, N. C. 27711

October 1973

The APTD (Air Pollution Technical Data) series of reports is issued by the Office of Air Quality Planning and Standards, Office of Air and Water Programs, Environmental Protection Agency, to report technical data of interest to a limited number of readers. Copies of APTD reports are available free of charge to Federal employees, current contractors and grantees, and non-profit organizations - as supplies permit - from the Air Pollution Technical Information Center, Environmental Protection Agency, Research Triangle Park, North Carolina 27711, or may be obtained, for a nominal cost, from the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22151.

This report was furnished to the Environmental Protection Agency by Alan M. Voorhees and Associates, Inc., McLean, Virginia, and Ryckman, Edgerley, Tomlinson and Associates, St. Louis, Missouri, in fulfillment of Contract No. CPA 70-100. The contents of this report are reproduced herein as received from Alan M. Voorhees and Associates and Ryckman, Edgerley, Tomlinson and Associates. The opinions, findings, and conclusions expressed are those of the author and not necessarily those of the Environmental Protection Agency. Mention of company or product names is not to be considered as an endorsement by the Environmental Protection Agency.

Publication No. APTD-0937

ACKNOWLEDGEMENTS

This report was prepared pursuant to contract No. CPA 70-100 by Alan M. Voorhees & Associates, Inc., and Ryckman, Edgerley, Tomlinson & Associates, Inc., under the guidance of the staff of the Office of Air Programs, Environmental Protection Agency. The text contained herein is substantially that of the contractors.

The project team at Alan M. Voorhees & Associates, Inc. (AMV) and Ryckman, Edgerley, Tomlinson & Associates, Inc. (RETA) consisted of:

AMV

Mr. Alan M. Voorhees
Project Director

Dr. Salvatore J. Bellomo
Project Manager & Coordinator

Mr. Robert L. Morris
Vice President

Mr. Stephen C. Nelson
Urban Planner

Mr. Joseph Brevard
Urban Planner

Mr. Edward Mierzejewski
Transportation Engineer

Miss Sally D. Liff
Transportation Planner

RETA

Dr. Edward Edgerley, Jr.
Project Manager

Dr. Frederick Brunner
Environmental Engineer

Mr. Kenneth W. Axtell, Jr.
Environmental Engineer

CONTENTS

CONTENTS (Continued)

CONTENTS (Continued)

FIGURES

TABLES

PREFACE

Urban planning is the process of guiding the growth and change of cities. Planners study physical, environmental, social, economic, and political ramifications of development proposals. In light of these studies, they recommend policy to local, regional, and state legislators. Although urban planning encompasses many different disciplines and kinds of activities, this Guide emphasizes only two aspects: land use and transportation planning. Other urban planning activities not directly concerned with the spatial arrangement of buildings, public facilities, streets, parks and the like, such as economic and social planning, are not considered in depth.

This Guide is designed to help planners understand the relationship of air quality to land use patterns and transportation systems. Specifically, the Guide has two purposes: to indicate the air pollution effects of various planning strategies, and to suggest how land use and transportation planning can be used directly to control air pollution. The first purpose is directed toward most planning work where air quality is one of several important considerations, but not the overriding objective. The second purpose relates to situations where air pollution control is the principal objective, and land use and transportation controls are two of several means for achieving the objective. Thus, state air quality control regions may include in their air quality implementation plans some of the land use and transportation controls recommended here.

Regardless of which purpose the planner has in mind, air quality considerations may portend substantial changes in traditional urban planning practices. For example, because Federal ambient air standards apply to all public areas of all cities, the practice of segregating polluting industries may have to end. The clustering of dirty industries might spare cleaner land uses from industrial smoke, dust, fumes, and odors; but clustering can overtax the ability of one neighborhood's atmosphere to dilute pollutants, while underutilizing it in another neighborhood. Thus, some cities, in order to expand their industrial base, may now find it necessary to disperse land uses that pollute the air. Another change in urban planning practices may be to repeal regulations requiring the construction of off-street parking facilities as new buildings go up in polluted areas. In fact, it may be necessary to prohibit off-street parking in these areas to discourage the use of automobiles.

Research activity in land use and transportation policies, as they relate to air quality, is expanding. This Guide summarizes existing knowledge. The Environmental Protection Agency (EPA) has funded research in ways of evaluating the air quality implications of alternative land use arrangements, and the use of air zoning and emission density zoning to control air pollution. Other Federal agencies recently have become active in this type of work. Thus, many of the recommendations in this Guide are subject to change as more insight is gained into the role of urban planning in air pollution control.

The Guide outlines the laws and regulations that require assessment of the air pollution impact of land use and transportation patterns. It then discusses the many urban planning strategies available to control air pollution. The appendices provide basic information on air pollution.

Ronald A. Venezia
Chief, Office of Land Use Planning
Office of Air Programs
Environmental Protection Agency

SUMMARY AND CONCLUSIONS

Urban planners, by nature of their responsibility for guiding urban growth and change, have a significant role to play in reducing air pollution and its effects. Urban planning agencies can and should support the development of regional source control programs but their major contribution lies in evaluating, proposing, and implementing measures which help disperse pollutant concentration, reduce exposure of people to pollutants and improve the efficiency of urban travel. To accomplish these aims, urban planners and their agencies should consider the following activities within planning programs:

1. Research should be conducted and supported in order to better understand current ambient air quality and the pollution sources, meteorology and other conditions which affect it;
2. Air pollution considerations should be incorporated and evaluated in the process of developing land use and transportation plans;
3. Air pollution considerations should be incorporated in the performance of plan implementation functions (i.e., zoning, subdivision regulation, project review, capital improvement programming, etc.)
4. Source control programs for both stationary sources and vehicles should be supported and a close working relationship with air pollution control agencies should be maintained; and,
5. Encouragement should be given for new local, state, and Federal legislation which would allow urban planning programs and source control programs to better meet air pollution abatement goals (i.e., code enforcement improvements, vehicle inspection programs, zoning improvements, open space funding, transit programs, etc.)

To assist planners and planning agencies in carrying out these activities this report evaluates eleven land use/public facility planning strategies and five transportation strategies which are of potential value in the reduction of air pollution impacts. Also described are the techniques which would be required in the implementation of these sixteen strategies. Following are the major conclusions drawn from the evaluation of these strategies and techniques.

There are no easy answers for the urban planner. Indeed many actions that will be beneficial will also have ancillary harmful effects. For example, increasing the average speed of traffic will reduce the concentration of hydrocarbons and carbon monoxide, but probably increase the concentration of oxides of nitrogen. Increased travel speed also tends to lengthen trips; thus resulting in increased use of automobiles. Decreasing the density of land development reduces concentrations of air pollution but increases dependence on the automobile as a transportation mode. Optimal location of industries according to air pollution considerations may result in severe tax and employment repercussions. Such trade-offs require close study in light of each urban area's unique conditions and priorities.

At this point, much of what can be described regarding basic relationships and strategies is at a crude stage of development. It is regrettable that precise approaches cannot be prescribed and that results cannot be guaranteed. Furthermore, it is frustrating to realize that the most far-reaching strategies often require implementation tools which local governments and planning agencies do not have within their grasp. However, future application of the described strategies in a way which can be quantitatively evaluated plus a major research program (as anticipated by the Office of Air Programs) should yield new and better tested guidelines within a few years.

Based upon available research and case evaluations, the following appear to be the most important relationships for consideration in an urban planning program:

1. Planned relationships among industrial, commercial and residential land use can reduce concentrations of aerial wastes.
2. More effective use of large open spaces and green belts can disperse pollutant concentrations and the number of people exposed to unacceptable air pollution levels.
3. Significant reduction in hydrocarbons and carbon dioxide can be gained through effective highway planning.
4. Improved public transportation can reduce vehicular travel and vehicular emissions in varying amounts, depending upon the areas involved.

5. Designing transportation facilities to be compatible with adjoining land uses can have a significant impact on the number of people exposed to undesirable levels of air pollution.

6. Control of arterial and freeway operations to ensure smoother traffic flow can be significant both for short range and long range reduction of automotive pollutants.

7. The selective creation of traffic-free zones, if supported by sound traffic-planning, can substantially reduce certain pollutants within congested activity areas.

In the short term (the next five years) the urban planner can expect to achieve the greatest payoffs from: traffic flow improvements such as those funded through the TOPICS Program; improvement of highway/land use relationships; tighter control over location of stationary air pollution sources and the land uses around such sources; and, creation of traffic-free zones within congested activity areas.

Long term payoffs from urban and transportation planning strategies can be much greater than short term. Within the next 30 years it is expected that the urban population in the United States will increase by 75-80 million. Provision for this enormous increase, together with necessary replacement of obsolete development, will provide a substantial opportunity to plan and build in a rational manner to minimize the impacts of air pollution. Careful consideration of regional land development strategies, transportation plans and new plan implementation techniques, as well as increased receptivity to the regulation of private vehicles, will be a necessity if this opportunity is to be seized.

CHAPTER 1

ROLE OF AND LEGISLATIVE MANDATE FOR URBAN PLANNING

A. THE ROLE OF URBAN PLANNING IN AIR POLLUTION CONTROL

Air pollution is increasing because the population and economy are expanding. Control technology is improving, but not fast enough to keep pollution in check. To close the gap, Congress decreed in 1970 that land use and transportation controls be added to the arsenal of weapons against air pollution.[1] Imposition of these controls requires both land use and transportation planning, which are collected here under the label of urban planning.

Urban planners work with many factors that affect air quality. They plan the spatial distribution of industries, power plants, and other related land uses commonly called "point sources" in air pollution control work. Planners lay out transportation routes or, in air pollution terminology, "line sources." They work with zoning laws controlling the density of residential neighborhoods, which are called "area sources" because of the way residential furnaces and incinerators are distributed. Planners influence the design, siting, and landscaping of buildings and the reservation of open-space -- all of which affect the dispersion of air pollutants by modifying the urban microclimate.

The treatment of the air pollution problem through urban planning is a complex process, as illustrated in Figure 1.1 The entire process outlined in the diagram is not covered in this report. Rather, it and the companion Guide for Reducing Automotive Air Pollution focus on the box labeled "Feedback for Plan Modification." The remaining elements of the diagram serve here to illustrate how the Guides fit into the full context of urban planning. It is hoped that the resulting program will serve as a model for similar work in other areas of planning for environmental protection so

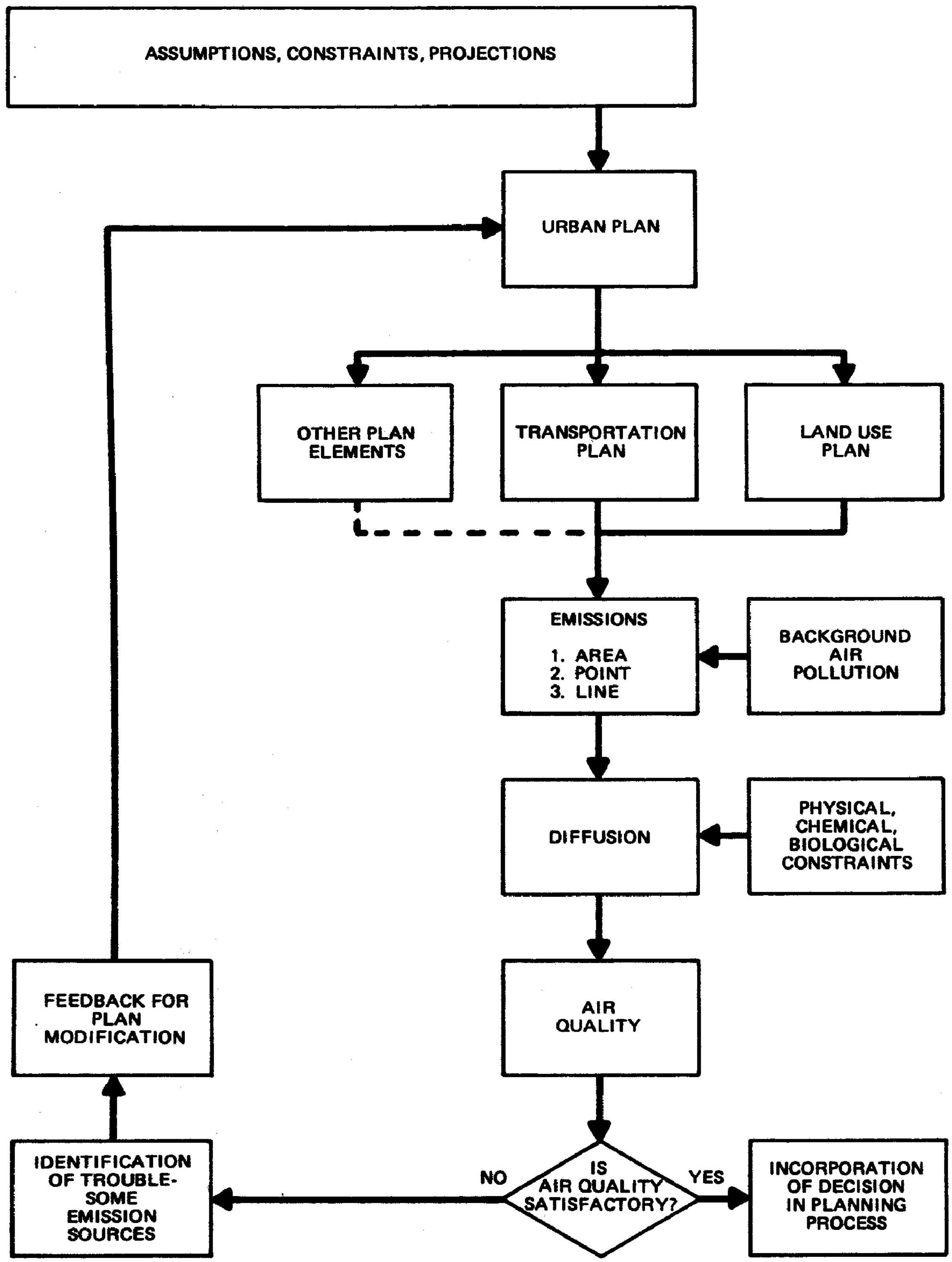

Figure 1.1 Air Quality Considerations in the Planning Process

that the tools for considering the aspects of such problems as water pollution and solid waste, for example, will be developed and used in the urban planning process.

The need for this Guide is based on the fact that urban planning decisions are often made without proper consideration of their air pollution consequences. For example, the choice of a highway system instead of a rapid transit system will affect an urban area's air quality. Most urban and transportation planning activities of the past have considered air pollution effects only indirectly if at all, and then only in a non-quantitative manner.

Three reasons explain the lack of consideration given to air pollution by planners and public decision-makers. First, they lack precise knowledge of the effect which the arrangement, design, and operation of urban elements have upon air pollution. Second, there are no established procedures for incorporating air pollution considerations into plan-making and plan-administration activities. Third, very few communities have the legal tools necessary to enforce land use policies of the breadth and depth required by the air pollution problem.

The urban planner must not define his role too narrowly. Where he lacks legal authority he can work to control air pollution through effective public relations and an aggressive program. Planners can go beyond land use and transportation control strategies and focus public attention on the quality of a region's source control program.

The Miami Valley Regional Planning Commission (MVRPC) in Dayton, Ohio is a case in point. The MVRPC staff cooperated with the County Health Department in discussions regarding the legal and organizational aspects of a regional air quality program. It gave moral and financial support to a local citizens' clean air group in generating a cadre of well-informed individuals able to forcefully testify and lobby for strict standards. Furthermore, the MVRPC strongly recommended strict standards to the Health Board. The Commission is now monitoring the effectiveness of the local control program, and supporting legislation to expand and improve it.

This Guide has been prepared to describe current air pollution relationships and planning strategies, however, it must be noted that the state of research and theory in this area is still quite meager.

B. THE LEGISLATIVE MANDATE FOR PLANNING ACTION

Recent Federal laws and regulations involve urban planners in air pollution control work.

1. National Environmental Policy Act of 1969

This act establishes a broad national policy directed toward improving the relationship between man and his environment, and creates the Council on Environmental Quality (CEQ). Section 102(2)(C) of the act is designed to ensure that the environmental effects of all major proposed federal legislation, plans, and programs are properly considered. For any proposed action significantly affecting the environment, a detailed statement must be submitted analyzing the following points:

"(i) the environmental impact of the proposed action,

(ii) any adverse environmental effects which cannot be avoided should the proposal be implemented,

(iii) alternatives to the proposed action,

(iv) the relationship between local short-term uses of man's environment and the maintenance of long-term productivity, and

(v) any irreversible and irretrievable commitments of resources which would be involved in the proposed action should it be implemented."

The Office of Management and Budget has established[2] a framework for communicating environmental information among Federal, state, and local agencies. This framework, originally intended to implement requirements for coordination set forth in other Federal legislation, was amended February 9, 1971 to include the coordination of environmental impact analyses. In this framework, selected state, regional, and local planning agencies are designated as "clearinghouses" to be notified by any state or local agency intending to submit an application for Federal financial assistance. The clearinghouse, in turn, notifies all potentially interested persons and groups within its jurisdiction of the planned project. The state or local agency requesting Federal aid then obtains comments from these persons and groups on the environmental impact of its project, and these comments are included in the request to the Federal agency. If, after reviewing the comments, the Federal agency determines there will be a significant impact on the environment, it must submit an impact statement to the CEQ. The impact statement, reflecting all the comments received through the clearinghouse process, becomes part of the public record.

For additional information on the implementation of Section 102(2)(C) of the act consult the "102 Monitor," published monthly by the CEQ.

2. 1970 Clean Air Act

This act calls for the establishment of primary (relating to health) and secondary (relating to welfare) ambient air quality standards by the Administrator of the Environmental Protection Agency (EPA). The Administrator is also required to set standards of performance for new stationary sources of pollution and for motor vehicles. The act requires states to prepare plans by January 30, 1972 for achieving and maintaining the air quality standards within three years. The act authorizes the Administrator to act if the states do not, and gives him powers of enforcement.

3. Regulations Promulgated Pursuant to Clean Air Act

The EPA set out requirements by which the states should prepare, adopt, and submit implementation plans for air quality standards achievement.[3] The requirements describe a "control strategy" by which a combination of measures are designated to achieve the aggregate reduction of emissions necessary to achieve and maintain a national standard. The measures might include:

a. Emission limitations.

b. Federal or state emission charges or taxes, or other economic incentives or disincentives.

c. Closing or relocation of residential, commercial, or industrial facilities.

d. Changes in schedules or methods of operating commercial or industrial facilities or transportation systems. These would include any short-term changes made in accordance with standby plans.

e. Periodic inspection and testing of motor vehicle emission control systems.

f. Emission control measures applicable to in-use motor vehicles, including mandatory maintenance, installation of control devices, and conversion to gaseous fuels.

g. Measures to reduce motor vehicle traffic, such as commuter taxes, fuel rationing, parking restrictions and staggered working hours.

h. Expanded use of mass transportation through measures such as increased frequency, convenience, or capacity, or by providing special bus lanes on streets and highways.

i. Any other land use or transportation control measures.

j. Any other variation of, or alternative to, the above measures.

The EPA established national ambient air quality standards for sulfur oxides (SO_x), particulate matter, carbon monoxide (CO), photochemical oxidants, hydrocarbons (HC), and nitrogen oxides (NO_x).[4] "Ambient air" means that portion of the atmosphere, external to buildings, to which the general public has access. It does not matter what the wind patterns are, how many people live, work, shop in any particular area, how long they remain there, or whether there are plants, buildings, or other land uses especially susceptible to air pollution damage in the area; the standards apply equally to all areas open to the general public.

4. 1970 Federal-Aid Highway Act

This act requires the Secretary of the Department of Transportation (DOT) to promulgate guidelines by October 1972 designed to ensure that new highways will be consistent with a state's air quality implementation plan. These guidelines will enable planners to predict and to minimize the effects of a proposed roadway on air quality. Highways should be designed, located, and operated so as not to hinder the achievement of air quality standards. Detailed information on the Act is available from the state representative of the Federal Highway Administration.

5. Urban Mass Transportation Assistance Act of 1970

This act amends the Urban Mass Transportation Act of 1964, placing grant and loan applications under the "A-95" review process.[2] In addition, it requires that the applicant afford adequate opportunity for public hearings for all parties interested in the economic, social, and environmental impact, and must hold hearings unless no one with significant economic, social, and environmental interest has requested such hearings. If hearings are held, the Secretary of DOT is required to ascertain that they were adequate and that all harmful environmental impacts have been minimized. Detailed information on the act is available from the Administrator, Urban Mass Transportation Administration, Washington, D. C., 20590.

CHAPTER 2

REDUCING AIR POLLUTION THROUGH LAND USE AND PUBLIC FACILITY PLANNING

Land use and public facility planning can be used to reduce air pollution. The methods range from large to small scale, from long-range to short-range, and from theoretical to applied.

Strategies are broad policies that define a course of action. Techniques are the legal, organizational, functional, and financial tools and processes through which strategies are implemented. Table 2.1 is an overview of the strategies and techniques that are discussed in this chapter.

Large scale, long-range, theoretical methods are discussed first, under the heading "Regional Development Strategies." These are goal-oriented, and treat air pollution as one criterion for reshaping the land use pattern of an entire region. Small scale, short-range, applied methods are discussed last, under the heading "Location and Design Strategies." These are geared to solving immediate problems without departing substantially from current land development trends. The evaluation of primary and secondary techniques is based on the consultants' experience and judgment.

A. REGIONAL DEVELOPMENT STRATEGIES

On the regional and metropolitan scale, urban planners have responsibility for preparing long range plans (20 to 50 years) for producing a more rational and more humanly satisfying environment. The achievement of this objective requires the sensitive consideration of alternative arrangements of the region's physical structure, including: the shape, density and organization of settlement areas; the orientation and composition of subareas; the pattern and type of transportation system; and, the shape and location of major open space. Four possible land use approaches, which have implications for the reduction of air pollution and its effects, are discussed below; regional transportation aspects are discussed in Chapter 3.

LEGEND

■ PRIMARY TECHNIQUES

● SECONDARY TECHNIQUES

TECHNIQUES / STRATEGIES	A. REGIONAL DEVELOPMENT				B. LOCATION & DESIGN						
	1. Alternative Regional Forms	2. Balanced Communities and Subregions	3. Low Density Development	4. Regional Open Space Patterns	1. Location of Stationary Sources	2. Relocation of Stationary Sources	3. Control of Land Use Around Sources	4. Location of Sensitive Receptors	5. Location & Design Control of New Towns	6. Planned Unit Developments	7. Small Open Spaces
Comprehensive & Project Planning	●	●	●	●	■	●	●	■	●	●	●
Localized Zoning (Location & Density)	●	●	■	●	●	●	■	■	●	■	●
Regional Zoning (Location & Density)	■	■	■	■	■	●	■	■	■		
Performance Zoning					●						
Non-Conforming Use Laws						●	●	●			
Zoning Regulations for Site Use										●	■
Air Zoning & Smokeless Zones			●		●						
Subdivision Regulations								●	■	■	
Land Dedication Regulations										■	
Planned Unit Development Regulations								●	■	■	
Building & Housing Codes			●							●	
Urban Renewal		●				●	●	●	●	●	●
Land Acquisition Programs	■		●	■				●		■	
Open Space Tax Incentives	■		●	●							
Location & Relocation Incentives	●	■	●		●				●		
Speculative Public Investment	●	■			●	■			●		
Tax Equalization or Gov't Consolidation	●				■	■			●		
A-95 Review	●	●		●	●				■		●
Direct Urban Design		●								●	●

Table 2.1 Urban Planning Strategies and Techniques for Reducing Air Pollution

1. Alternative Regional Forms

There exist numerous strategies for urban form and growth which entail specific land use arrangements. These strategies may have particular importance for air pollution control. In selecting from a variety of urban growth concepts, therefore, the planner should be conscious of their relative significance for air pollution control, particularly with regard to potentials for improving air pollution dispersion efficiency and reducing automobile travel (and thus auto emissions).

The following discussion of studies conducted in Hartford, Chicago, Seattle, and Prince George's-Montgomery Counties, Maryland, demonstrates the relationship between land development patterns and air pollution.

Hartford Studies -- A comprehensive analysis of the relationship between air pollution and land use was undertaken for Hartford, Connecticut, by Yocom and others.[5] This study showed clearly that the distribution of air pollution concentrations was related to the arrangement of land development. Emission inventory maps were developed, based on the predicted geographical distribution of land development and population, as well as on assumptions about control technology. The land use development pattern for the year 2000, approved by the Capital Region Planning Agency, was used as a basis for estimating future air quality.

An alternate plan for the Capital Region would terminate all further development in the Connecticut Valley, and concentrate all future development along two highways to the northwest and the southeast. This arrangement would produce a developed area elongated in a direction perpendicular to the prevailing winds in the region. This scheme would produce by the year 2000 an air quality pattern with the total area of unacceptable air quality somewhat less than the approved plan but with the area of questionable air quality somewhat larger.

Another study for the Hartford region has looked into the interrelationships between land use and trip length.[6] The study considered five alternative land use plans, illustrated in Figure 2.1, for the year 2000. These land use plans represent the development pattern required by present zoning regulations and four alternative arrangements of land use that might be selected as desirable goals for the region's growth.

In each case, the population and number of jobs are the same but the distribution and intensity vary. The black dots in the figure represent regional or subregional centers, and the gray areas stand for intense urban development, primarily industry or high-density residence. The remaining white areas are considered low-density development and open space.

The significance of Figure 2.1 is the average trip lengths which result from the different land use plans. The difference between the trip lengths, and hence in automotive air pollution, produced by the Balanced Community and the Single Center Concepts could be as high as 22 percent. Land use plans can have significant effect on trip lengths, and consequently on automobile-produced air pollution.

<u>Chicago Study</u> -- In Chicago, the air pollution implications of three alternative metropolitan plans were analyzed on the basis of emission estimates for two pollutants: oxides of nitrogen emissions and suspended particulate emissions from certain industry groups.[7] The alternative plans investigated consisted of a Finger Plan (high-density corridors), a Multi-Towns Plan, and a Satellite Cities Plan. For these two pollutants, it was found that the Finger Plan and Satellite Cities Plan were equivalent with respect to particulates, and both were about 30 percent lower than the Multi-Town Plan; the Finger Plan, however, produced fewer oxides of nitrogen than the other two plans.

On the basis of these tests, it was concluded that the Finger Plan was the best alternative for air quality. Although this plan had fairly high residential and industrial concentrations, it also provided dilution potential

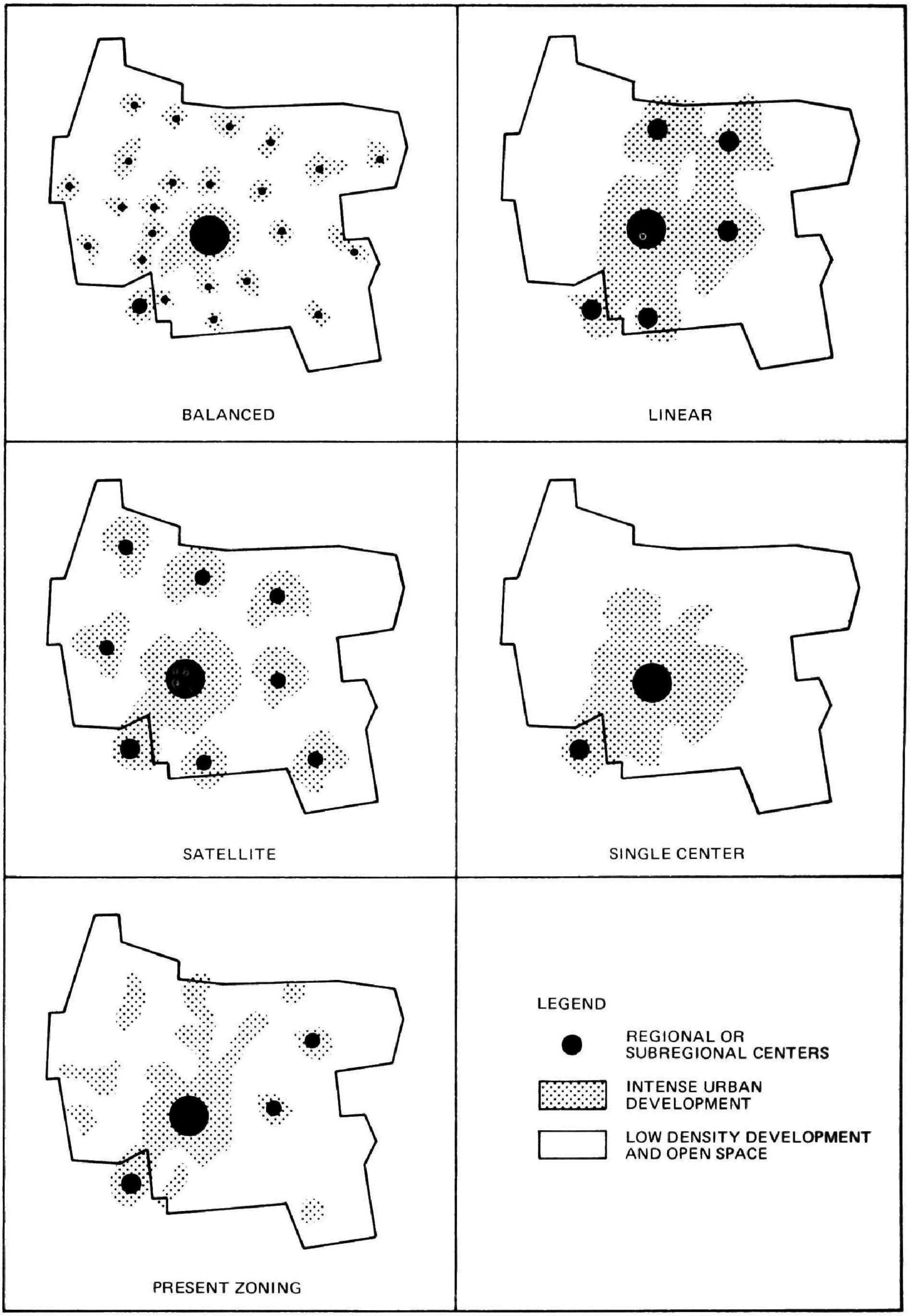

Figure 2.1 Alternative Land Use Plans for Hartford[6]

for pollutants. This was true because the development corridors were elongated and bordered on either side by large green areas. Thus, the presence of green areas adjacent to pollutant sources is an important land use factor in pollution reduction. In both cases, the land use option providing the greatest opportunity for pollutant dispersion over green areas resulted in lower apparent pollutant concentration.

Seattle Study -- In Seattle, Washington, two alternative transportation networks, based on two different land use systems, were evaluated for their effect on air pollution.[8] The two plans were: Plan A, continuation of the existing trends in land development; and Plan B, development patterned into a "Cities and Corridors" concept. Total emissions associated with Plan A were about 12 percent higher than those associated with Plan B. The analysis concluded, however, that the land use configuration preferable for air pollution reduction cannot be determined until total area emissions and, more importantly, total ambient pollutant concentrations are estimated and compared.

Maryland (Montgomery-Prince George's Counties) Study -- The effect of alternative land use plans, transportation networks, and operational characteristics in reducing air pollution were also evaluated for Montgomery and Prince George's Counties in Maryland.[9] In order to quantify the effect of alternative land use plans and highway networks on air pollution, a measure of the amount of air pollutants generated by automobile travel associated with each land use plan was required. Relationships were developed between vehicle miles of travel, emissions of pollutants, and speed. On the basis of curves relating emissions to auto speeds, air pollution produced by the alternative plans was calculated based on congested and average operating speeds. Table 2.2 shows a comparison of the pollutant production for the alternative plans. In comparing the alternatives an index

Table 2.2. SUMMARY COMPARISON OF POLLUTANT PRODUCTION[9]

(Pounds/Day)

	Existing System		Alternative 2 General Plan		Alternative 5 Concept Plan C		Alternative 6 General Plan Capacity	
	Pre-1968	Post-1975	Pre-1968	Post-1975	Pre-1968	Post-1975	Pre-1968	Post-1975
Montgomery County								
Hydrocarbons	56,300	4,570	149,500	12,870	147,700	12,180	232,950	19,520
Carbon Monoxide	663,260	95,460	1,874,290	275,100	1,794,390	262,600	3,048,110	454,700
Total Production/ Vehicle Miles	0.145	0.0218	0.158	0.0242	0.145	0.022	0.188	0.0286
Prince George's County								
Hydrocarbons	70,650	5,820	198,600	16,500	200,200	16,440	238,320	19,700
Carbon Monoxide	856,440	127,150	2,491,880	365,100	2,435,540	354,820	2,994,720	439,060
Total Production/ Vehicle Miles	0.154	0.0235	0.157	0.0238	0.146	0.0220	0.160	0.0242

of the weighted average of pollutants produced per vehicle mile was calculated. This index was used to choose the plan that contributed the least air pollution as a result of less overall congestion in the network and the arrangement of the transportation system and urban development.

Conclusions -- As indicated by research that has been done to date, improved regional development patterns should reduce auto emissions and the number of persons exposed to pollutants from both vehicles and stationary sources. However, as was concluded in the Seattle study, the determination of preferable land use patterns cannot be made until total area emissions and, more importantly, total ambient pollutant concentrations are estimated and compared. Two basic conclusions can be drawn regarding the effect of regional development concepts:

a. Models for simulating the air pollution impacts of alternative development forms need to be made more comprehensive in their capacity to accommodate corridor variables (i.e., trip length, travel speed, population density, ambient air conditions, stationary source emissions, etc.) None of the studies reviewed for this project, for instance, evaluated development plans from the standpoint of both auto and stationary emissions.

b. Even when such multi-variable models are developed, it will be difficult to make generalizations about optimal development forms. Localized investigations will be required due to significant variations in regional ambient air quality levels, the location of major stationary sources, the climatological conditions, and the travel behavior of residents.

With regard to trip lengths, it remains for the planner to consider the effect of various land use concepts upon trip length in a given metropolitan area. Minimum travel distance should be incorporated into the land use plan selection criteria. It must be understood, however, that shortening trip lengths is not a universal panacea for improving air quality. As pointed out in subsequent sections, it is important to give equal attention to increasing traffic speed and population density reductions, both of which can be incongruous with the minimum travel distance criterion.

By taking a small area approach to regional and metropolitan development it is possible to increase opportunity, accessibility, and convenience. The net result of creating subregions, each having a balanced supply of employment facilities, retail and service centers, and housing types and prices, can be a significant reduction in peak-hour auto travel. One study[6] concluded that travel could be minimized through creation of defined subareas. The key factors in this type of development are:

a. Populations should range in the order of 100,000 to 200,000. (The effect on internal trip lengths on communities of 100,000 to 200,000 may be observed from the curve shown in Figure 2.2.)

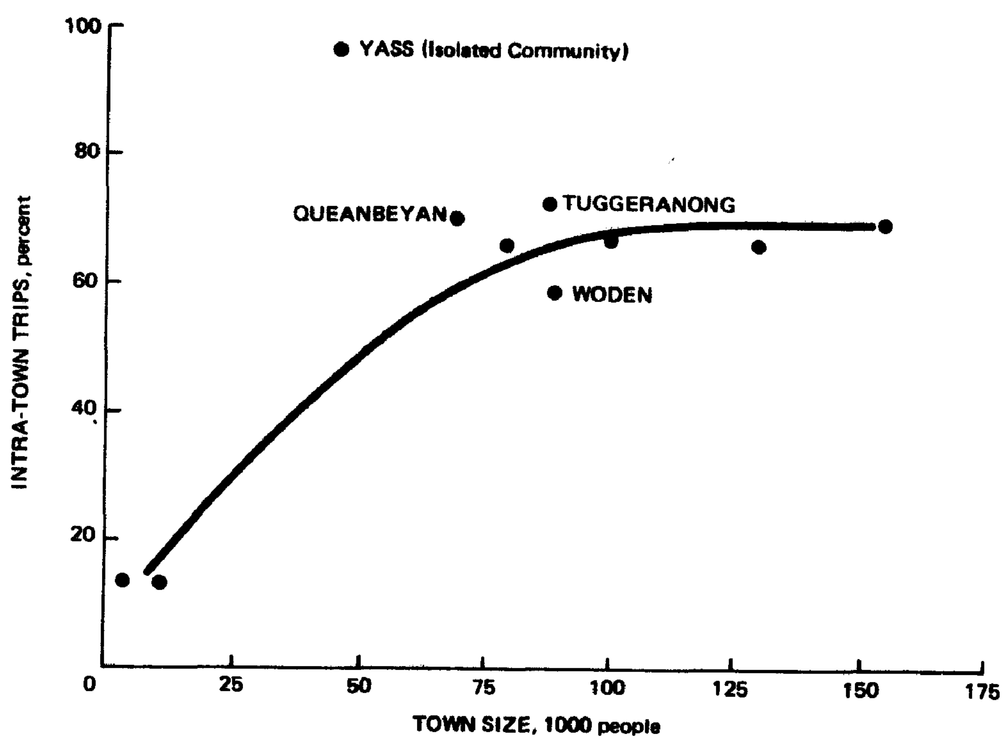

Figure 2.2 Correlation of Internal Trips With Population Size[10]

b. Subregions should be as distinct and isolated from one another as the natural topography and existing development pattern will permit.

c. Street and highway systems should be laid out to focus on the subregional center(s).

d. High density residential development should be located within 10 minutes travel time of high density commercial and employment areas.

e. Housing must provide a wide range of types that will attract a diversity of social and economic groups.

The reduction of trip lengths and the increased potential for non-auto trips (transit and walking) caused by implementing this balanced subregional concept (see Figure 2.3 for an illustration of how such subregions could be planned and designed), results in a reduction of auto pollution emissions comparable to the reduction of auto travel.[11] Furthermore, this type of development pattern is also highly compatible with other planning objectives (i.e., wider housing opportunities, reduced sprawl, more economical public service delivery, revitalization of central business district, etc.).

The subregionalization concept could be applied in a number of ways:

a. Guiding the establishment and design of new towns which are currently being considered, planned, or developed in a number of metropolitan areas.

b. Providing a framework for new suburban development.

c. Restructuring and renewal of built-up sections of metropolitan regions, including "new towns-intown."

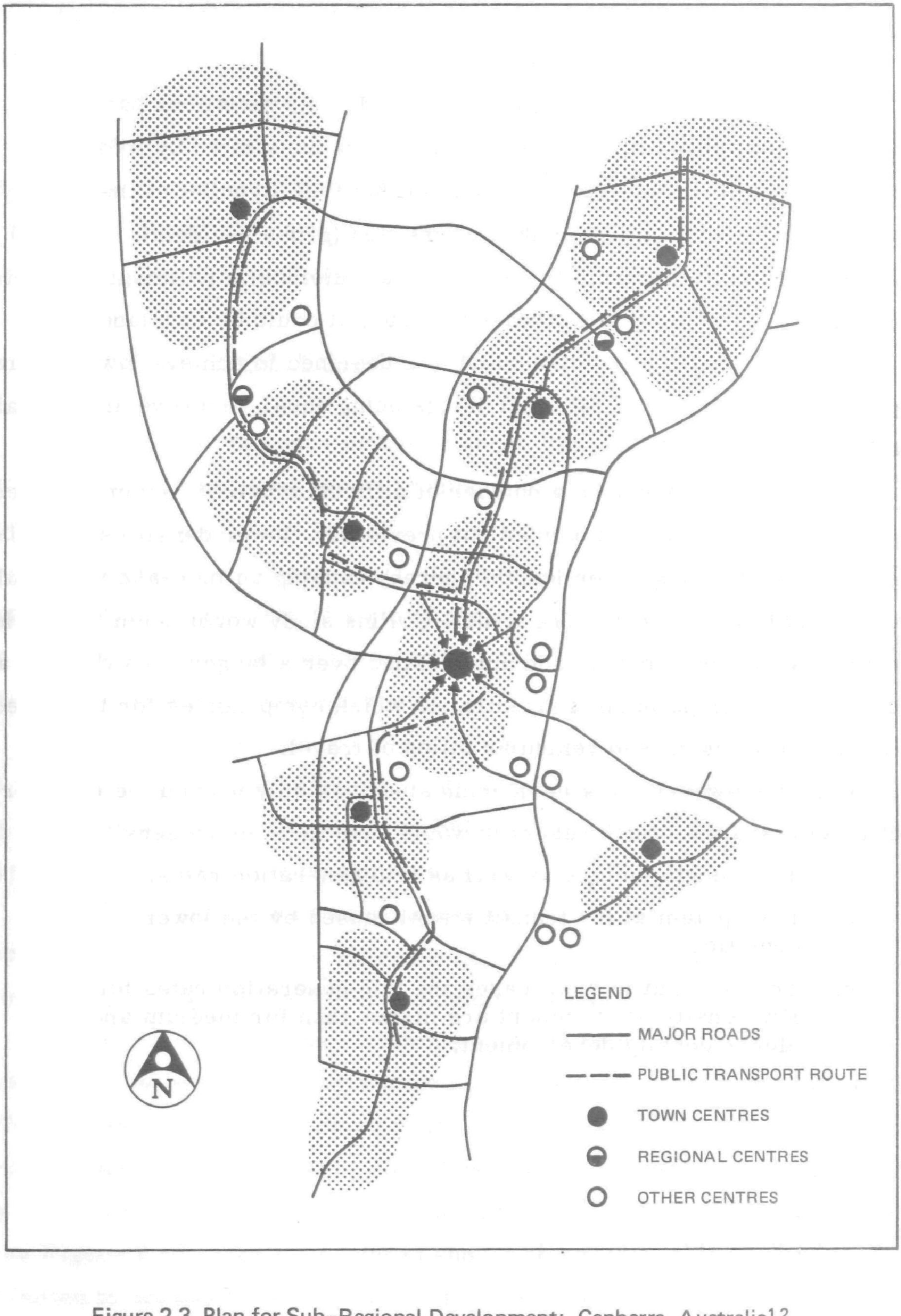

Figure 2.3 Plan for Sub-Regional Development: Canberra, Australia[12]

3. Low Density Development

The potential impact which population density variations have upon automobile pollution concentrations has been demonstrated by Rydell and Collins in a simulation study.[13] Application of the Rydell-Collins density equation over the range of population densities (gross residential density) occurring in the simulated city revealed that automobile pollutant concentrations decreased as density decreased. Thus, it could be concluded from this study that land use policies which are designed to achieve lower overall population densities will, all other things being equal, improve ambient air quality.

Obviously, this raises a number of difficult questions about the effect of residential density. As pointed out previously, lower densities stimulate trips of consistently greater length, thereby causing an increase in overall travel of 10 to 20 percent. The Rydell-Collins study would seem to conclude that the dispersion of people and automobiles over a larger area creates a condition of lower pollutant concentration which compensates for the added pollution due to increased vehicular miles of travel.

In fact, however, this pioneering study has only proven the need for additional research. Such research would have to be more sensitive to:

a. Trip length factors as well as trip generation rates.

b. Lost potential for transit travel caused by the lower densities.

c. The fact that in most cases the trip generation rates for low density development are higher than for medium and higher density development.

For the time being, density changes on a broad scale appear to be somewhat neutral in effect. On a smaller scale, however, density reduction can have a significant effect. For example, reducing density of development around major stationary sources of aerial wastes, such as industries or power plants, will, depending upon climatological and topographic conditions, tend to reduce the number of people affected by emissions from such sources.

4. Regional Open Space Patterns

The use of open space or buffer zones to separate aerial waste sources from residences has long been a technique employed by planners. In addition, open spaces can be used to shape the community into the desired growth pattern; more recently, it has become known that open space can provide better dispersion of air pollutants. Some research has been done on this subject and much more is underway and needed, but there are some known techniques which are relevant.

Effective dispersion of air pollutants does occur over open space and is increased if the land is planted. By absorbing moisture and then cooling by evaporation, greenery creates a cooler, more humid surface which keeps dust and other pollutants on the surface.[14]

The location and size of open spaces are important. Wind direction, type of pollutants, etc. are all relevant. Generally the width must be much wider than the narrow buffer strips common today.

A variety of open space systems some of them empirically derived, has been proposed on the basis of potential diluting, absorbing, and settling effects of buffer space. Hilberseimer has suggested[15] that when winds blow from a single direction, there should be rows of built-up areas separated by green zones, with the industries on the leeward side of the development (see Figure 2.4). The green zones should be broad enough to reduce air pollution to acceptable levels before the winds reach each succeeding

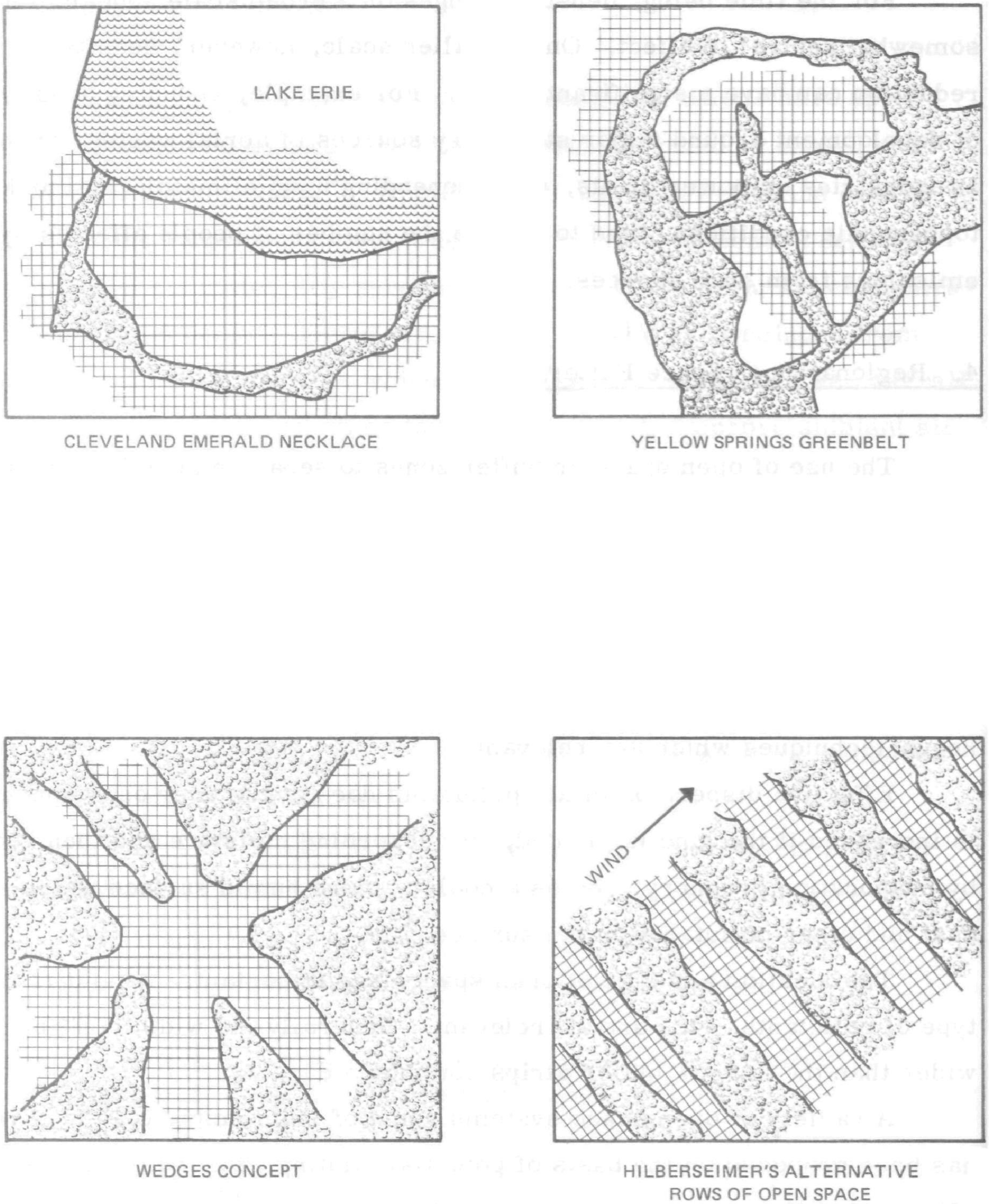

Figure 2.4 Examples of Large Open Space Systems

residential strip. When the wind direction varies over a range of less than 180 degrees, Hilberseimer has concluded that diamond-shaped arrays of industrial and residential locations are best; and over a range of more than 180 degrees, triangular arrays are best.

In certain geographical areas, however, the green bands strategy may be very difficult to implement. For example, because of the dispersed wind pattern and source locations in the Chicago area, it would serve little purpose to plan land use according to wind direction. Generally speaking, the area's wind patterns pose a threat to people in all directions from major sources. In such a case, buffer zones would have to completely surround these sources. The 5,000 acre greenbelt being preserved around Yellow Springs, Ohio, as well as circumferential park systems (the Emerald Necklace) around Cleveland, Ohio, are examples of this pattern of buffering (see Figure 2.4).

Perhaps more effective is the creation of open wedges or corridors radiating from penetrating toward the center of the metropolitan area (see Figure 2.4). In this system almost all development is only minutes away from open areas. Such proximity to open space helps in the diffusion of aerial wastes. This was well supported in the Chicago tests on alternative development forms in which the Finger Plan (i.e., a concept based upon corridors of development and wedges of open space) proved to generate the least air pollution impacts in spite of the proximity of several of the fingers to high concentrations of stationary pollution sources.

While the research is still inadequate, it does appear that the use of regional open space systems to help disperse pollutants can be of significant value. Furthermore, when its dispersion potential is added to all the other benefits of open space preservation, the case for implementation of land preservation programs becomes quite convincing.

5. Implementation of Regional Development Strategies

To accomplish the restructuring of metropolitan areas according to the strategies described above would call for every tool planners have in their kit, plus some that have yet to be developed. Regional zoning would be a most effective tool but only a few areas such as the Jacksonville, Indianapolis, and Nashville consolidated governments are currently able to exercise such power. In absence of such centralized public land control in most areas, a high degree of voluntary coordination, review, and referral must suffice. Furthermore, implementation will call for a very carefully executed program of reclassifying vacant land to buildable zoning districts. If intensification of land use, redevelopment of built-up sections, and preservation of open space are to occur, land must be made a scarce resource so that developers, builders, employers, and politicians will be deterred from current "spread city" development patterns. Some alternative tools which might convince development interests to follow new development strategies include:

a. Massive open space preservation programs which tend to define and channel development opportunities (techniques could include fee simple or easement acquisition, new tougher conservation zones, and tax deferrals).

b. Restrictive public sewer and water extension policies in concert with tight regulation of on-site sewer and water systems.

c. Tax incentives for developments which follow the "plan."

d. Entry of local and state governments in the business of development and redevelopment. (New York's Urban Development Corporation is one of the best examples of "public interest" developers.)

e. Control of new town locations and designs through metropolitan and state clearing houses in their exercise of A-95 review powers.

f. Decentralization of low and moderate income housing from congested cities to all sections of the metropolis so that employment facilities can be closer to the total range of needed occupational skills. (A-95 review power over all federally assisted housing, presently limited to single-family housing developments of more than 50 units and multi-family developments of more than 100 units, would be the tool for promoting such housing goals.)

g. Selection of urban renewal projects which would encourage concentration of jobs and people in close proximity. However, judging from the difficulty many renewal programs have had in attracting developers, additional incentives may be required.

h. Selective placement of public facilities and services so that they serve as positive "development shapers." In other words, through capital improvement programs, model cities programs, A-95 review of federally assisted facilities, and the planning and programming of improvements of highway and utility systems, development can be stimulated, shaped, intensified or modified. This kind of public entreprenuership departs from the standard "supply follows demand" philosophy, but it is being done more and more frequently by local governments. Furthermore, denial of public service and facility improvements can maintain clarity and definition of the subregional cluster boundaries.

B. LOCATION AND DESIGN STRATEGIES

While modifications of regional and metropolitan form can apparently provide pollution-reduction payoffs for relatively large numbers of metropolitan dwellers, the facts remain that those payoffs are long-range and that we currently lack some of the more important land use tools required to implement them. Through selective application of location and design strategies, however, it is possible to generate some shorter range effects which fall essentially within the current range of planning powers. The following discussion describes and evaluates some of these strategies.

1. Location of Stationary Sources

In formulating comprehensive plans, the planner should attempt to locate large industries and industrial areas so as to minimize their effects on residential and commercial air quality. Hazardous air quality conditions which exist today can often be traced to poorly located industry. For example, many industrial areas historically developed in river valleys in order to benefit from cheap transportation.[16] Depending on the surrounding topography, such valleys are often the worst locations for sources of harmful emissions.

The impact of pollution from industrial land uses can be reduced not only by source control technology, but also by careful location planning of such areas with respect to the local dispersion characteristics and with respect to residential development location and densities. Because it is always desirable to ensure that aerial wastes are discharged away from residential areas, the planner must make increasingly comprehensive studies of local meteorology, climatology, and topography in order to improve spatial arrangements of industrial, commercial, and residential areas. In fact, these considerations should become fundamental determinants of industrial location decision-making along with such criteria as amount of existing vacant land, land cost, accessibility, demand for existing industrial activity, and compatibility with adjacent land uses.

In general, the ideal site for industrial sources of aerial waste is comparatively level terrain in a region where the average wind velocity is ten miles per hour or more, and where deep temperature inversions rarely occur.[17] However, because dispersion characteristics vary among regions, the planner is urged to investigate the relevant conditions of specific areas and to assess land uses accordingly. Following are two examples, illustrating the significance of local dispersion characteristics in land use planning.

When rebuilding Volgograd (formerly Stalingrad) after World War II, its planners recognized that the wind almost always blows from the same direction. They designed the city in major land use strips perpendicular to the wind. The wind does not pass over the industrial area until it has passed all of the other uses.

Placing the industrial area on the leeward side of the city is not always the solution, however. In Linz, Austria,[14] located in a mountain valley, industrial sources were sited on the eastern side of the city to take advantage of the prevailing westerly winds. On occasions when the more mild easterly wind is in effect the pollution is banked against the mountains and the residential area is often blanketed by smoke.

The problem at Linz was caused by the effect of low velocity winds on air pollution concentrations. While high velocity winds disperse air borne pollutants, low velocity winds may prevent dispersion. Wind frequencies and speed must be considered in the planning process prior to locating industrial areas to keep emissions away from residents.

Zoning -- The implementation of such plans for new industrial locations is normally carried out through zoning regulations, which generally have between one and five categories of industrial land. The list of major stationary pollution sources shown in Table 2.3 should prove helpful to the planner in determining permitted uses within different zoning districts. The consideration of air pollution and other obnoxious effects abttributable to industry has taken place for a number of years. However, the regulatory process has been only partially effective because:

a. Community leaders are increasingly anxious to strengthen the tax base with industrial development and often will amend zoning regulations to allow industries to locate wherever they desire.

b. Zoning power is decentralized to many local jurisdictions within a region, and inter-community air pollution effects are often not considered.

Table 2.3. MAJOR POLLUTANT SOURCES

Chemical Process Industries

Adipic acid
Ammonia
Ammonium nitrate
Carbon black[a]
Charcoal[a]
Chlorine
Detergent and soap[a]
Explosives (TNT and Nitrocellulose)[a]
Hydrofluoric acid[a]
Nitric acid
Paint and varnish manufacturing[a]
Phosphoric acid[a]
Phthalic anhydride
Plastics manufacturing[a]
Printing ink manufacturing[a]
Sodium carbonate[a]
Sulfuric acid[a]
Synthetic fibers
Synthetic rubber
Terephthalic acid

Food and Agricultural Industries

Alfalfa dehydrating[a]
Ammonium nitrate
Coffee roasting[a]
Cotton ginning[a]
Feed and grain[a]
Fermentation processes
Fertilizers[a]
Fish meal processing
Meat smoke houses[a]
Starch manufacturing[a]
Sugar cane processing

Petroleum Refining and Petrochemical Operations[a]

Wood Processing

Petroleum storage (storage tanks and bulk terminals)

Mineral Products Industries

Asphalt roofing[a]
Asphaltic concrete batching[a]
Bricks and related clay refractories[a]
Calcium carbide[a]
Castable refractories[a]
Cement[a]
Ceramic and clay processes[a]
Clay and fly ash sintering[a]
Coal cleaning[a]
Concrete batching[a]
Fiberglass manufacturing[a]
Frit manufacturing[a]
Glass manufacturing[a]
Gypsum manufacturing[a]
Lime manufacturing[a]
Mineral wool manufacturing[a]
Paperboard manufacturing[a]
Perlite manufacturing[a]
Phosphate rock preparation[a]
Rock, gravel, and sand quarrying and processing[a]

Metallurgical Industries

Primary metals industries:
- Aluminum ore reduction[a]
- Copper Smelters[a]
- Ferroalloy production[a]
- Iron and steel mills[a]
- Lead smelters[a]
- Metallurgical coke manufacturing[a]
- Zinc[a]

Secondary metals industries:
- Aluminum operations[a]
- Brass and bronze smelting[a]
- Ferroalloys[a]
- Gray iron foundries[a]
- Lead smelting[a]
- Magnesium smelting[a]
- Steel foundires[a]
- Zinc processes[a]

Miscellaneous

Fossil fuel steam electric powerplants[a]
Municipal or equivalent incinerators[a]
Open burning dumps[a]

---

[a]Major sources of sulfur oxides and/or particulate matter.

c. Almost every city (particularly large central cities) has its share of improperly located heavy industry which was built prior to the adoption of zoning. Non-conforming use provisions have not had the enforcement procedures necessary to relocate those industries which are in conflict with surrounding uses.

In spite of these drawbacks to use of the zoning power, it remains the best tool available and has been used with increasing effectiveness in locating suburban industrial areas. Zoning regulations, in order to promote further reduction of air pollution concentration, must be reexamined in light of the effect that metropolitan meteorological and topographic characteristics have upon pollutant dispersal.

Performance Zoning -- Consideration ought to be given to the performance zoning approach. Performance standards are a method, usually limited to industrial classifications, under which zoning districts are established not by a detailed catalog of specific permitted uses, but by scientific measurement of the external nuisance impact of the operation. Any use may be located in any industrial district if it can comply with measurable standards for noise, glare, odor, vibration, fire safety, smoke and toxic matter. The excerpt from the Cook County, Illinois, zoning ordinance (Appendix B) illustrates the type of emission standards which can be applied.

The use of performance standards has much in its favor, but it does have some drawbacks which have not yet been overcome:

a. Performance zoning requires extra enforcement personnel with high technical ability. (One suggested solution is to shift the measurement and enforcement costs to the industry.)

b. Some industries are reportedly unwilling to locate in areas where they cannot determine compliance with the standards until after their plants are built.

c. If, after the plant is built, it is concluded that the emission standards cannot be met, local governments are going to be quite reluctant to tell that industry to relocate.

d. The emission standards are usually limited to particulates and toxic matter when , in fact, carbon monoxide, sulfur oxides, oxides of nitrogen, and hydrocarbons may be equally harmful to the health of surrounding households.

e. Since meteorological conditions are not taken into account in setting standards, the actual air pollution impact may vary from plant to plant.

Another important factor is the relationship between performance standards, which are usually administered by planners, and emission codes, which are usually administered by health departments or air pollution authorities. Obviously, a conflict of standards is undesirable. Because source control is so important, it is suggested that planners encourage the proper local authorities to adopt comprehensive emission codes and enforcement programs. If this happens, then the zoning performance standards relating to stationary source emissions should be made compatible or deleted from the ordinance.

For example, under the 1967 Clean Air Act passed by the State of Washington, performance standards are superseded by the rules and standards promulgated by county, multi-county, or regional air pollution control authorities unless the zoning performance standards are more stringent. Furthermore, agreements should be drawn up to describe the mutually supportive roles to be performed by each agency. The most logical approach would be for the health department or air pollution authority to concentrate on obtaining compliance from existing industries while the planning agency concentrates on trying to avoid new problems.

If there is no county or regional air pollution authority or if emission regulations have not been developed, it is suggested that the planning agency amend the zoning regulations to include measurable air emission standards governing the performance of source operation. Such standards should cover all major types of pollutants (i.e., gaseous as well as particulate emission) and should be backed by a well staffed enforcement program. However, if the jurisdiction's inspection office is understaffed or is not able to obtain the expertise required to develop and enforce such standards, it is probably wiser not to venture into this area. As Rutgers law professor Norman Williams observed, "It is a bit fantastic to make a big deal about working out more elaborate planning controls, involving much more complex administration, and then to turn it over to administrative machinery which can't keep track of a copy of the current zoning map."[18] In such a case, the greatest contribution to be made by the planning agency is to build air pollution considerations into the location of industrial areas on the zoning district map and to encourage development of a county or regional air pollution monitoring and enforcement program.

Air Zoning -- Another variation of the zoning power would be to establish restricted areas within which pollution producing industries would not be permitted. Such restricted areas would be based upon evaluation of current ambient air quality, topography, land use, population density, and the atmospheric dispersion characteristics. In Britain, "smokeless zones" have been legislated in order to eventually eliminate aerial wastes within designated areas. In practice this strategy has suffered from highly subjective judgments and difficulties in enforcement. Furthermore, like performance zoning standards, only particulate emissions are regulated. However, it would seem possible to modify the approach so as to broaden the range of pollutants and to provide more objective measures and enforcement programs.

The primary value of this approach is that such zones could be imposed at the regional level as an overlay district, without having to take all zoning powers away from the localities. This makes it much more practical to implement than regional or metropolitan zoning. It would, in most cases, require new state legislation to create both the authority and the organizational machinery to establish, evaluate, and enforce such air quality zones. In effect, this would result in the setting of subregional ambient air standards for critical sections of a region, except that, in this case, the standards would be attached to the authority to exercise the "police power" as it relates to land use.

Even if not carried through to legislative action, the designation of such air quality zones in regional and community comprehensive plans would be of service to public officials. The zones would provide a valuable input to the consideration of zoning amendments and the location of new public facilities.

Power Plants and Airports

Power generation plants and airports also have critical impact upon air quality. Locational decisions regarding these two land uses are required infrequently, but when they are it is important that the planner become fully involved in the consideration of alternative sites.

Power plants are usually the largest single source of sulfur oxides; airports, particularly the new regional jetports, are generators of particulates, carbon monoxide, oxides of nitrogen, and hydrocarbons (concentrations of the latter are being reduced through modification of jet engines).

The location of electrical power plants, which generally consume extraordinary amounts of coal, can be best controlled by making them a "special permit use" or "special exception" rather than by considering them a "use by right" within specific zoning districts. The "special use" approach allows more flexibility in defining the best location and also provides the planning agency with greater control over the location and site planning of such a major land use. Future power plants apparently will be shifting to nuclear fuel but there are still problems of public safety with regard to operation and disposal of nuclear wastes. (See Appendix C)

As with industry, locations should be determined on the basis of good atmospheric and topographic diffusion characteristics and should be downwind from urban development. Buffers are usually of little value due to the wide area affected by power plant emissions. Strict control of new locations, plus public regulation of existing source operations (i. e., fuel conversions, emergency production curtailment, and emission codes) should produce the greatest improvement.

Airports and jetports are expanding rapidly and new locations are being considered in several metropolitan areas. A recent study concludes ". . . it is difficult to escape the conclusion that the expansion of airports to capacities near (100 million) passengers/year will result in a noticeable air pollution problem for large distances downwind from the airport."[19] The control which an urban planner has over public airport location lies more in his planning role than in his administration of zoning regulations. Since the airport is usually a public use, it is generally permitted in any district. Although certain zoning regulations consider airports as "special permit uses," there is often a provision which allows the legislative body to exercise such locational decisions without review by, and recommendation from, the planning or zoning board. Thus, the most important contribution of the planner is in the evaluation of the air pollution aspects of various alternative locations and/or expansions during the early stages of airport improvement studies.

Solid Waste Disposal

With regard to solid waste disposal, the first step is to outlaw open burning. Most states have already done this, but the implementation of these laws can be speeded up through the provision of alternative disposal systems (i. e., landfills and incinerators). Landfills, if well operated and managed offer only small problems in aerial waste generation (dustfall and blowing debris). New incinerators, however, can be major sources and require the planner's attention in considering rezonings and in preparing solid waste disposal plans. The best solution is: (1) advance planning of future sites on the basis of minimizing environmental impact; and, (2) promoting public acquisition of such sites in advance of urbanization so they will be available when needed. Air pollution emissions from incinerators can be reduced somewhat through the use of buffer zones. But again, it must be emphasized that any planning strategy or technique must be accompanied by controls at the source.

2. Relocation of Stationary Sources

Although the principles of industrial location have changed significantly since the early 1900's, there are still large numbers of manufacturing plants located too close to medium and high density residential areas and within low lying basins which do not easily diffuse aerial wastes. Many of these plants also produce blighting influences due to their traffic generation, noise, safety hazards, structural deterioration, and water pollution. Most were constructed prior to the local government's adoption of zoning regulations.

Within most metropolitan areas, these industrial plants expose between 20 and 50 percent of the current population to emissions of particulates, carbon monoxide, sulfur oxides, and hydrocarbons. To complicate matters further, most of the affected persons are in low and moderate income categories and can least afford the cost of relocation, of medical bills for treating respiratory ailments, or the loss of a few days work.

Ideally, the solution would be to relocate these industrial operations to areas where their pollutants would be more adequately dispersed and where there would be few nearby receptors. When this option is approached practically, however, many legal, financial, social, and physical issues arise. How will the neighborhood residents travel to the plant's new location? Can the city afford the tax revenue losses if the plant is relocated in another jurisdiction? Will the industry close down if this additional economic burden is placed on its shoulders? Can the plant, through enforcement of emission standards, be made to reduce emissions to standard levels thus avoiding the need for a move? Does government have a clear legal right to force relocation? All these questions must be answered for each community's unique situation before relocation programs can be formulated and implemented.

Assuming for the moment that the answers to all these questions are positive, how does one go about the task of implementing a relocation program for major stationary air pollution sources? Some combination of the following techniques would be required for relocating major stationary sources:

a. Non-conforming use provisions have been contained in zoning ordinances for years for the purpose of restricting the expansion and the extended existence of land or structural uses which are deemed incompatibly located. Occasionally such provisions have incorporated amortization schedules in order to set time limits for the cessation of non-conforming uses. This is a "venturesome area with few guide-posts."[20] Some state courts have expressed opposition to amortization techniques; where they have been tried, "unpopular" uses such as billboards, gas stations and auto wrecking yards have received most of the attention. Non-conforming use provisions, singularly, do not appear to offer great potential for relocation of sources.

b. Urban renewal projects and planning which precedes them (Community Renewal Programs and Neighborhood Development Programs) could be used to remove incompatible sources within blighted areas. Although most urban renewal programs have chosen to concentrate on clearance of housing and marginal commercial structures, some communities have used either spot clearance or comprehensive redevelopment programs to eliminate small polluting industries which are barriers to the redevelopment potential of the site.

c. Financial relocation incentives appear to be a necessary ingredient in any program for the removal of waste producing industries, either in combination with the zoning and renewal techniques or by themselves. Many inner-city industries do not have the capital to absorb relocation costs and, if incentives are not provided, they may be forced to go out of business. Incentives could take the form of direct relocation allowances or tax credits.

d. Tax equalization or governmental consolidation would be the most important incentive to industrial relocation. Most communities are quite reluctant to force an industry to move for fear that the industry will relocate outside the political jurisdiction, thus causing a loss in property and income tax revenue. It is doubtful then that any substantial relocation could occur until local taxation systems are made less competitive and more responsive to region-wide considerations.

In summary, although it would appear that a substantial portion of our population would be affected by relocating major industrial air pollution sources, the issue is far too interwoven with social, political, and economic factors to show any near-term promise of contributing to air quality improvement.

3. Control of Land Use Around Sources

If it is not possible to locate or relocate stationary sources so that their emissions are diverted from population concentrations (and this is often the case either because of dispersed wind patterns or traditional development patterns), certain actions can be taken to improve the situation through better control of development around the sources.

The following actions could be taken by the urban planner on the basis of his knowledge of ambient air conditions and dispersal characteristics of the areas around such sources.

a. "Exclusive use" districting to prohibit housing and commercial development within industrial zones.

b. Planning and zoning for low density development and limited building heights within the affected areas.

c. Providing buffers around sources in the form of open land (the best filtering effects come from a combination of rows of trees, shrubbery and lawn).

d. Within industrial areas, providing for a gradation of pollution and employment outward from the middle. Industries with the worst pollution could be located in the center; "cleaner" industries could be located on the outside.

e. Within developed areas where conflicts exist:

   1. Preventing increases in population through zoning amendments; and

   2. Conducting redevelopment and spot clearance programs in order to remove dwelling units which are blighted by, among other things, the presence of air pollution.

Concerning the value of buffers, around sources, it is important to recognize the variability of their impact. Their value increases in direct proportion to the amount of source control of pollution that is effected. For instance, a study was conducted in Chicago which estimated diffusion effects on two gray iron foundries. Diffusion effects from foliage and structures were ignored. Uncontrolled and 75 percent controls were calculated for both plants; 95 percent controls were also calculated for the larger unit. (The smaller unit was rated at 10 tons per hour, while the larger foundry was rated at 25 tons.)

> "At low or high wind speeds a buffer zone around an uncontrolled foundry would have to be unrealistically large to satisfactorily reduce downwind ground concentrations of particulate matter. With 75 percent controls for the smaller (unit) a buffer 2,130 feet deep would bring concentrations outside the zone below 100 micrograms per cubic meter. With an 82 foot stack, the plant would have to be centered on a site totalling some 400 acres. With 95 percent control of the larger unit, concentrations at any point downwind would not go above the 100 microgram mark."[7]

Through control of peripheral development around sources in a manner which more sensitively incorporates air pollution considerations, a large part of the effect of aerial wastes can be reduced for a large number of people. Furthermore, the techniques described here, for the most part, are within the range of feasibility.

4. Location of Sensitive Receptors

In planning the land use patterns near emission sources, it is important to pay special attention to areas to be used by sensitive receptors: the young, elderly, and sick. Although no specific distance standards are available, the following land uses should be kept remote from emission sources:

a. Elementary and secondary schools.

b. Intensely used recreational facilities, especially outdoor play areas.

c. Orphanages and children's homes.

d. Elderly housing facilities, senior citizen centers, and nursing homes.

e. Hospitals, clinics, medical centers, and rehabilitation centers.

The techniques for properly locating these land uses include zoning regulation, the A-95 review of federally assisted projects (health facilities and housing projects fall under this review), and close coordination with school administrators and recreation officials regarding advance planning of their site acquisitions. Where facilities within areas of poor air quality are impossible to avoid, either because they are there now or because such facilities have to be in close proximity to the neighborhood residents, improvements can perhaps be made to the site, the buildings, or the facility's operation (i.e., installing central air-conditioning, scheduling outdoor activities at non-peak hours, providing landscaped buffers, etc.).

5. Location and Design Control of New Towns

The Urban Growth and New Community Development Act of 1970 is now encouraging a great deal of new town development activity. At last count, "public and private developers from 23 states and territories have demonstrated substantial interest in building new communities . . . ."[21]

Several new town projects are already under construction and indications are that the trend is just beginning to pick up momentum. The National Committee on Urban Growth recommends the creation of 100 new communities with 100,000 persons each and ten new cities of at least one million persons each. This would account for about 20 percent of this country's urban growth between now and the year 2000, but the financing required to make this happen is still a major obstacle.[22] However, even looking at the new town potential with a more conservative eye, it would seem possible that between 5 and 10 percent of metropolitan growth could be attracted to new towns built either as satellite communities or as new towns in-town.

New town location and design will be important factors in improving the quality of urban life; more specifically, they will offer the urban planner the opportunity to more effectively deal with the air pollution problem.

First, the location of new towns offers an opportunity to more carefully place an entire community with regard to optimal diffusion characteristics. As was pointed out in the discussion of open space strategies, the separation of communities or subregions by large amounts of green space (as would be the case in many new towns) is an effective strategy. Furthermore, a new town can be situated with better regard for wind direction and speeds.

Second, through careful consideration of the new town's internal design it is possible to reduce the effect of locally generated airborne wastes. This can be accomplished through better location of stationary sources, the use of internal open space, the design of traffic/land-use relationships, and the reduction of trip lengths and auto reliance.

Even if new towns are not successful in diverting large numbers of households away from the more conventionally developed suburbs and central cities, they have a large contribution to make in the area of experimentation and demonstration. New techniques of reducing air pollution and its impacts can more easily be tested in new developments and, if successful, then applied to the cities. For example, in France, a new city, Vaudreuil, is being planned for the lower Seine region outside Paris. The city will provide housing and employment for up to 150,000 residents. The design will utilize new technology to eliminate as much noise and air pollution as possible. Among the concepts under consideration are routing of traffic through underground passages and tunnels, carrying smoke from factories in underground conduits, burning gases off at the source, and processing refuse to supply part of the city's central heating. The U.S. Department of Housing and Urban Development, together with other U.S. agencies, will make technical contributions to the French effort. The results of such innovative demonstrations will have great significance for our existing cities.

Urban planners can exert influence on the location and design of new towns through land use controls (zoning, subdivision regulations, special new community zoning districts, etc.), the encouragement or discouragement of such developments through the location and type of governmental capital facility investments, and the review of new community applications for Federal financial assistance (guarantees, loans and grants). Professionals and lay boards at all levels of planning (state, regional, county and local) can play a role in encouraging and guiding new town developments.

6. Planned Unit Developments

For many of the same reasons related above, except on a smaller scale, urban planners should encourage more innovative approaches to land development. In most cases planners are already providing such encouragement and are revising land regulations to allow more flexibility for development concepts such as planned unit development, cluster subdivisions, and density zoning. Such development forms will increase convenience and thus reduce trip length. Equally important, however, is the fact that such concepts permit the preservation of buffers and open spaces between emission sources (principally roads) and residences.

Most planned unit developments created thus far tend to be predominantly residential. However, the same concepts of design flexibility and mixing of land use types apply to the development of multi-use centers. A multi-use center (MUC) may be described as a concentration of living, working and shopping land uses that are physically integrated by internal pedestrian systems.[23] The air pollution abatement contribution which an MUC can make lies in the significant reduction in trip lengths and the reduced need for automotive travel between the contained activities.

The Twin Cities Area Metropolitan Development Guide calls for 20 "diversified centers," essentially the same as MUC's, as part of the 1985 Constellation Cities Plan. Figure 2.5 represents such a diversified center. The unified architectural complex would house commercial facilities, offices, high-rise apartments, public facilities such as a hospital, and perhaps a college with easy pedestrian access. A metropolitan transit line would feed directly into the center, which would also be connected to the nearby freeway by its own interchange. An industrial park (upper left) would be located nearby to share in many of the public facilities and services, such as mass transit, required by the diversified center. Parking closest to the center's facilities is accommodated in structures; more distant parking is accommodated on surface lots.[24]

Although Figure 2.5 portrays an MUC for a suburban area, the concept can be, and has been, applied within central cities (e.g., downtown Montreal, Baltimore's Charles Center, and Philadelphia's Penn Center) and new towns (e.g., the Vallingby Town Center and Reston's Lake Anne Village Center). The development of suburban regional shopping centers, however, appears to be the greatest opportunity for creation of multi-use centers. Many shopping centers stimulate an intense development pattern around them but, because the surrounding land has not been planned and controlled comprehensively, they generally fail to generate the advantages of an integrated MUC. Such centers should be complementary to existing central business districts in large urban areas where there is a need to accommodate growth. The techniques through which new, more convenient land use forms can be created include:

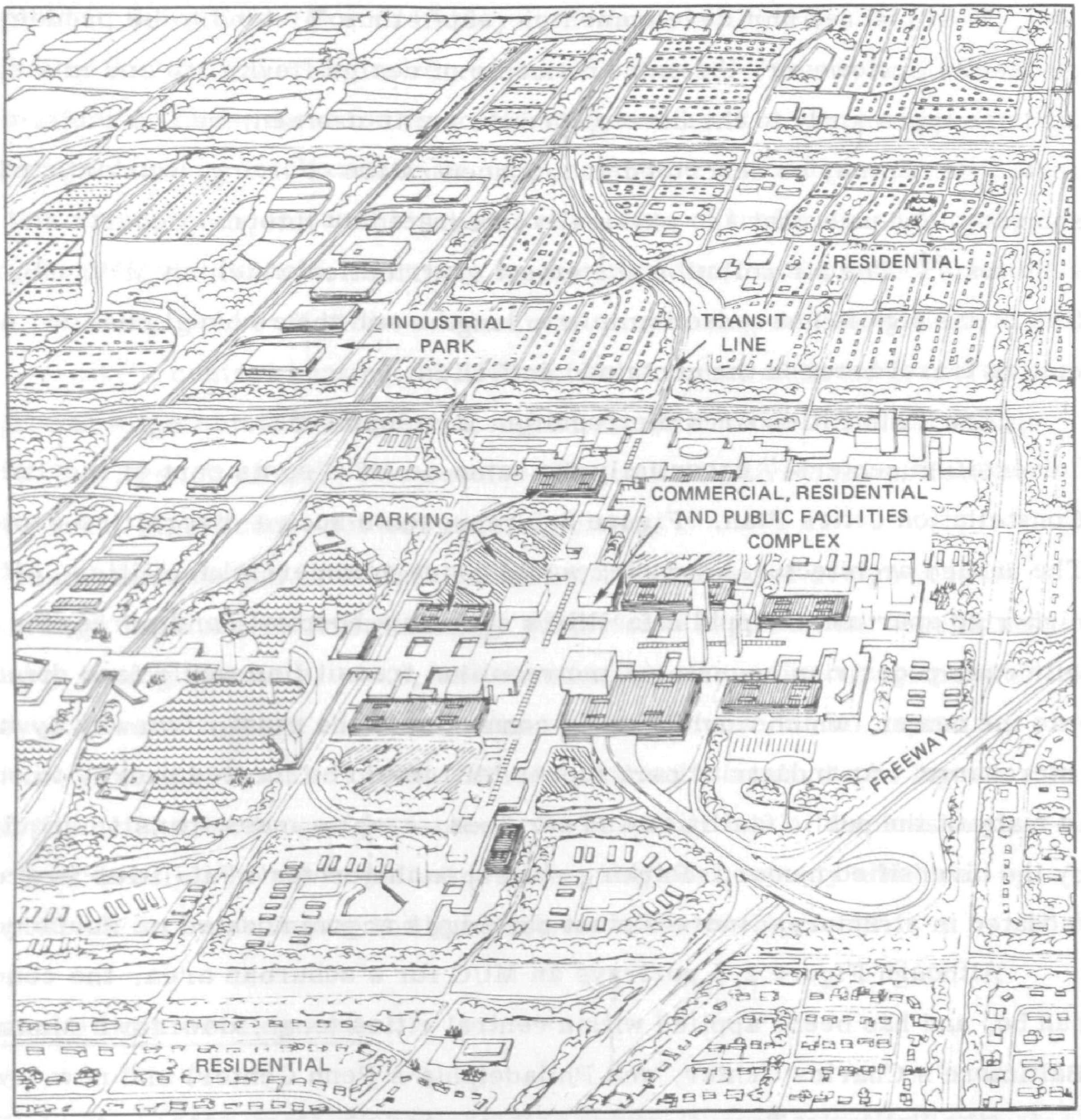

Figure 2.5 Prototype Multi-Use Center[24]

a. Broadened planned unit development regulations which make all large commercial, industrial, and residential developments subject to site plan review and conditional approval agreements.

b. Urban renewal planning and project implementation,

c. Detailed planning studies, designed to pinpoint the best locations for multi-use centers, that define alternative ways of stimulating their development.

7. Small Open Spaces

The impact of open space upon air pollutants is ill defined and somewhat non-quantifiable at this time. General consensus is that open spaces and buffers must be quite large in order to perform an adequate diffusion function. However, Figure 2.6 indicates that small buffer corridors along roadways could have a dissipating effect on automotive carbon monoxide

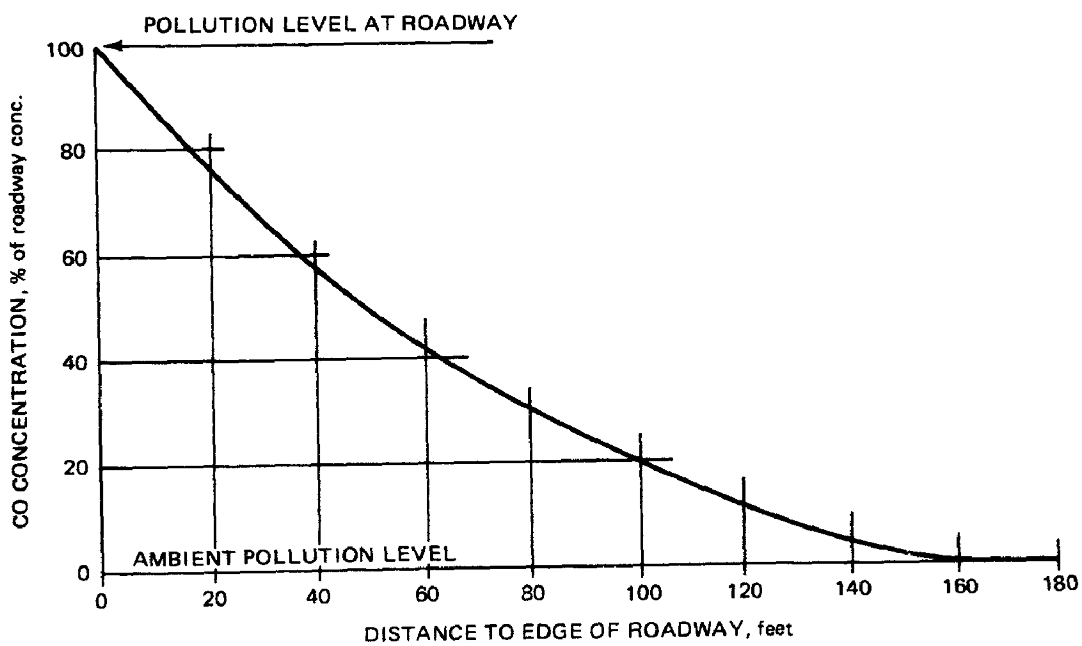

Figure 2.6 Pollution Level Vs. Distance to Edge of Roadway[25]

emissions. If developments were kept away from the roadway edge a reduction could be obtained in carbon monoxide concentrations. The placement of plant materials within that buffer could further increase the dispersal of pollutants and the protection of nearby residences. Although research has not been done in this area, the fact that trees and other forms of vegetation create some air turbulence and produce more humidity which can trap particulates appears to justify the creation of small open spaces.

The urban planner can contribute to the creation and preservation of these small open spaces by:

a. Developing regulations for requiring developers to provide land for parks or cash in lieu of the land.

b. Encouraging and guiding planned unit development.

c. Providing subdivision site plan reviews.

d. Expanding the right-of-way standards for thoroughfares.

e. Requiring larger setbacks.

f. Instituting beautification and roadside landscaping programs.

g. Developing tree preservation regulations.

CHAPTER 3

REDUCING AIR POLLUTION THROUGH TRANSPORTATION PLANNING, DESIGN AND OPERATIONS

In dealing with air pollution at both the regional and local levels, it is important to recognize the significance of transportation facilities in urban planning. Pollutant concentrations caused by vehicular traffic, or "line sources," accumulate along high-volume freeways and arterials and are widely recognized as severe health hazards.

One of the major questions involves the allocation of resources to achieve the goal of developing a rapid and convenient transportation system which may be in conflict with the goal of preserving a clean air environment. There are a number of feasible transportation alternatives, however, which may have varying levels of environmental impact.

Both the role of the urban planner and the highway designer should be concerned that the transportation plan, design, and operational alternatives selected are sensitive to air quality criteria. Because transportation facilities influence land uses, and vice versa, there is a high degree of interrelationship in these functions.

Recent Federal legislation has underscored the urgency of integrating transportation planning and pollution reduction programs. The Federal-Aid Highway Act of 1970 specifically indicates that Federal air quality standards be observed in the construction of highways. It states:

> "The Secretary, after consultation with the Administrator of the Environmental Protection Agency, shall develop and promulgate guidelines to assure that highways constructed pursuant to this title are consistent with any approved plan for the implementation of any ambient air quality standard for any air quality control region designated pursuant to the clean air act as amended."[26]

This section of the Guide deals with the transportation planning approach toward reducing air pollution. Suggested techniques are offered to the planner who is attempting to incorporate air quality criteria into the planning process.

A. TRANSPORTATION SYSTEM PLANNING STRATEGIES

Among the methods available to the planner are several which offer a number of alternatives or combinations of alternatives, including consideration of: decreasing highway travel by expanding transit use; improving route location planning for new highways and the configuration of existing roadway networks; developing compatible highway/land-use relationships.

1. Multi-Modal Planning

One important way in which the planner can approach air pollution reduction is by developing plans which may tend to decrease highway travel through expanded transit usage. Strategies which call for wider use of mass transit, including commuter rail, rapid transit, and buses should be investigated and advocated where appropriate. Substitution of bus or rapid rail transit for automobile travel can reduce hydrocarbon, carbon monoxide, and nitrogen oxide concentrations.

The simulation described below was conducted to investigate the metropolitan significance of mode choice and urban development for pollution reduction.

Travel patterns were simulated by computer for a hypothetical 625 square-mile metropolitan area of two and one-half million people, under varying assumptions about urban patterns, highway networks, and transit networks.[27] Figure 3.1 illustrates the varying assumptions used in the analysis. Eight different urban patterns were investigated. The spatial allocations of population and employment investigated included:

- Sprawl
- Moderate corridors
- Heavy corridors
- Corridors rotated
- Extreme corridors rotated
- Satellite cities
- Centralized employment, sprawl population
- Centralized employment, radial population.

Four highway networks were examined:

- A basic arterial grid
- Freeways along major arterials
- Major radial freeways with an outer beltway and inner loop added
- Additional radial freeways and an inner beltway added for maximum coverage.

Three basic transit networks were examined:

- A basic bus network with express bus service
- Rapid rail along major radials with bus service
- Relocated rapid rail service and an outer rapid rail loop.

A series of alternatives was then constructed consisting of a land use-highway-transit arrangement; work travel patterns were simulated to arrive at estimates of work trip length, average network speed, and transit usage.

Analysis of the data indicated that the Satellite City Concept with the maximum transit network and basic arterial highway system yields the minimum length in miles. Transit usage is maximized by centralizing employment and increasing urban densities in radial corridors.

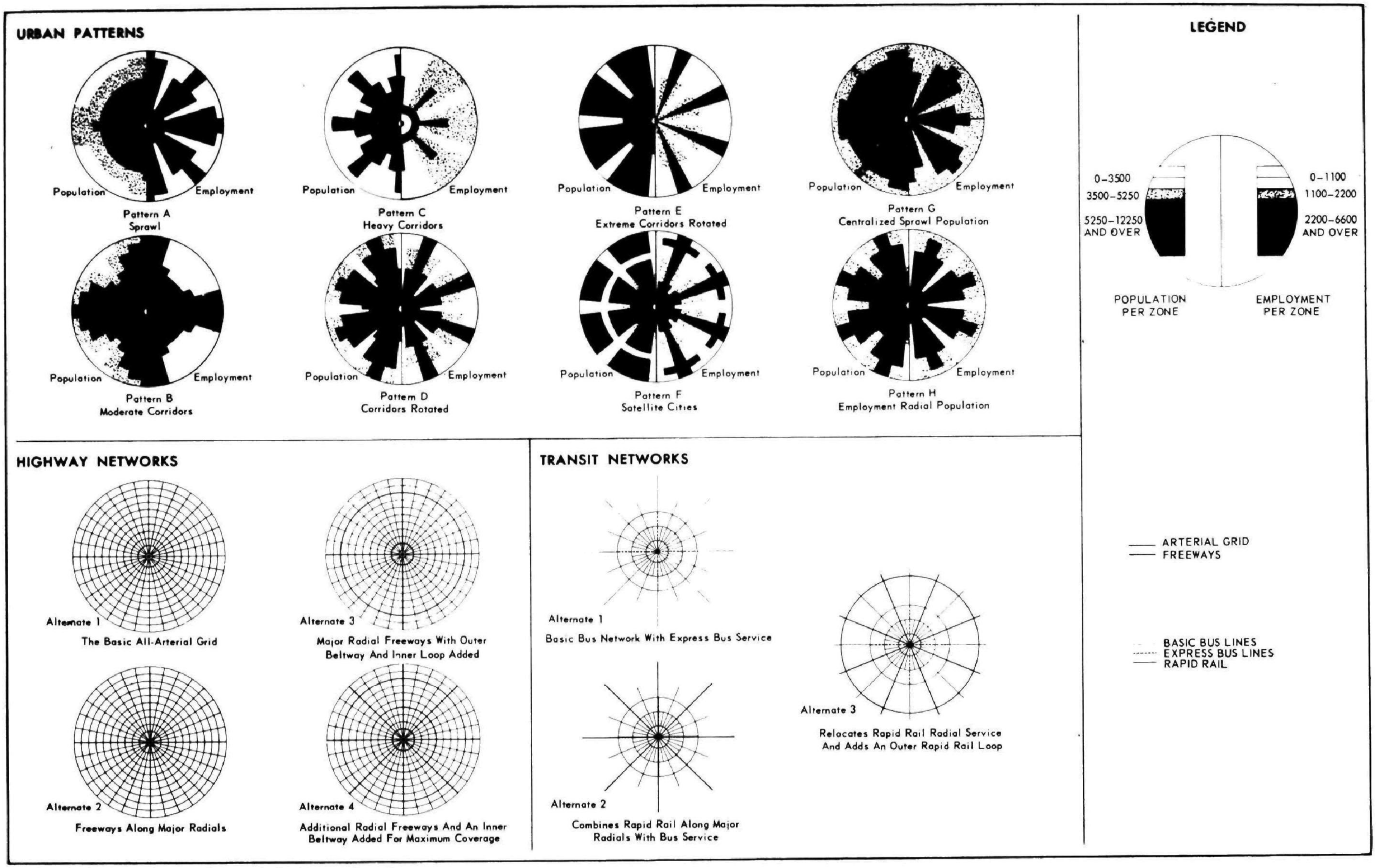

Figure 3.1 Description of Urban Forms and Transportation System Simulation Study[27]

These simulated changes in trip length, speed, and transit usage indicate the substantial advantages of expanded transit operations in the center city. Improved transit service and corridorization help increase transit usage for work trips and reduce air pollution during the peak period. Figure 3.2 illustrates the effect of improved transit service on modal split and air pollution reductions taking into account distance from the Central Business District (CBD). Transit System 2 represents an improved level of transit service over Transit System 1, thereby diverting riders from automobiles and causing a reduction in automobile emissions.

The effect is to reduce air pollution from 18 percent in the CBD to one percent in the periphery of the hypothetical city. At a distance of four to five miles from the CBD there is a significant reduction in automobile air pollution as a result of the improved transit service.

Other studies of modal split have indicated similar findings. In the Twin Cities area, for example, the regional air pollution impact of transit was negligible.[28] However, the positive effects (air pollution reductions) in the downtown area were considerable. Auto use during peak hours could be reduced by about 13 percent by 1985 in and within about two miles of the downtown area as a result of substantially improved express transit. Automotive pollution in these critical areas could be expected to be reduced by a similar amount.

Conclusions which have emerged from studies in the metropolitan Chicago area indicate the influence which shifts to transit have upon air pollution concentrations. The Skokie-Swift mass transit demonstration project was opened in the Chicago area early in 1964 under the joint sponsorship of HUD, the Chicago Transit Authority, and the Village of Skokie to provide improved CBD access for suburban residents.[29, 30] As a result of this operation, auto trips declined by approximately 2000 trips per day, creating an estimated reduction in airborne hydrocarbons of 13 percent.

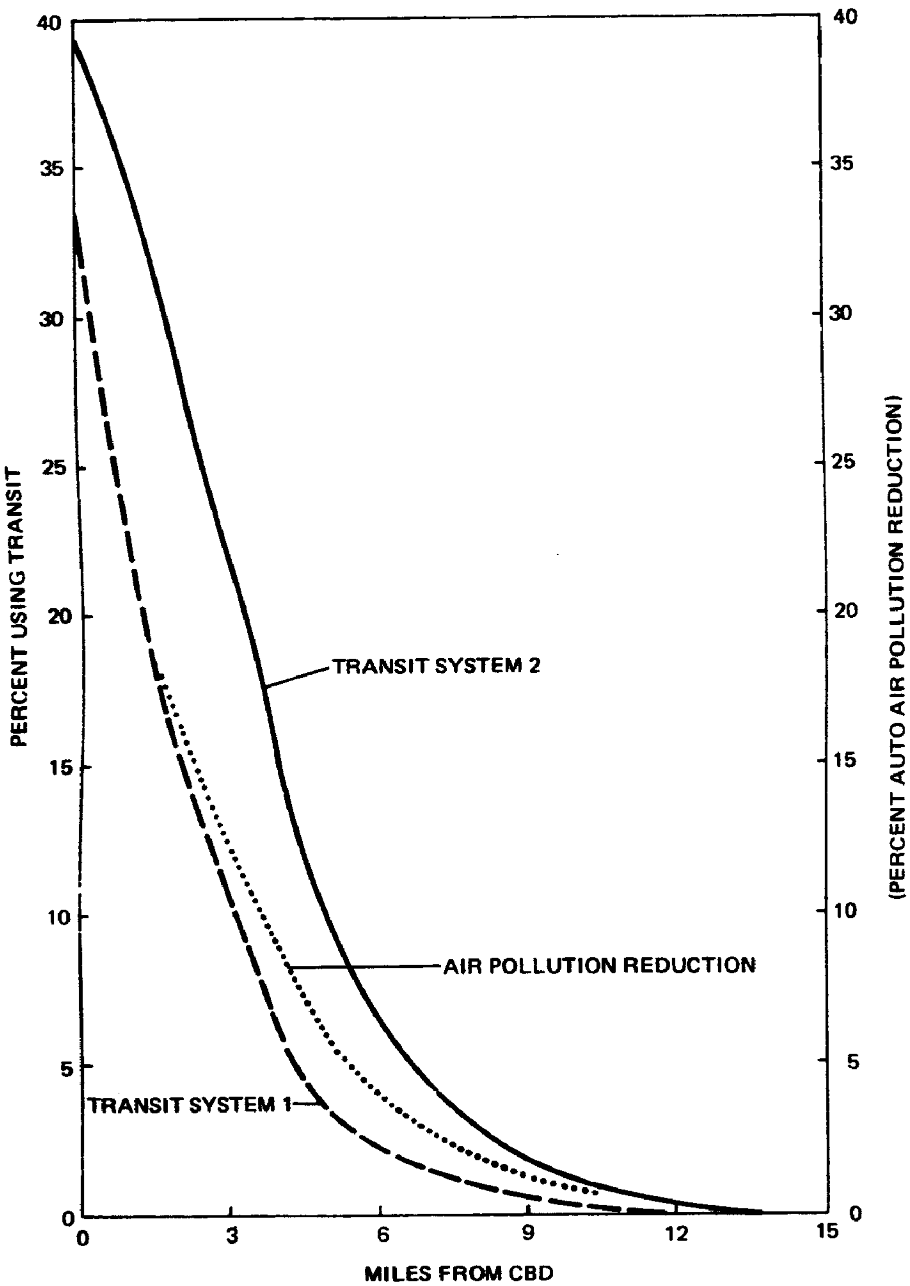

Figure 3.2 Effect of Improved Transit Service on Modal Split and Air Pollution in a High Density Corridor[27]

Transit improvements and associated policies which result in higher transit ridership levels may result in reduction of pollutant concentration. However, a policy of high density corridorization to support transit as described above can conceivably be self-defeating with regard to reduction of pollution if other urbanization effects contribute to air pollution levels. It should be noted that transit, particularly rail rapid transit, is not a singular panacea for transportation and air quality problems. All elements of the transportation and urban plan must be jointly evaluated.

2. Improved Highway Location and Network Configuration

In considering alternative highway systems, the planner should consult with the local air pollution control office. A planning framework should be devised within which pollutant concentrations associated with various highway alternatives can be predicted. Based upon such a framework, planners could determine impacts with regard to location and capacity.

In conjunction with conventional travel forecasts, total emission rates of various pollutants can be determined from individual automobile emissions. However, methodologies are needed to translate such traffic estimates into anticipated pollutant concentrations at various distances from the highway and under varying meteorological and topographical conditions. Dispersion modeling techniques need to be more effectively implemented to provide this information. Armed with such data, the planner can consider the impact on adjacent land uses in accordance with expected pollutant behavior.

A suitable planning framework has been suggested by Schneiderman et al., in the form of proposed legislation.[31] It would require the assembly of data which comprehensively describes the pollution effects of a proposed highway facility. The suggested framework is:

1. State highway departments shall obtain and consider the following information in considering the air pollution effects of the proposed location:

1) Estimated future concentrations of each of the following substances measured at intervals of 50 feet horizontally and vertically from the center line of the proposed highway to a distance of 2500 feet from the center line:

   (a) carbon monoxide
   (b) oxidants
   (c) nitrogen oxides
   (d) hydrocarbons
   (e) asbestos
   (f) lead
   (g) particulate matter.

   Such estimates shall be based on estimates of traffic contained in FHWA Form PR-1, and shall employ the method set forth for estimating diffusion from line sources in D. Turner, <u>Workbook of Atmospheric Dispersion Estimates</u> (Public Health Service Pub. No. 999-AP-26 1967). Such estimates shall be made for the various climatic conditions prevailing in the area throughout the year on a 24-hour, 8-hour and peak hour basis.

2. Existing concentrations of pollutants for each 50 foot interval shall be made for the proposed route of the highway. Such measurements shall be made under the various climatic conditions prevailing in the area throughout the year and shall be made on a 24-hour, 8-hour and peak hour basis.

3. Existing average concentrations and estimated concentrations after construction of the highway of each of the pollutants listed in section (1) for the metropolitan area as a whole and for each geographical subregion of the metropolitan area through which the proposed highway will pass.

4. Existing land use in each 50 foot interval for which estimates and measurements are made under subsections (1) and (2) and land use shown on any official regional or metropolitan plan.

5. The most recent medical and scientific research of the effects upon humans, animals, vegetation, and property of the estimated concentrations of the substances at each 50 foot interval.[31]

This framework is discussed only to indicate a satisfactory level of comprehensiveness for highway pollution data. Particular requirements and standards utilized would have to be coordinated with local ambient air quality standards. Using a similar procedure, an analysis of the proposed Lower Manhattan Expressway undertaken by the New York City Department of Air Resources revealed that excessively high carbon monoxide conditions would have resulted.

Thus, the first step in highway pollution reduction for new facilities would be the structuring of a planning process which estimates pollution impact. The implementation of such a procedure may influence highway air pollution impact in three ways:

a. Proposed facilities with high emission potential might be diverted from sensitive areas.

b. Proposed facilities might be reconsidered in favor of a less hazardous alternative.

c. Land adjacent to the proposed highway can be planned in accordance with anticipated pollution levels.

Highway exhaust emission studies are unlikely to result in any significant pollution impact reduction in the short run. However, over the long term and in conjunction with sound land use planning, a substantial percentage of new development may be expected to be relatively free from excessively high automobile pollutant concentrations.

Decisions regarding the type of metropolitan transportation network or the relative traffic loads on freeways versus arterials, or the merits of constructing new roadway links versus improving existing ones are of significance to the goal of air pollution reduction. However, establishing guidelines for such network decisions is quite complex and will depend to a large extent upon the particular area and its travel characteristics. Among the goals to be considered are network configurations that:

a. Reduce trip length and total automobile travel.

b. Move traffic at faster and more consistent speeds.

c. Support the expanded use of transit.

d. Do not induce large amounts of new traffic to enter congested areas.

Generally, an increase in average network speed decreases carbon monoxide and hydrocarbon emission rates per vehicle mile. Figure 3.3 shows emissions per vehicle mile versus average network speed in miles per hour for two major air pollutants, carbon monoxide (CO) and hydrocarbons (HC). These relationships, combined with travel simulation information, make it possible to identify the effect of different transport networks on exhaust emissions for similar urban patterns.

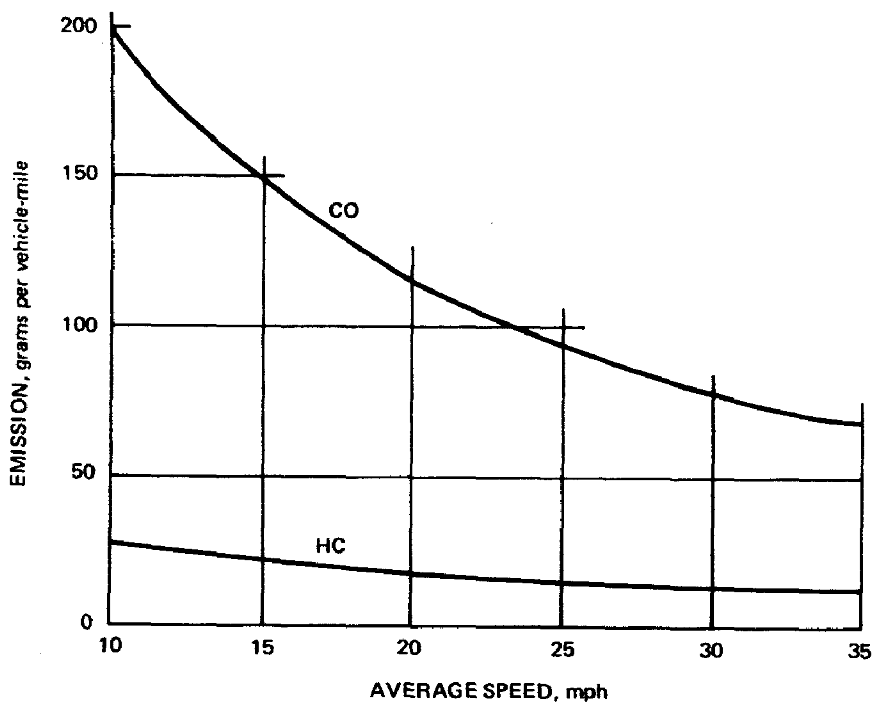

Figure 3.3 Relationship of Carbon Monoxide and Hydrocarbon Emissions to Speed[32]

Nitrogen oxide emissions increase with higher air/fuel ratios, compression ratios, and engine temperatures. The relationship between nitrogen oxide emissions and vehicular speed is not so well established.

It was found in the simulation study[27] described at the beginning of this chapter that highway network alternative 4 (see Figure 3.1), additional radial freeways and an inner beltway for maximum coverage) provided the best overall reduction in carbon monoxide and hydrocarbon emissions essentially because of its increased average speed. It should be noted, however, that the increase in speed is facilitated by the lower density of the sprawl and heavy corridor configurations which were tested. Urban planners should give close attention to this trade-off relationship between trip length and average travel speed (i.e., trip length and travel speed tend to be inversely proportional) since it will vary from city to city, depending on various land uses and travel behavior.

A new high-speed highway will tend to induce new automobile traffic to enter the city, possibly negating emission reductions due to higher average speeds. (For a discussion of "induced" travel demand see reference 33.) Even though a new road may merely divert traffic from other links, the resulting higher pollution concentrations may be serious. The outputs of certain pollutants from a highway may be exceeded by the total outputs from a number of arterials; but the highway, as a single line source of concentrated pollutants, exceeds the emissions from any one of the arterial streets.[31]

However, it must also be recognized that streams of slow moving vehicles may, under certain meteorological conditions, produce extremely high pollutant concentrations in arterial street canyons. If adjacent regions are heavily populated, the impact may be great enough to outweigh the highway effects noted earlier. Such network configuration decisions are complicated and vary among specialized situations, but it is essential that the planner incorporate all these considerations in order to achieve the maximum reduction in air pollution.

3. Compatible Highway/Land Use Relationships

A general approach to the reduction of pollution impact is through the regulation of joint corridor development and land uses adjacent to rights-of-way. If a highway has been determined to be absolutely necessary, then it remains for the planner to ensure that receptors are sufficiently removed from the area of high pollutant concentration.

In a study soon to be released, the General Electric Company performed comprehensive air quality monitoring in area adjacent to highways. The results of this study should substantially improve our knowledge of the basic factors related to air quality and automobile emissions. Also the District of Columbia Department of Highways is sponsoring a project to investigate the concentrations of carbon monoxide adjacent to freeways.

Buffers between major roadways and resident locations are a most effective technique for improving the compatibility of those roadways as shown in Figure 2.6. Automotive carbon monoxide emissions dissipate by about one percent for each of the first 50 feet of distance from the roadway edge. Furthermore, carbon monoxide concentrations approach background level at a distance of 160 feet.

One way to achieve this buffering is by utilizing legal provisions to include extensive adjacent land during the process of advance right-of-way acquisition. Depending upon comprehensive projections of pollutant behavior, state highway departments can adopt land acquisition policies which provide for buffer strips of variable width. However, the most effective buffer strips are quite wide, and extensive acquisition of property for this purpose may conceivably meet with legal opposition if conventional standards of "public use" are observed. This would especially be true if right-of-way acquisition involved massive relocation or displacement of property for which there is a great deal of political sentiment.

But new highway development within less developed areas is unlikely to create such a conflict. Furthermore, there appears to be adequate allowance in the law for acquiring buffer property, if the objectives of the project contribute reasonably to public health, safety, or welfare. Some state courts consider such a public use test satisfied if formal commitments are secured, assuring that such projects will not be resold or diverted from public use for a stated period.

A number of state constitutions now allow the taking of land for suitable building purposes on either side of a highway. Other states have passed statutes allowing the acqusition of entire lots even though only a portion of the lot is needed for the highway.

In the long term, therefore, it would be possible for the planner to legally ensure adequate buffer space during the process of right-of-way acquisition. This land could then be reserved for planted open space or left vacant. An additional advantage of such a strategy is the uniformity of administrative control over the land. Rather than being subject to the conflicting goals of perhaps several jurisdictions, an entire highway corridor would be under the control of a state highway agency.

Through the administration of subdivision regulations, it is also possible for local governments to increase their right-of-way standards for public acquisition projects and land-owner dedications. The goal of pollution impact reduction coincides with numerous other planning justifications for increased right-of-way widths (the encouragement of frontage roads so that access can be channelized, the reduction of highway traffic noise, and the flexibility for future widening and traffic flow improvements).

Regulatory control of corridor land uses in developed areas is another method of reducing pollutant impact. Devices such as municipal setback requirements and corridor zoning can be utilized to achieve such control. Objectives of using this kind of regulatory approach would be to impose selective limitations upon both commercial strip development and proximity of inhabited structures to highways.

Corridor zoning has been applied chiefly to protect the highway environment by controlling abutting land use. But if applied with respect to new highway development at the state or Federal level, it could become a useful device for reducing pollution impact.

Zoning ordinances have been only moderately successful in providing effective district controls for highway corridor land. One remedy might be for Federal agencies to encourage uniform corridor development regulations through preparation and dissemination of model regulations. A more promising Federal or state action would be to require the existence of local controls which prescribe setback distances for various land uses and highway classifications. Setbacks would be based upon sensitivity of the particular land use to air pollutants, current and forecasted traffic volumes, and local dispersion characteristics. Certain highly sensitive receptors such as hospitals, senior citizen housing projects and schools would be prohibited from close locations. Making such regulations a condition of qualification for Federal and state fund allocations would possibly stimulate responsive local action.

As pointed out earlier, the presence of plant materials within buffer strips can increase the dispersion of emission. More sensitive treatment of existing woodlands as well as increased and improved post-construction landscaping would be wise practices for highway departments. Urban and transportation planners can work toward improved landscaping through local zoning provisions which call for buffers, through the conduct of route studies and through A-95 reviews of corridor location plans and design plans.

Another point which must be considered by the planner is the regulation of joint development and multiple uses of highway rights-of-way. Many planners feel that joint projects involving transportation rights-of-way offer great potential for integrating land use and transportation systems, minimizing negative effects from freeways, opening up the limitations on buildable space, and innovative urban designs. Joint-use projects may include land within the right-of-way and may also be developed using the airspace both above and below highways.

Although the joint development approach reduces many of the environmental impacts caused by highways, it can also magnify air pollution problems. Numerous studies have shown that locating inhabited structures such as the George Washington Bridge apartments in close proximity to highway facilities is likely to result in an unsatisfactory air quality situation.[31] Not only will excessive concentrations accumulate within the buildings themselves, but the increased urban density results in more intense traffic conditions and more exposure of people to the pollutants. In the process of designing or reviewing joint development projects, the planner should pay particular attention to improving the dispersion of pollutant concentrations.

B. TRANSPORTATION DESIGN AND OPERATION TECHNIQUES

In addition to benefits to be derived from general transportation planning, many benefits can be derived from small scale facility design improvements and operational changes. These measures encompass the following means of reducing harmful exposure to air pollutants:

- Smoothing the flow of traffic
- Reducing concentrations of traffic, both geographically and by time of day
- Reducing the total amount of automobile travel.

The Guide for Reducing Automotive Air Pollution, a companion document oriented toward transportation and traffic specialists, discusses a number of techniques. All have been previously used or at least proposed in the context of improving the capacity and quality of the urban transportation system. The following discussion of techniques at the design and operational level is a summary of the above-referenced guide, and that reference should be consulted for more detailed information.

1. Techniques for Improving Traffic Flow

Carbon monoxide and hydrocarbon emissions increase with congested traffic and decrease with freely flowing traffic. If the objective is to reduce carbon monoxide and hydrocarbons, any measure that would smooth the flow of traffic by reducing rapid acceleration and deceleration of vehicles would be beneficial. Some techniques for accomplishing this are listed below. The reader should clearly understand, however, that easing congestion may have ancillary effects that would tend to undermine the goal of cleaner air. The relationship between increased travel speed and increased trip length has been established.[27] Furthermore, a reduction in congestion may tend to induce more people to drive. If no steps are taken to reduce auto travel, the net result of improved traffic flow might be more, longer, and more dispersed trips with greater amounts of pollutants spread over a wider area. Thus, it is strongly recommended that other measures set forth below be used concomitantly with improved traffic flow techniques to reduce the overall number and length of automobile trips in urban areas.

Each technique listed in Table 3.1 for improving traffic flow is rated according to its "probable effectiveness," using a scale of 1 (least effective) through 5 (most effective). While it is impossible to place a precise measure of effectiveness on each technique, there is sufficient knowledge to assign an approximate value. The effectiveness ratings are

TABLE 3.1

TECHNIQUES FOR IMPROVING TRAFFIC FLOW

		Probable Effectiveness
A.	Freeways	
	1. Reverse-lane operations	3
	2. Driver advisory displays	1
	3. Ramp control	2
	4. Interchange design	2
B.	Arterials	
	1. Alinement	1
	2. Widening intersections	3
	3. Parking restrictions	2
	4. Signal progression	2
	5. Reversible lanes	3
	6. Reversible one-way streets	3
	7. Helicopter reports	2
C.	Downtown Distribution	
	1. Traffic responsive control	5
	2. One-way street operations	3
	3. Loading regulations	3
	4. Pedestrian control	1
	5. Traffic Operations Program to Increase Capacity and Safety (TOPICS)	5

based on traffic volume affected, pollution reduction, population exposure, and any adverse pollution affect (e.g., more or longer trips likely to be induced, or likely to cause traffic congestion). The techniques apply to the following areas:

a. Freeways -- Freeways have been the subject of numerous operational studies and experiments. As a result, the techniques for improving traffic flow on freeways are relatively well developed.

b. Arterials -- Arterials are the backbone of most urban street systems. Quite often, however, these systems are unsuited for modern traffic demands and have received less attention during recent years.

c. Downtown Distribution -- The downtown transportation system is probably the most complex component of the urban road system. From a functional viewpoint, the nature of the downtown street system is largely circulatory -- designed to serve adjacent land uses -- with the level of service to through traffic being of secondary concern. Traffic flow is interrupted frequently by pedestrian movements, vehicle turning conflicts, traffic signals, and a high number of stop-start transit vehicles in the traffic stream. A major portion of vehicle time is spent idling, accelerating, and decelerating, the result being a relatively high level of air pollutant emissions. Any operational techniques that can improve the stop-start nature of downtown traffic flow can significantly reduce air pollution levels. Due to high daytime population densities in the downtown area, reduction in air pollution levels can benefit a relatively large percentage of the population.

Although the application of these traffic-flow improvement techniques lies basically with traffic engineers, it is important that the planner be aware of them. Furthermore, there are several techniques that the planner could use directly in the administration of a planning program. For instance:

a. Central business district planning efforts should use these techniques for improving downtown traffic and pedestrian movement.

b. Zoning ordinances should regulate loading operations.

c. Planners who have a role in preparing a TOPICS (Traffic Operations Program to Increase Capacity and Safety) program should be increasingly sensitive to its pollution-reduction payoffs.

2. Techniques for Reducing Pollution Concentration

The utilization and design of highways can be effective in reducing the air pollution concentrations in the ambient air. If peak-hour traffic concentrations were reduced by distributing traffic over a larger area and over a longer period of time, that air space available to disperse pollutants would be greater. Also, good design can imporve the operational characteristics of the transportation system and thus minimize the concentration of air pollution to which people, plants and structures are exposed. Concentration reduction techniques and their probable effectiveness are listed in Table 3.2

TABLE 3.2

TECHNIQUES FOR REDUCING POLLUTION CONCENTRATION

		Probable Effectiveness
A.	Staggered Work Hours	3
B.	Roadway Concentrations	2
C.	Cross-sections	2
D.	Elevated, At-grade, Depressed Roadways	2

A possible means of reducing peak-hour demands is to spread travel over a longer period of time by staggering work hours. Staggered work hours were first used in the United States during World War II, when approximately 60 cities used the idea to alleviate the critical problem of mass transportation capacity shortages. All cases achieved some degree of success; many cities reduced peak period travel demand by as much as 30 percent. A more recent experiment in lower Manhattan[34] has shown a changed pattern in peaking characteristics. Figure 3.4 indicates the effects for the afternoon peak of staggered work hours at the Port of New York Authority Hudson Terminal.

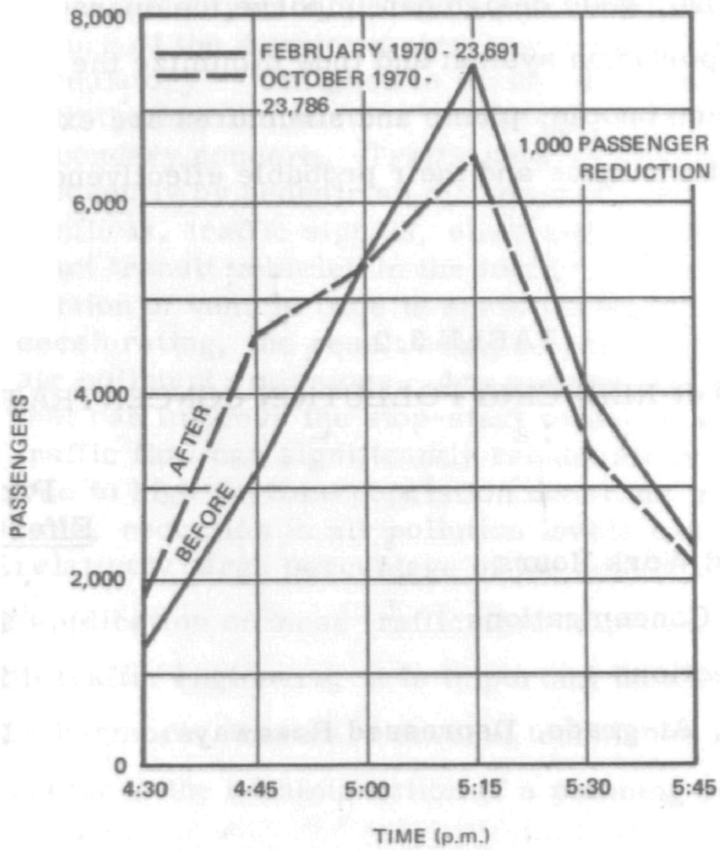

Figure 3.4 Effects of Staggered Work Hours, Hudson Terminal Afternoon Passenger Volumes[34]

The decision to design a new highway as an elevated, at-grade or depressed facility can have a major effect on its air pollution impact. Arguments in favor of depressing highways in urban areas usually point to reduced neighborhood disruption and noise. These arguments may be valid, but depressing a highway affords little opportunity for local wind currents to disperse the emissions. Thus, the motorists traveling on a depressed highway, as well as persons in adjacent areas, may be exposed to unusually high concentrations.

Elevated highways, on the other hand, promote rapid dispersal of pollutants away from the motorist. By virtue of being elevated, they are more exposed to wind currents which transport as well as disperse pollutants. While this pollutant dispersal represents a positive factor for the motorist, the highway design engineer and urban planner must pay close attention to how it affects adjacent land uses. It may benefit the motorist to have all the pollutants transported away from an elevated highway, but if they are transported directly into an adjacent building the result may be a serious detriment to the occupants. In this regard, local meteorologists should be consulted to determine the micro-climate of the design corridor. Needless to say, the aesthetic aspects and other environmental impacts of elevated highways have to be considered.

Efforts to reduce air pollution by changing highway design may not be aimed as much at reducing total emissions as at reducing concentrations at various significant distances from the roadway. Emissions can be reduced by the design of the highway itself, or by regulating the relationship between the highway and the adjoining land use.

3. Techniques for Reducing Auto Traffic Flow

Any program that focuses exclusively on improving traffic flow to reduce air pollution is likely to be self-defeating. Traffic flow improvement efforts must be accompanied by techniques for the reduction of auto travel.

Currently, the best short-range approaches to reducing auto travel are: to improve public transportation services, to reduce the number and length of trips and to regulate the use of automobiles.

Traffic reduction techniques and their effectiveness ratings are given in Table 3.3.

TABLE 3.3

TECHNIQUES FOR REDUCING AUTO TRAFFIC

		Probable Effectiveness
A.	Transit Operations	
	1. Bus lanes on city streets	1
	2. Bus lanes on freeways	1
	3. One-way streets with two-way buses	1
	4. Park-ride, kiss-ride	3
	5. Service improvements and cost reductions	2
B.	Regulation	
	1. Parking bans	4
	2. Auto-free zones	4
	3. Gasoline rationing	5
	4. Idling restrictions	2
	5. Four-day, forty-hour week	2
C.	Pricing Policy	
	1. Parking policy	2
	2. Road-user tax	5
	3. Gasoline tax	5
	4. Car pool incentives	2
D.	Planned Unit Development	2

a. Transit Operations -- The modal choice decision is influenced by the myriad characteristics of competing modes. Of particular importance are relative travel time, relative cost, and relative service levels.

Because of the difficulty of providing effective bus service in low density residential areas, one of the most promising transit improvements is the provision of park-ride and kiss-ride facilities in conjunction with express bus or other transit services.

b. Regulation -- There are several governmental policies that go beyond the normal pricing policy in that they regulate traffic by writ. Although they may be difficult to implement in the political framework of decision making, there can be no doubt about their effectiveness in reducing traffic congestion and air pollution. In any event, they may be useful measures to bear in mind for possible implementation during emergency air episodes.

The most effective potential technique -- gasoline rationing -- is unfortunately the least likely to be adopted and the most difficult to implement. Basically, each vehicle would be alloted a certain amount of gasoline per unit of time. It would be up to the vehicle owner to limit his trips to those which he could accomplish within his gasoline allotment.

Banning vehicles completely in certain parts of a city has been tried in many locales. Tokyo has banned cars from 122 of its busiest streets on Sundays, the busiest shopping day in Japan; air pollution levels were cut in half. New York City took similar action, resulting in as much as a 90-percent reduction in carbon monoxide levels on some auto-less streets. However, such a ban tends to raise traffic levels, congestion, and attendant pollution levels in adjacent areas.

c. Pricing Policy -- One way to reduce emissions is to impose operating penalties or disincentives, which would place special charges on traffic using congested roads.

Implementation of these techniques is often difficult. These techniques, together with the urban planning strategies described in Chapter 2 offer some methods for the planner to include when considering the impact of alternative plans on urban air quality.

APPENDIX A
INTRODUCTION TO AIR POLLUTION

To effectively incorporate air pollution considerations into urban planning, the planner must become familiar with air pollution terminology and characteristics. The purpose of this appendix is to provide this information.

TYPES OF POLLUTANTS AND THEIR SOURCES

Classification of Pollutants

Air pollutants are commonly classified as either gaseous or particulate. Gaseous pollutants behave much like the air itself; they do not settle out. Particulate pollutants may be either solid or liquid, and their performance in the atmosphere varies according to chemical composition and size: heavier particles settle close to the point of emission; and smaller, less-dense particles travel great distances. Urban aerosols, formed by the grinding or atomization of solids and liquids, are particulate matter ranging in size from approximately 6×10^{-7} to 1 micron; they include mist, smoke, dust, fumes, and spray.

Air pollutants also can be categorized as either primary or secondary. A primary pollutant is emitted directly into the atmosphere and initially retains its form as emitted. A secondary pollutant is formed in the atmosphere from reactions that may be chemical, photochemical, or biological.

A third way of classifying pollutants is by chemical composition -- either organic or inorganic. Many of the most common pollutants -- the oxides of carbon, nitrogen, and sulfur -- are inorganic; organic pollutants include hydrocarbons, aldehydes, and ketones.

To classify an air pollutant properly, all three classifications should be used; for example, carbon monoxide is a primary, inorganic, gaseous pollutant.

Units of Air Pollution Measurement

Air pollutants can be quantified in several ways: on the basis of emissions from sources, according to concentrations in the ambient air, or according to rates of exposure.

The source strength of air pollutants can be quantified in units of mass or weight per unit volume; for example, grams per cubic meter of air or pounds per cubic foot. Emissions may also be stated in terms of weight per unit time, weight per unit weight of product, weight per BTU, weight per unit area for area sources, or mass per unit distance for vehicles.

Concentrations of pollutants in the ambient air are normally reported as mass or weight per unit volume of air, such as micrograms per cubic meter. The unit parts per million (ppm), although used, is being discontinued. Settleable particulate matter sometimes is expressed in terms of tons per square mile per month or the currently recommended grams per square meter per month; and suspended particulate is measured in micrograms per cubic meter or Coh's (Coefficient of Haze), a unit of measurement of visibility interference.

Also of concern in the expression of concentrations of air pollutants is the quantity and duration of exposure experienced by plants, animals, or humans. Called the dosage or rate of exposure, units indicate both concentration and time involvement, with levels stated in terms of micrograms per cubic meter either per hour, 8-hour period, day, or year. In many cases, the average concentration over a given period of time is of concern; in other cases, the maximum concentration is more important.

When reviewing regulations or statements concerning concentrations of air pollutants, it is important to understand the units used; that is, whether they relate to the ambient air concentrations, to emissions, or to exposure dosages.

Air Pollutants and Their Sources

Pollutants emitted to the air in greatest abundance are carbon monoxide (CO), particulate matter, oxides of sulfur (SO_x), oxides of nitrogen (NO_x), and hydrocarbons (HC). Emission inventories of these five pollutants are commonly divided into five source categories: transportation, fuel combustion in stationary sources, industrial processes, solid waste disposal, and miscellaneous. Nationwide emissions by category for 1969, presented in Table A. 1, indicate that carbon monoxide is the major pollutant by weight, and that transportation activities are the major carbon monoxide contributor.[35] A different study[36] indicates that emissions of urban origin from stationary combustion and transportation activities account for greater than 75 percent of the total emissions in these five pollutant categories. The motor vehicle (gasoline and diesel) is a major contributor to air pollution. It contributes approximately 60 percent of the total carbon monoxide from all sources, about 50 percent of the hydrocarbons, and 35 percent of the nitrogen oxides.

Oxides of sulfur are chiefly products of fossil fuel combustion. About 80 percent of the sulfur in coal and nearly all that in liquid and gas fuels appears in flue gases as sulfur dioxide (SO_2). Almost all fuels, except wood, contain sulfur; however, they differ widely in their sulfur content. Bituminous coal has a high sulfur content; in some locales as high as 6 percent. Most crude oil contains less than 1 percent. Gasoline seldom contains more than 0. 25 percent. For the relative sulfur content of various fuels, see Table A. 2. Natural gas is virtually free of sulfur.

TABLE A. 1. ESTIMATED EMISSIONS OF AIR POLLUTANTS BY WEIGHT,[a] NATIONWIDE, 1969[35]

Source	CO	Particulates	SO_x	HC	NO_x
Transportation	111.5	0.8	1.1	19.8	11.2
Fuel combustion in stationary sources	1.8	7.2	24.4	0.9	10.0
Industrial processes	12.0	14.4	7.5	5.5	0.2
Solid waste disposal	7.9	1.4	0.2	2.0	0.4
Miscellaneous	18.2	11.4	0.2	9.2	2.0
Total	151.4	35.2	33.4	37.4	23.8

[a]In millions of tons per year.

TABLE A. 2. SULFUR CONTENT OF FUELS[36]

Type of Fuel	Percent by Weight
Bituminous	0.3 - 6.0
Anthracite	0.6 - 1.0
Coke	1.0 maximum
Wood	Negligible
Crude Oil	0.2 - 1.7
Fuel Oil	1.0 maximum
Diesel Oil	0.5 maximum
Gasoline	0.1 - 1.0

Another common source of SO_2 in the atmosphere is metallurgical operations. Many ores, such as copper, lead, and zinc are primarily sulfides. During the smelting of these ores, sulfur is oxidized and is evolved as sulfur dioxide.

The more important sources of particulate matter are industrial process operations, domestic heating plants, industrial power plants, refuse incinerators, open fires, construction activities, diesel engines, and automobiles (see Table A.3). The amount of particulate matter released from each of these sources varies considerably. The most common emissions are carbon or soot particles, metallic oxides and salts, oily and tarry droplets, acid droplets, silicates and other inorganic dusts, and metallic fumes.

Ozone is the principal constituent of the atmospheric substances called photochemical oxidants. They are secondary pollutants, formed by the action of sunlight in a series of complex reactions between hydrocarbons and oxides of nitrogen, which are both emitted primarily from transportation sources.

VARIATIONS IN AIR POLLUTION CONCENTRATIONS

Variations in air pollutant concentration at or near ground level are a function of both meteorological parameters and emissions, both of which vary in time and space. Both fluctuate from place to place according to daily and annual patterns; the latter also exhibit weekly variations. Thus, pollutant concentrations are a function of location, time of day, day of the week, and season of the year.

Variations According to Location

Variations according to location are the natural produce of non-uniform distribution of pollution sources (freeway versus center city

TABLE A.3. SOURCES OF ATMOSPHERIC PARTICULATE MATTER

Combustion	Materials Handling and Processing	Earth Moving	Miscellaneous
Fuel burning	Loading and unloading (sand, gravel, ores, coal, lime, bulk chemicals)	Construction (roads, dams, buildings, site clearance)	House cleaning
Incineration	Mixing and packaging (fertilizers, chemicals, feed)	Mining (blasting, sorting, refuse disposal)	Sand blasting
Open fires	Crushing and grinding (ores, gravel, chemicals, cement)	Agriculture (land preparation, soil tilling)	Crop spraying
Burning dumps	Food processing (milling, e.g., flour, cornstarch; drying; handling grain)		Poultry feeding
Forest fires			Rubber-tire abrasion
			Engine exhaust

traffic) and the random movements of air and weather patterns (rain and fog). Figure A.1 illustrates significant variations in pollutant concentration (in this case, carbon monoxide) as recorded at three different sites in the Detroit area.

The many meteorological observations accumulated over decades permit a fairly reliable estimate of the air pollution potential in various sections of the United States. Regions with a clean sweep of winds within the major storm tracks are least likely to develop high pollution conditions; regions dominated by stagnant air masses and light winds are most likely to experience high pollution conditions.

Variations by Time Periods

Space heating and solar radiation are the two major factors influencing seasonal variations in air pollution levels. Secondary pollutants, such as photochemical oxidants, generally are worst in the late summer or autumn when optimal combinations of solar radiation, temperature, and atmospheric stagnations coincide.

Weekly variations in carbon monoxide are a function of the different transportation and activity patterns associated with weekdays, weekends, and holidays. A study[38] revealed a distinct 20 percent decrease in the average carbon monoxide concentrations during the weekend compared to the higher weekday levels. In urban communities where there are many weekend travelers, the reduction is considerably less.

In general, meteorological conditions at night encourage the accumulation of pollutants; those in the day encourage their rapid dispersion Diurnal variations in carbon monoxide concentrations are illustrated in Figure A.1. Figure A.2 shows diurnal variation in concentrations of hydrocarbons, nitrogen oxides, and oxidants. In these examples, carbon monoxide, hydrocarbons, and nitrogen oxides exhibit two daily peaks. Considerable work[40] has been directed toward correlating these peaks

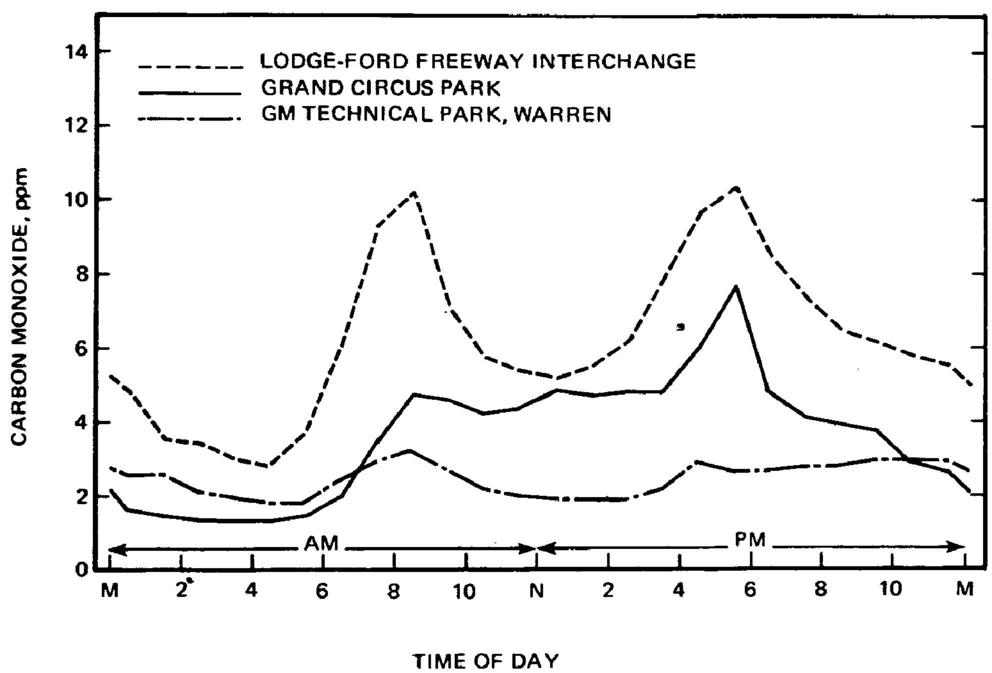

Figure A.1 Hourly Carbon Monoxide Concentrations on Weekdays in Detroit Area[38] with traffic flow and meteorological factors. The studies have indicated that concentrations of these three pollutants generally exhibit a higher correlation with traffic volume than with meteorological conditions. Only one peak has been observed for photochemical oxidants. It generally occurs near midday, in spite of more atmospheric mixing at that time, due to favorable reaction conditions of solar radiation and temperature. A delay between the hydrocarbon and nitrogen oxide peaks and the oxidant peak is normal because the oxidants are produced by chemical reactions involving hydrocarbons and nitrogen oxides.

Figure A.3 illustrates the daily variation in ground-level pollutant concentrations that can be expected some distance downwind from a tall stack on a clear day with light winds. In this example, the pollutant is emitted from the stack at a constant rate; therefore, the changes shown in ground-level concentration result entirely from meteorological influences. The morning maximum is due to a stable atmosphere and prevention of upward dispersion of the pollutant by an inversion layer, a meteorological condition described in the following section. The rapid decrease in concentration is due to the heating of a progressively deeper layer of air above the ground and mixing of the pollutant throughout this layer. After the period of maximum heating, increased stability near the surface causes concentrations to increase in the late afternoon.

METEOROLOGY

Meteorological and topographical conditions in some areas favor the accumulation of pollutants. Lighter particles and gases diffuse only as rapidly as meteorological conditions permit. During this diffusion, the nature of the pollutants may be changed by natural, physical, or chemical processes, such as solar radiation, rain, fog, and interaction with the normal constituents of the atmosphere. Typical examples are the oxidation of nitric oxide to nitrogen dioxide and the photochemical action that forms oxidants.

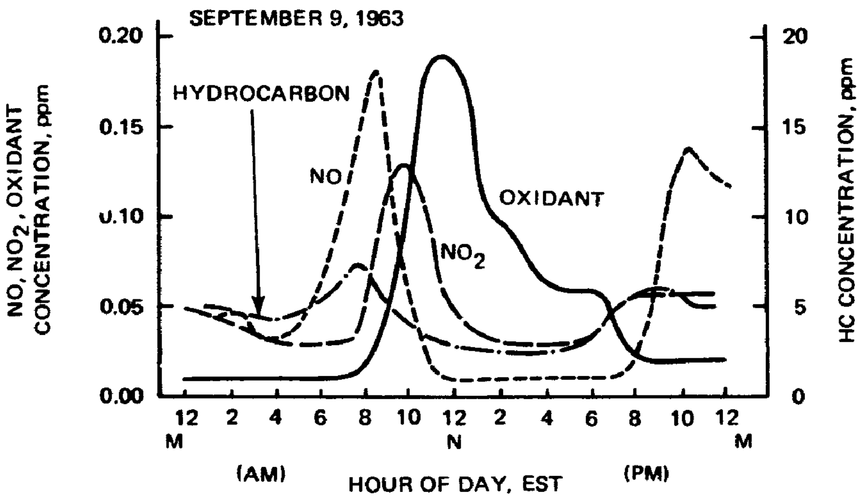

Figure A.2 Concentrations of Nitric Oxide, Nitrogen Dioxide, Hydrocarbon, and Oxidant During a Smoggy Day in Cincinnati, Ohio[39]

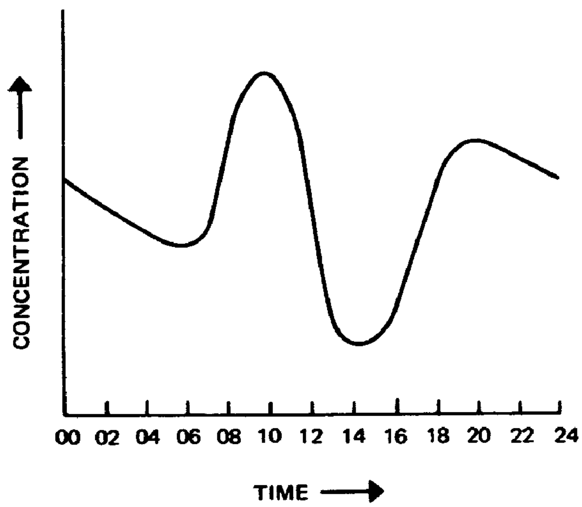

Figure A.3 Diurnal Variation of Ground Level Concentrations From Elevated Urban Sources[37]

In a dry atmosphere, the adiabatic lapse rate (rate of temperature decrease with increase in elevation) is $1^{o}C$ per 1000 meters ($5.4^{o}F$ per 1,000 feet). When the actual lapse rate is greater than this theoretical rate, a parcel of air that begins to rise continues to do so, and the atmospheric condition is called "unstable." If, however, the actual lapse rate is less than the adiabatic rate, the surface air remains near the surface and the atmospheric condition is called "stable."

An increase of temperature with altitude (an inversion) can occur at any time, but is most common during the night and early morning. An inversion acts as a lid; it separates layers of air and prevents polluted air from rising. If an inversion is accompanied by low winds, a layer of highly polluted air may build up over a broad area.

Three major forces -- wind, heating, and cooling -- cause shifts from stable to unstable conditions and back again. Wind, in addition to horizonatal motion, usually has vertical eddies and, since rapid vertical air motions tend to be adiabatic, helps to establish an adiabatic lapse rate. The sun, which heats the surface more than the air, increases the lapse rate, and, thus, contributes to instability. Conversely, at night the ground loses more heat by radiation than the air does, tending to make the surface cooler than the air layers above; this cooling contributes to stability. Usually there is a daily cycle from stability to instability and back again. When the cycle is broken and the atmosphere remains stable for a prolonged period, a serious accumulation of pollutants is possible.

High pollution potentials are generally favored by light winds and clear skies which promote the formation of temperature inversions. A buildup of high pollution concentrations in the central core of the cities then occurs as the result of this inversion "lid" coupled with a near-surface air movement toward the center city. This air flow is the result of the heat island effect in which the asphalt and concrete city heats up and acts like a chimney, drawing in cooler air from the surrounding areas.

High pollution potential is defined as a stagnating anticyclonic condition which, coupled with the continued operation of several sources, is conducive to the occurrence of high concentrations of pollution. As defined, the high pollution potential refers to developing meteorological conditions only. The National Meteorological Center in Suitland, Maryland, prepares daily 36-hour alerts. This information, called Air Stagnation Advisories (ASA), is available through U. S. Weather Bureau Stations. Being an objective system, the method has its shortcomings, the greatest of which is the lack of individual appraisal and forecasting for each city, based on its local meteorology and areal distribution of pollution sources. The local air pollution control office can provide the necessary in-depth knowledge of a specific urban community.

Within the space of a few miles, microclimatic conditions may considerably influence the effects of pollution. A detailed survey of the meteorological terrain is needed to assess variations in local conditions; this is particularly advisable when planning future communities and industrial areas. For example, it used to be a rule of thumb to locate industrial areas downwind of a settlement with respect to the prevailing wind direction. Unfortunately, in many instances the wind at times of stagnation or near-stagnation conditions may be quite different from the most frequent wind. In some cases, the slight draft under those conditions may be entirely opposite to the prevailing wind, thereby causing a more severe pollution condition than would have been anticipated.

SITE CONDITIONS AFFECTING DISPERSION

The city in a general sense may be considered a collection of microclimates. The pattern and profile of the air motion in the total atmosphere over an urban area are modified, sometimes considerably, in each of these microclimates by the spatial arrangement and character of buildings and other structures, by surrounding vegetation, and by roadway configurations.

Superimposed on this is the air movement resulting from traffic flow. In addition, the relative influence of each of these factors depends on the magnitude of the background air movement and solar heating conditions. Factors found to be dominant at higher wind speeds may decline in significance at the lower wind speeds which present the greater potential for severe pollution episodes.

Urban Heat Island Effect

The combined effects of topography and urbanization decidedly influence the radiation, moisture, and temperature conditions of a city. These, in turn, modify the wind flow patterns. In an urbanized region, vegetation is replaced by a vast man-made environment, resulting in changes in moisture conditions which, in turn, alter the heat distribution. The air is heated by multiple sources including industries, automobiles, space heating, and solar radiation.

It has been estimated that the automobile is an important artifical heat source in the street canyons of a city. Very heavy traffic in parts of London, for example, add an estimated $8^{o}F$ to the air temperature. Bach[41] calculated that for the built-up area of Sheffield, England, the annual artificial heat generation is about one-fifth of the direct solar radiation received. The ratio is one-third for Berlin. Particulate matter, a by-product of most artificial heat generation, may be 5 to 25 times greater in the urban area than in the rural area.

Temperatures in the urban heat island have been found to be on the order of $5\text{-}8^{o}C$ greater at night than in the surrounding rural areas. Sidewalks, roads, and concrete buildings have relatively high heat capacities and conductivities. The daytime heat storage is greater than for grass-covered fields or forests. The lack of evaporational cooling from the dry building surfaces increases the stored solar energy. After sunset, the stored daytime heat is released from buildings and pavements resulting in air temperatures and winds in the city higher than those occurring in the surrounding country. Munn[42] notes that the heat storage ability of a city is believed to be the major factor of the heat island formation. He adds that the city is a collection of microclimates, each dependent upon the character of a built-up area within the entire city.

The heat island effect is found to be maximum in late summer and early autumn when the skies are clear and winds are light. Figures A.4 and A.5 illustrate the morning and evening air culation and dispersion models in a city and in the surrounding country under anticyclonic conditions.

Building Configuration Effects

The orientation of a building with respect to the winds produces significant distortions in the local wind pattern. The significance of the flow distortions becomes clear when vehicular emissions exist within an area surrounded by buildings. Air currents can trap pollution, confining it close to the buildings. Pollutants emitted from building roof vents may also become trapped. Hence, roadway vehicular emissions and emissions from rooftops can be conveyed into windows, doorways, and air intake systems.

As background wind speeds decrease, the effect of the vertical temperature profile (lapse rate) increases and becomes a major controlling factor in the atmospheric dispersion of vehicular emissions in the urban street canyon.

During periods of light winds and clear skies, air flow around buildings is, to a great degree, the result of convective updrafts coupled with winds flowing into the center of the urban heat island. The updrafts remove pollutants from the area of the building more effectively than strong horizontal winds if no inversion exists.

The upward dispersion of vehicular emissions is often restricted in the early morning hours by the presence of a stable layer existing from the

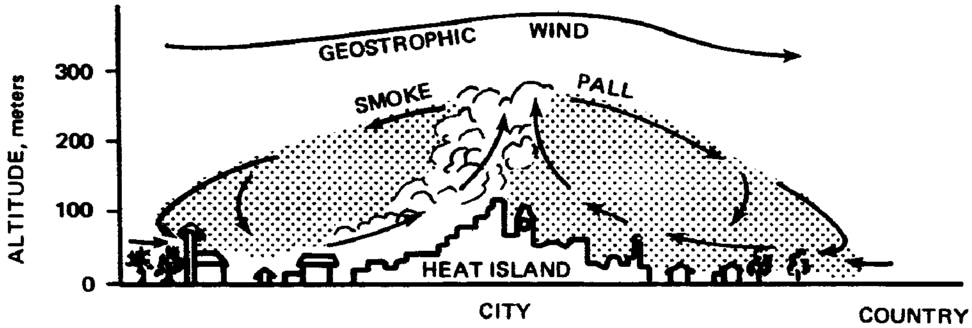

Figure A.4 Urban Circulation and Dispersion After Sunrise[41]

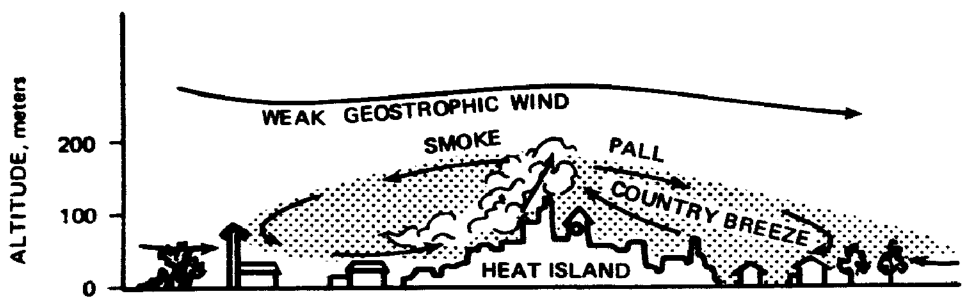

Figure A.5 Urban Circulation and Dispersion After Sunset[41] ground to roof level. The pollutants are trapped in or below this layer. This phenomenon is most pronounced in the walled street canyons of urban centers.

Various building configurations and orientations alter the air flow pattern considerably. Rows of tall buildings lining urban streets modify the microclimate by changing the topography and general aerodynamic boundaries. In these street canyons the dispersion of the pollutants is determined by the turbulent wake of the traffic, by the differential heating of building tops and streets, and by the general background air movement. Wind speeds at street level may be only 40 percent of the wind speed above the roofs of the buildings.

More open roadway planning with the buildings set back will alleviate this canyon effect. While traffic volume along a roadway section has the most direct relationship to emissions, the higher midafternoon wind speeds are the most effective factor in reducing the urban street canyon air pollution concentrations. This effect is gradually lost later in the afternoon as the overall wind speeds start to decrease and traffic volume once again peaks.

Roughness Effects

The background wind is also modified by the texture and height of surrounding features: buildings, trees, grass, brush, and streets. For example, as wind passes from an orchard to an open field, the wake effect is similar in many ways to that behind a building. Within approximately one-quarter mile, the original near-surface wind speed is re-established. There is an updraft in the air movement as it encounters a rougher surface, such as a row of trees.

Thus, a wide tree-covered green belt along both sides of a major traffic artery provides more rapid dispersion of vehicular emissions. In an urban area, similar transitions can be arranged -- between roadway and green belt, park and buildings, parking lots and streets, and low- and high-rise buildings. The resulting turbulence can lead to more dispersion and dilution.

URBAN AIR POLLUTION MODELS

Many mathematical models describing the diffusion process have been developed to relate pollutant emissions to ambient pollutant levels. These models vary from one equation of plume dispersion from a single source to complex programs capable of considering all sources in a major metropolitan area and providing the resulting ground-level concentrations at all locations in the area. The great number of calculations in all but the most simple models requires the use of a computer.

A mathematical model, with appropriate input data and the proper interpretation of results, can be a valuable tool for the planner. It can be used to determine: (a) consequences of a new pollution source on pollutant levels and patterns; (b) effects of alternative solutions in urban planning on pollution levels; (c) evolving pollution patterns in an expanding city; (d) effectiveness of various control strategies to reduce pollution levels in an area; and (e) emergency curtailment measures to be taken during episodes of high pollution levels.

A model should be selected to match the amount of data available, types of sources being considered, and time span of importance (e.g., long-term pollutant average for planning purposes and one-hour maximum for emergency episode prevention). The data required fall into three categories: (1) source information, including location, emission rates, and stack exit parameters; (2) meteorology, particularly wind speed, wind direction, and mixing depth; and (3) measured pollutant levels to verify or calibrate the model output.

Some caution should be exercised in using modeling results. The accuracy of output values is limited by the accuracy and adequacy of the input data. Also, the models are derived by assuming normal dispersion patterns and, therefore, are generally not capable of predicting pollutant levels near localized obstructions or in the vicinity of highly irregular topography.

APPENDIX B

COOK COUNTY ZONING ORDINANCE

This excerpt from the Cook County, Illinois, Zoning Ordinance illustrates the type of emission standards which can be applied in an urban area.

PERFORMANCE STANDARDS -- SMOKE AND PARTICULATE MATTER

A. Any use established in a Manufacturing District or in a Motor Freight Terminal District after the effective date of this comprehensive amendment shall be so operated as to comply with the performance standards governing smoke and particulate matter set forth hereinafter for the district in which such use shall be located. No use lawfully established on the effective date of this comprehensive amendment shall be so altered or modified as to conflict with, or further conflict with, the performance standards governing smoke and particulate matter established hereinafter for the district in which such use is located. Any use lawfully established on the effective date of this comprehensive amendment shall be permitted to be altered, enlarged, expanded, or modified, provided that new sources of smoke and/or particulate matter conform to the performance standards established hereinafter for the district in which such use is located. The total emission weight of particulate matter from all sources within the boundaries of the lot shall not exceed the net amount permitted in the district in which the use is located after such alteration, enlargement, or modification.

B. In addition to the performance standards specified hereinafter, the emission of smoke or particulate matter in such manner or quantity as to be detrimental to or endanger the public health, safety, comfort, or welfare is hereby declared to be a public nuisance and shall henceforth be unlawful.

C. For the purpose of grading the density of smoke, the Ringelmann Chart, published and used by the United States Bureau of Mines, shall be employed. The emission of smoke or particulate matter of a density greater than No. 2 on the Ringelmann Chart is prohibited at all times, except as otherwise provided hereinafter.

ALLOWANCE FOR HEIGHT OF EMISSION[a]

Height of Emission Above Grade (Feet)	(Pounds Per Hour Per Acre)
50	0.01
100	0.06
150	0.10
200	0.16
300	0.30
400	0.50

[a] Interpolate for intermediate values not shown in table.

Determination of the total net rate of emission of particulate matter within the boundaries of any lot shall be made as follows:

1. Determine the maximum emission in pounds per hour from each source of emission and divide this figure by the number of acres of lot area -- thereby obtaining the gross hourly rate of emission in pounds per acre.
2. From each gross hourly rate of emission derived in (1) above, deduct the correction factor (interpolating as required) for height of emission set forth in the table, thereby obtaining the <u>net</u> rate of emission in pounds per acre per hour from each source of emission.
3. Add together the individual net rates of emission derived in (2) above, to obtain the total <u>net</u> rate of emission from all sources of emission within the boundaries of the lot. Such total shall not exceed one pound per acre of lot area during any one hour.

PERFORMANCE STANDARDS -- TOXIC MATTER

Any use established in a Manufacturing District or in a Motor Freight-Terminal District after the effective date of this comprehensive amendment shall be so operated as to comply with the performance standards governing emission of toxic matter set forth hereinafter for the district in which such use is located.

Performance Standards -- Toxic Matter -- M1 District

In the M1 District, no activity or operation shall cause, at any time, the discharge of toxic matter across lot lines in such concentrations as to be detrimental to or endanger the public health, safety, comfort, or welfare, or cause injury or damage to property or business.

PERFORMANCE STANDARDS -- NOXIOUS AND ODOROUS MATTER

A. Any use established in a Manufacturing District or in a Motor Freight-Terminal District after the effective date of this comprehensive amendment shall be so operated as to comply with the performance standards governing noxious and odorous materials set forth hereinafter for the district in which such use shall be located. No use lawfully established on the effective date of this comprehensive amendment shall be so altered or modified as to conflict with, or further conflict with, the performance standards governing noxious and odorous materials established hereinafter for the district in which such use is located.

B. In addition to the performance standards specified hereinafter, the emission of noxious and odorous matter in such manner or quantity as to be detrimental to or endanger the public health, safety, comfort, or welfare is hereby declared to be a public nuisance and shall henceforth be unlawful.

Performance Standards -- Noxious and Odorous Matter -- M1 District

In the M1 Districts no activ ity or operation shall cause at any time the discharge of matter across lot lines in such concentration as to be noxious. The emission of matter in such quantities as to be readily detectible as an odor at any point along lot lines is prohibited.

APPENDIX C

FUEL ALTERNATIVES AND STACK HEIGHT

This Guide discusses land use and transportation planning as it may be used to achieve better ambient air quality. There are many air pollution controls that are not ordinarily considered as land use or transportation planning. These include emission controls, changes in industrial processes and raw materials, fuel switching, changes in industrial operation and maintenance procedures, and regulations governing stack height. Planners may, on occasions, deal with all of these controls. Two are discussed below.

FUEL ALTERNATIVES

Today's economy is profoundly dependent upon oil and gas. Petroleum provides the fuels for practically all of the nation's transportation, and oil and gas together satisfy over 90 percent of the national requirement for heat, three-fourths of the energy used by commerce and industry, and nearly a third of the fuel used for power generation.

Two fossil fuels, coal and oil, have been and remain widely used fuels for space heating and industrial uses. The types of coals used in early times, and even until recent years, were selected on the basis of cost and BTU production rather than on their air pollution potential. High sulfur content and low temperature of combustion often result in the emission of vast amounts of sulfur compounds and particulates to the air environment. In fact, coal fires produce smoke, sulfur dioxide, nitrogen oxides, and particulates. The use of oil as a new source of fossil fuel has greatly diminished particulate air pollution because of its nearly total combustion.

The third fossil fuel, natural gas, has now become a major source of energy for power production and residential space heating and is attractive because of its extremely low air pollution potential. Although there is an abundance of natural gas now, it is likely to be the first energy source to experience shortages. Based on current trends natural gas consumption will continue to increase at the rate of 4 to 5 percent per year in the immediate future, but after that, when it becomes less available for large volume, long-term contracts, it will be used less and less by large consumers where other fuels can serve as well.

Two non-combustive sources of energy are of particular interest. These are nuclear and hydroelectric power plants. It is also conceivable that solar energy will eventually be a major "clean" source, but major technological development will be required.

Hydroelectric power is a limited source because of the practical restriction in available sites for power generating plants. Hydroelectric plants account for less than 5 percent of the energy produced in the United States, considering both stationary and non-stationary sources. Although the amount of energy from this source will increase substantially, it is forecast to decline as a percentage of total national energy consumption.

It appears that there may be a tendency toward increasing use of nuclear energy. One of the vital planning functions in the coming decade, therefore, will be the location of power plants on a regional basis. The plants should preferably be near the urban areas of power demand; however, planners must contend with thermal pollution. Nuclear power plants require approximately 50 percent more cooling capacity than do fossil fuel plants of equivalent size. If cooling towers are installed, as proposed for some nuclear power plants, air quality effects such as fog and humidity should be considered. If cooling is accomplished by cold water from rivers, lakes, or oceans, the quantities of water required would affect the site selection of nuclear power plants.

The ranking of fuels from the lowest to the highest cost per energy unit begins with coal, and then proceeds to oil, natural gas, and finally to nuclear energy. Because of the higher costs and other problems of nuclear reactors, combustion of fossil fuels (coal, oil, and natural gas) is certain to increase for a number of years. Coal and oil combustion, however, create the worst air pollution; more than 50 percent of the sulfur dioxide, 25 percent of the nitrogen oxides, and nearly 30 percent of the particulates of the total tonnage of pollutants are produced by electric power generation.

During times of air pollution emergency, proper planning can reduce emissions either by fuel switching techniques or by production curtailment. As an example of the impact of fuel changes, Figure C-1 shows the reduction in pollution achieved through switching from high-sulfur fuel to low-sulfur fuel in residential heating units. The changes from coal to fuel oil and natural gas have a drastic impact on emission quantities.

Significant gains can be realized through such an approach, especially in the reductions of pollutant emission due to space heating. In particular, urban renewal programs and administration of housing codes offer opportunities for the planner to exercise some control over residential and commercial heating system conversion. One study[43] defined the four basic factors that influence the change in the levels of sulfur oxides in Chicago. These are: the control ordinance limiting the sulfur content of fuel, the natural evolution of the city, changes in fuel use patterns, and industrial relocation. The degree to which each of these factors affects the individual components of the region, such as manufacturing, residential, utility, and commercial areas is shown in Table C-1 which presents data and projections for total yearly sulfur oxide emissions for 1970, 1975, and 1980, based upon anticipated control of the sulfur content of fuels and on changing patterns in the urban area.

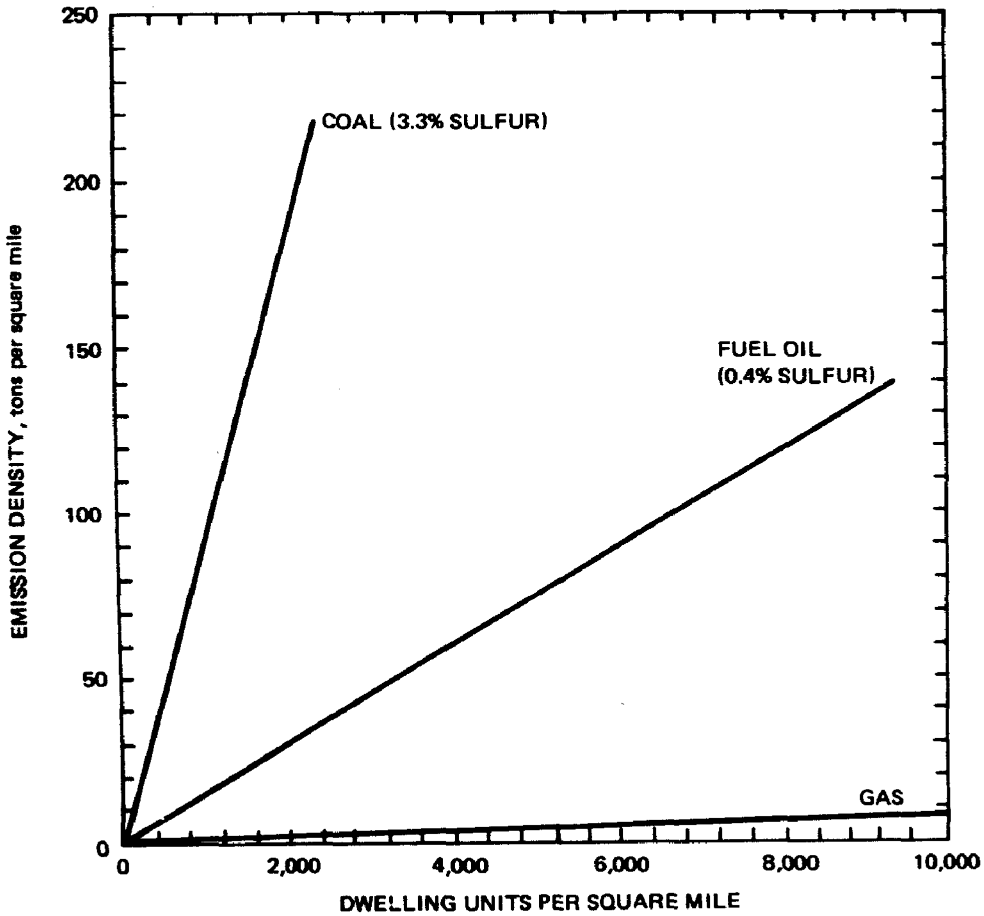

Figure C.1 Sulfur Oxide Emissions from Burning Different Fuels in Residential Heating—St. Louis

Table C.1. ESTIMATED YEARLY SULFUR OXIDE EMISSIONS IN TONS FOR CHICAGO[43]

	Heavy Manufacturing	Residential	Utility	Light Industry	Commercial	Total
1970	56,300	69,400	169,800	30,900	11,300	337,700
	17%	21%	50%	9%	3%	100%
1975	32,700	32,900	200	17,000	6,800	89,600
	36%	37%	0%	19%	8%	100%
1980	35,900	27,300	0	19,800	6,800	89,800
	40%	30%	0%	22%	8%	100%

It may be effective to institute a broad policy of economic incentives through penalties and tax advantages to accelerate the conversion of existing heating units to low sulfur fuels. Long-term low interest loans and tax advantages could be applied to entice homeowners to replace old heating units. In areas identified as seriously polluted, such a policy could be implemented by requiring property owners to convert to low-pollution units within a specified period.

Another approach to fuel conversion would be to legislate dwelling unit density/fuel ratios for new and redeveloped areas. Depending upon the ambient concentration of, for example, sulfur dioxide, the density of development can be controlled by municipal subdivision regulations. Based upon the maximum tolerable pollutant concentration, density limits can be calculated for various fuels of differing sulfur content. Because natural gas produces virtually no sulfur dioxide emissions and electricity produces none, regulations would not restrict densities in areas where these heat sources are used.

STACK HEIGHTS

In addition to site changes, there are other measures, associated with source configuration, which can be taken to reduce the sphere of pollutant impact. Because methods of isolating sources through land use regulation must be coordinated with their emission characteristics, it is important that the planner consider some of the more significant design aspects of stationary sources.

For example, there exist methods of determining the required minimum height of a discharge stack that will prevent accumulation of pollutant concentrations from exceeding permissible limits near the ground. Such methods can be applied to assess the actual ground level pollution hazard of specific industrial or power facilities, permitting a useful basis for altering land use allocations.

Taller stacks generally result in the reduction of contaminants near ground level. To alleviate air pollution hazards, tall stacks that tend to emit gaseous wastes to the atmosphere can be built. Increasing the stack height can also modify the impact of a looping plume. A looping plume may result when a turbulent eddy, caused by certain brisk winds, encloses a puff of smoke and brings it rapidly down to ground level with little dilution of pollution. The taller stack reduces the frequency of ground level effects from looping plumes, but widens the area of possible impact.

For over 30 years, stack heights of 400 to 600 feet have been found to be effective in reducing sulfur dioxide pollution from smelting operations and other forms of air pollution. There must, however, be a practical upper limit to the maximum power plant stack height and size because of the diminishing returns and questions of cost, construction difficulty, and aircraft hazards. What this size limit may be depends upon the amount of pollution emitted, the frequency of the unfavorable meteorological conditions, and the definition of acceptable concentration levels. Given these quantities, the planner can evaluate the potential effect of devices such as buffer zones.

APPENDIX D

GLOSSARY

Adiabatic	Occuring without gain or loss of heat.
Aerosol	A dispersion of solid or liquid particles of microscopic size in gaseous media. Examples are smoke, fog, and mist.
Air pollution	The presence of unwanted material in the air in sufficient amount and under such circumstances as to interfere significantly with comfort, health, or welfare of persons, or with full use and enjoyment of property.
Ambient air quality	A physical and chemical measure of the concentration of various chemicals in the outside air. The quality is usually determined over a specific time period (for example, 5 minutes, 1 hour, 1 day).
Anticyclone	An area of relatively high atmospheric pressure. In the northern hemisphere, the wind blows spirally outward in a clockwise direction.
Arterial	A major through street, four lanes or more with no (or only limited) access control.
At-grade roadway	Roadway which is at the same level with adjacent land.
BTU	British thermal unit. A measure of heat, specifically, 1 BTU is the amount of heat required to raise the temperature of 1 pound of water $1^{o}F$ at or near $39.2^{o}F$.
Coh	Coefficient of haze. A unit of measurement of visibility interference.
Convective updraft	Vertical component of a circulatory air movement caused by differences in density within an air mass of non-uniform temperature.

Corridor	An area extending radially from the central business district generally served by a major transportation route.
Depressed roadway	Roadway which is below adjacent land.
Diffusion	Mixing of pollutants with surrounding air by means of random particle or molecular motion. (Often used interchangeably with dispersion.)
Dispersion	Transport of pollutants by atmospheric currents. (Often used interchangeably with diffusion.)
Diurnal	Daily, especially pertaining to actions or events that are completed within 24 hours and that recur every 24 hours.
Downtown distribution system	The local streets in the downtown area that serve adjacent buildings and facilities.
Dust	A term loosely applied to solid particles, predominantly larger than colloidal, capable of temporary suspension in air or other gases.
Elevated roadway	Roadway which is above adjacent land.
Emissions	The total substances discharged into the air from a stack, vent, tail pipe, carburetor, or other source.
Episode	The occurrence of stagnant air masses during which air pollutants accumulate, so that the population is exposed to an elevated concentration of airborne contaminants.
Freeway	A major limited access highway of 4 or more lanes.

Gas	One of the three states of aggregation of matter, having neither independent shape nor volume, and tending to expand indefinitely.
Geostrophic wind	Wind that exists in a region approximately 300 to 1000 meters above the surface of the earth and is generally not influenced by surface friction. Its speed constitutes a balance of the forces from the pressure gradient and rotation of the earth.
Inversion	A layer of air in which temperature increases with height.
Modal split	The calculation of the proportion of total person trips which will use available transportation modes.
Mode	Method of transportation such as bus, auto, walking, rapid transit, or taxi.
Model	A mathematical set of equations intended to simulate a real life situation.
Month	For reporting analysis of ambient air on a monthly basis, results are calculated to a base of 30 consecutive 24-hour periods.
Peak traffic demand	That traffic flow on an individual street or in an entire area which is the greatest. Usually, the peak traffic demand is considered over a short period of time (15-60 minutes) per day.
Plume	A column of smoke.
Right-of-way	The land occupied by a roadway.
Smog	A combination of smoke and fog. Extensive atmospheric contamination by aerosols arising partly through natural processes and partly from human activities. Often used loosely for any air contamination.

Smoke	Small gas-borne particles that are produced by incomplete combustion, consisting predominantly of carbon and other combustible material, and present in sufficient quantity to be detectable independently in the presence of other solids.
Topography	The configuration of a surface, including its relief and the position of its natural and man-made features.
Vapor	The gaseous phase of matter that normally exists in a liquid or solid state.
Weaving	The crossing of traffic streams moving in the same general direction, accomplished by merging and diverging.
Year	For reporting analysis of ambient air on a yearly basis, results are calculated to a base of 12 30-day periods.

APPENDIX E

REFERENCES

1. U. S. Clean Air Act (42 U.S.C. 1857 et seq.) sec. 110 (a)(2). (This is commonly called the 1970 Clean Air Act and includes the Clean Air Act of 1963 and all amendments through December 31, 1970.)

2. U.S. Office of Management and Budget. Circular No. A-95. Revised February 9 and July 26, 1971.

3. EPA. Requirements for Preparation, Adoption, and Submittal of Implementation Plans. Federal Register, 36:158, August 14, 1971.

4. EPA. National Primary and Secondary Ambient Air Quality Standards. Federal Register, 36:84, April 30, 1971.

5. Yocom, J. E., D. A. Chisholm, and G. F. Collins. Air Pollution Study of the Capital Region. Capital Region Planning Agency, Hartford, Connecticut, December 1967.

6. Voorhees, A. M., C. F. Barnes, Jr., and F. E. Coleman. Traffic Patterns and Land Use Alternatives. Highway Research Board Meeting, Washington, D. C., January 1962.

7. Northeastern Illinois Planning Commission. Managing the Air Resource in Northeastern Illinois, Technical Report No. 6. August 1967.

8. Kurtzweg, J. A. and D. W. Weig. Determining Air Pollution Emissions from Transportation Systems. National Air Pollution Control Administration. National Air Pollution Control Administration.

9. Voorhees, A. M. and Associates, Inc. A Transportation Study for Montgomery and Prince George's Counties, Maryland. The Maryland National Capital Park and Planning Commission, June 1970.

10. National Capital Development Commission. Canberra Land Use Transportation Study: General Plan Concept, January 1967.

11. For example see: Alan M. Voorhees & Associates, Inc. Factors and Trends in Trip Lengths. National Cooperative Highway Research Program, Report 89, 1960.

12. National Capital Development Commission. Tomorrow's Canberra. Australian National University Press, 1970.

13. Rydell, C. P. and Collins, D. Air Pollution and Optimal Urban Forms. National Center for Air Pollution Control. June 1967.

14. Rydell, C. P. and Schwarz, G. Air Pollution and Urban Form: A Review of Current Literature. AIP Journal, March 1968.

15. Hilberseimer, L. The New City. Chicago: Paul Theobold, 1944.

16. Urban Land Institute. Land Use Control, Research Monograph No. 17, 1970.

17. St. Louis Area Council of Governments. Report and Recommendation of East-West Gateway Coordination Council as a Coordinated Air Pollution Abatement Program for the St. Louis Metropolitan Area. January 1967.

18. Williams, Norman. Development Controls and Planning Controls -- The View from 1964. Proceedings of the 1964 Annual Conference, American Institute of Planners.

19. Fay, J. A. Air Pollution from Future Giant Jetports. Air Pollution Control Association, June 1970.

20. Babcock, Richard F. Report on Contemporary Land Use Control Methods and Techniques. Dayton Plan Board, 1966.

21. American City Corporation. Urban Life in New and Renewing Communities, No. 6. July 1971.

22. Rockeffer, D. New Communities, A New Avenue for Social-Purpose Investing. Address before New York Bond Club, April 1971.

23. Kwantes, P. W. General Transportation Aspects of Multi-Use Centers. Unpublished paper, 1971.

24. The Joint Program (now the Twin Cities Metropolitan Council), Twin Cities Area Metropolitan Development Guide, Report No. 5. April 1968.

25. Tippets, Abbet, McCarthy. and Stratton. Air Rights Potentials in Major Highways -- Criteria for Joint Development, October 1969.

26. U.S. Congress. Federal-Aid Highway Act of 1970. Public Law 91-605, 91st Congress, H. R. 19504, Sec. 137, 1970.

27. This hypothetical simulation was conducted by Alan M. Voorhees & Associates, Inc. and Ryckman, Edgerley, Tomlinson & Associates and was based upon research findings from: Bellomo, S. J., , R. B. Dial, and A. M. Voorhees. Factors, Trends and Guidelines Related to Trip Length. National Cooperative Highway Research Program Report 89, 1970.

28. Voorhees, Alan M. & Associates, Inc. Development of a Long Range Transit Improvement Program for the Twin Cities Area. Twin Cities Metropolitan Transit Commission, November 1969.

29. Wohl, M. Users of Urban Transportation Services and Their Income Circumstances. Traffic Quarterly, January 1970.

30. Krambles, G. Putting New Spokes in Urban Transit. Conference on New Approaches to Urban Transportation, Washington, D. C., November 1967.

31. Schneiderman, M, C. K. Cohn, and G. Raulson. Air Pollution and Urban Freeways: Making a Record on Hazards to Health and Property. The Catholic University Law Review, Fall 1970.

32. EPA. Air Pollution Emission Factors. Preliminary Document, AP-42, April 1971.

33. Wohl, M. and B. V. Martin. Traffic System Analysis for Engineers and Planners. New York: McGraw-Hill, 1967.

34. Downtown-Lower Manhattan Association and the Port Authority of New York. Staggered Work Hours in Lower Manhattan -- First Anniversary Report. April 1971.

35. The Mitre Corp. Environmental Trends: Radiation, Air Pollution, Oil Spills. MTR-6013. May 1971.

36. HEW, U.S. Public Health Service. Nationwide Inventory of Air Pollutant Emissions, 1968. NAPCA Publication AP-73, August 1970.

37. Crocker, B. B. and K. B. Schnelle. Introduction to Air Pollution Control. American Institute of Chemical Engineers Today Series, 1969.

38. Colucci, J.M. and C. R. Begeman. Carbon Monoxide in Detroit, New York, and Los Angeles Air. Environmental Science and Technology. 3:1, p. 41-47, January 1969.

39. Stern, Arthur C., ed. Air Pollution, Vol. 1, 2nd ed. Academic Press, New York: 1968.

40. Brunner, F. A. and K. B. Schnelle, Jr. Air Pollution Patterns in an Urban Street Canyon. Paper presented at ASCE National Environmental Engineering Meeting, St. Louis, Missouri. October 1971.

41. Bach, W. An Urban Circulation Model. Arch. Met. Geoph. Biokl., Series B. 18:155-168, 1970.

42. Munn, R. E. Descriptive Micrometeorology. Academic Press. New York: 1968.

43. Cohen, A. S. and A. P. Hurter, Urban Evaluation and Air Pollution. Air Pollution Control Association, June 1970.

☆ G. P. O. 1973 – 747-788 / 331. REGION NO. 4