ENVIRONMENTAL IMPLICATIONS OF AUTOMOBILE-FREE ZONES

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The purpose of this paper is to clarify some of the environmental issues associated with automobile-free zones and to determine whether automobile-free zones can reduce environmental problems. It is designed to give planners an overview of the subject and to suggest some procedures for future studies. Past experience with automobile-free zones has indicated that noise and air pollution are significantly reduced on streets where automobiles are banned. As to the wider, external effect of automobile-free zones, few or no data exist, but an analytical procedure is suggested to assess this effect: compare trips to a target area, with and without the automobile-free zone, and convert this trip information into pollution-emission data. Although the relationship between automobile-free zones and nonautomobile modes is not certain, it appears that these modes conserve more energy than do automobiles and that they emit lower levels of certain pollutants. To reduce area-wide environmental problems, it is suggested that automobile-free zones be centrally located in relation to market areas and transit systems, that provisions be made to handle rerouted traffic, and that use of nonautomobile modes to automobile-free zones be encouraged.

•THE PRACTICE of reserving areas free of road traffic can be traced back to ancient times but current interest in this concept stems from the problems generated by automobiles in modern cities. The term automobile-free zone (AFZ) might apply to any area in which traffic is banned, but in this paper it will refer to districts of high activity in urban areas where the use of private automobiles has been severely curtailed or prohibited. A common example is a central shopping district closed to automobile traffic on a full- or part-time basis. AFZs can also be found in residential, institutional, and recreational areas.

It has been maintained that the creation of AFZs will help reduce the environmental damage caused by automobiles. This paper will investigate this claim in greater depth. For the purposes of this paper, "environment" will be used in a somewhat restricted manner to refer only to air quality, noise level, and natural resource consumption. Analytical procedures for further research will be suggested throughout the text.

ENVIRONMENTAL EFFECTS OF AUTOMOBILES

With regard to AFZs, the major environmental effects of automobile use have been air and noise pollution. The following is an overview of these two phenomena as a background for studying AFZs.

Air Pollution

The most lethal environmental effect of automobiles is the pollution caused by engine exhausts. Based on Environmental Protection Agency data for 1971, motor vehicles

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account for as much as 62 percent of all nationwide carbon monoxide emissions (Table 1). This percentage is even higher when only urbanized areas are considered as in Table 2 (10). Air pollution is usually measured in terms of the concentration of pollutant over time [such as parts per million (mg/m^3) of air per hour] or in terms of pollution to vehicle usage in grams per vehicle-mile.

The primary pollutants in automobile exhaust are carbon monoxide (CO); hydrocarbons (HC); nitrogen oxides (NO_x), mostly nitrogen dioxide; lead (Pb); and particulate matter. Larger automotive engines also emit considerable amounts of sulfur oxides (SO_x), mostly sulfur dioxide. Lead is generally excluded from emission tables because of the current uncertainty regarding its effect and criticality; sulfur oxides are included in emission tables because of their significance as emissions from stationary sources and from nonautomobile modes of transportation. The effects of these pollutants on humans, in the amounts common in urban areas, range from the irritation of mucus membranes to the shortening of the lives of many individuals (1).

Air pollution can vary from place to place, depending on such factors as local climatic conditions and the physical structure of the environment. Even local design considerations play a role. For example, pollution is generally magnified on streets fronted by solid rows of tall buildings, which interfere with normal wind patterns; these conditions can create heated channels in which inversion layers are formed and photochemical processes are made easy.

The emission rates of automobiles vary considerably; high engine displacement, cold starts, poor engine maintenance, leaded fuel, and stop-and-go driving conditions all contribute to higher pollution. Average emission rates, in grams per vehicle-mile (1 vehicle-mile = 1.6 vehicle-kilometre), for automobiles in 1973 were as follows:

Pollutant	1973	1974
CO	62	56
HC	8.5	7.5
NO_x	5.4	5.2
SO_x	0.2	0.2
Particulates	0.6	0.6
All	76.7	69.5

Standards have been formulated by the U.S. Environmental Protection Agency for the emissions of various engine types and for the air quality of entire geographic regions.

Noise

Less dangerous than air pollution, but perhaps more annoying, is the problem of vehicular noise. This has several sources, but recent studies have identified the chief cause in automobiles as tire-roadway interaction and in trucks as exhaust noises (3).

Noise levels are measured in decibels (dB) on a logarithmic, rather than an arithmetic, scale. For example, a decrease of only 10 dB appears to an observer as a halving of the original noise. A soft whisper at 5 ft (1.5 m) will register about 34 dB; the interior of a quiet office will average around 55 dB; and the sound level at the side of an expressway may be as high as 90 dB (4). Since the human ear does not respond in the same manner to all frequencies, a special "A-weighted" scale is generally used for measurements with sound-level meters. This scale gives readings in dBA, a measure that more accurately represents the apparent noise levels of vehicles. Because noise is a function of varying sound levels occurring over time, a tenth percentile (L_{10}) measurement is often used. This indicates a specified median noise level exceeded during only 10 percent of the period in question. Decibels indicate only sound level or intensity, and thus, high-pitched and intermittent sounds, which are more objectionable than low-pitched and steady sounds, are not distinguished by simple dBA measurements.

The effect of traffic noise on humans seems to be more a matter of psychology than physiology. A number of studies have pointed to "annoyance" as being the most widespread effect (5, 6). It is doubtful that highway noises alone cause hearing damage, but the effects of noise annoyance on behavior and mental health cannot be disregarded. One report found that high noise levels are often accepted by the public because noise is "no worse here than elsewhere" or "busy areas are expected to be noisy" (7).

Sound levels measured 50 ft (15.2 m) from vehicles traveling at 30 to 39 mph (13.5 to 17.5 m/s) average from 60 to 70 dBA for autos, 63 to 82 dBA for motorcycles, and 72 to 86 dBA for trucks. A single automobile will register about 65 dBA while traveling along a roadway, and a stream of automobiles may average as high as 78 dBA. A number of studies have reported that heavy trucks in the traffic stream constitute the primary source of highway noise complaints. These can be responsible for sound levels in excess of 95 dBA (8). It appears that sound-level complaints are associated more with individual vehicular noise than with volume flow (7). Complaints of traffic noise generally occur when levels rise above 68 or 70 dBA (3).

Various agencies have attempted to set maximum noise levels. These commonly range from a low of 45 or 50 dBA for quiet areas at night to a high of 75 dBA for busy areas during the day (3). Ambient noise in cities is already at a level of about 60 dBA during the day and 50 dBA at night (3).

EFFECTS WITHIN THE AFZ

It would seem logical that, if automobiles are banned from a particular area, the environmental nuisance they create in that area will be reduced. To test this, a number of experiments have been conducted before and after the restriction of automobiles in certain districts, and a selection of these is summarized on the following pages and in Tables 3 and 4 (8, 9, 10). The only air pollutant measured by the studies quoted here is CO. This is because CO is more inert and more localized than the other pollutants and it is generally easier to associate changes in the CO levels along roadways with changes in automotive use.

All "before and after" studies should be carefully examined with regard to methodology and basic assumptions. Only a series of observations taken over a period of time can be considered valid. Because data collection procedures vary widely in different studies and direct comparisons of results are of doubtful value, the information presented here is perhaps more useful for indicating what ranges can be expected in reducing noise and air pollution, than for comparing and predicting precise levels. Although the studies presented here may not be directly comparable, they do confirm that local levels of noise and air pollution have been lowered significantly where auto traffic has been restricted.

Gothenburg, Sweden

Since 1970, the center of Gothenburg has been divided into quadrants, and through traffic between these quadrants is prevented by physical barriers. Only transit vehicles and local automobiles enter the core area. These measures reduced CO concentrations by 25 ppm (28.75 mg/m^3) from 30 to 5 ppm (34.50 to 5.75 mg/m^3). Noise tests indicated a drop of 3 dBA in the average level from 75 to 72 dBA (8).

Marseilles, France

A series of experiments at limiting traffic was carried out in the central area of Marseilles in October 1971. For 10 days, private automobiles were banned and only taxis and buses were allowed into the core. Surveys taken before the ban indicated CO concentrations averaging 18.8 ppm (21.62 mg/m^3), while the levels during the ban averaged only 3.6 ppm (4.14 mg/m^3). A second experiment was carried out in which traffic was again allowed into the core, but all parking was prohibited. The results of this test were less dramatic, but the CO level was still reduced by as much as 44 percent to an average of 10.4 to 12.9 ppm (11.96 to 14.835 mg/m^3) (8).

New York City

In April 1971, New York City's Department of Air Resources conducted tests to determine the reduction of noise and air pollution that resulted from prohibiting all traffic

Table 1. Estimated nationwide emissions of five major pollutants, 1971.

Source of Emission	CO	HC	NO_x	SO_x	Particulates
Gasoline motor vehicles[a]	62.2	11.4	6.8	0.2	0.7
Other vehicles	15.3	3.3	4.4	0.8	0.3
All modes	77.5	14.7	11.2	1.0	1.0
Stationary facilities	1.0	0.3	10.2	26.3	6.5
Industrial processes	11.4	5.6	0.2	5.1	13.5
Solid waste disposal	3.8	1.0	0.2	0.1	0.7
Other	6.5	5.0	0.2	0.1	5.2
All sources	100.2	26.6	22.0	32.6	26.9

Note: Amounts are in millions of tons, where 1 ton = 907.18 kg.

[a]Gasoline motor vehicles account for 62 percent of CO emissions, 43 percent of HC emissions, 37 percent of NO_x emissions, 0.9 percent of SO_x emissions, and 3 percent of particulate emissions.

Table 2. Contribution of motor vehicles to total atmospheric emissions in twelve metropolitan areas.

City	CO	HC	NO_x
Stockholm	99	93	53
Tokyo	99	95	33
Osaka	99	95	25
Los Angeles	98	66	72
Toronto	98	69	19
New York City	97	63	31
Washington, D.C.	96	86	44
Madrid	95	90	35
Chicago	94	81	35
Pittsburgh	80	70	29
Ankara	75	57	52
Philadelphia	70	47	27

Note: Amounts are in percentages of total emissions.

Table 3. Reductions in carbon monoxide levels before and after the restriction of automobiles.

			Reduction	
Area	Before	After	Amount	Percent
Gothenburg, central area	30.0	5.0	-25.0	83.3
Marseilles				
Auto ban	18.8	3.6	-15.2	80.8
Parking ban	18.8	11.6	-7.2	38.2
New York, Madison Avenue	14.0	6.9	-7.1	50.7
Tokyo				
Asakusa	2.5	2.1	-0.4	16.0
Ginza	8.3	2.6	-5.7	68.6
Ikebukuro	7.3	3.5	-3.8	52.0
Shinjuku	7.7	2.0	-5.7	74.0
Vienna, central area	7.4	4.1	-3.3	44.6

Note: Amounts are in parts per million, where 1 ppm = 1.15 mg/m^3.

Table 4. Reductions in noise levels before and after the restriction of automobiles.

			Reduction	
Area	Before	After	Amount	Percent
Gothenburg, central area	75.0	72.0	-3.0	4.0
Tokyo, Ginza	75.0	70.0	-5.0	6.4
New York, Madison Avenue	73.2	66.4	-7.2	9.8
Vienna, central area	—[a]	—[a]	-3 to -6	

Note: Amounts are in dBA.

[a]Not available.

(except buses) on a major street. The tests were made on Madison Avenue, which was closed from noon to 2:00 p.m. on weekdays for 2 weeks. The department reported that a 40 to 75 percent reduction of the usual morning concentrations of CO occurred during the periods of the traffic ban. Their data indicated that the periods ordinarily exhibiting levels as high as 22 or 23 ppm (25.30 or 26.45 mg/m^3) never rose above 9 ppm (10.35 mg/m^3) and sometimes went as low as 3.5 ppm (4.025 mg/m^3). After the street closing experiment ended, pollution levels went up to their previous levels or higher (9).

Noise measurements taken during the traffic ban averaged 65 to 68 dBA, in contrast to the usual 70 to 78 dBA. Intermittent peak values also decreased to 72 to 82 dBA during the ban, from 79 to 106 dBA. General background noises under both ban and nonban conditions were in the 60 to 68 dBA range (9).

Tokyo

Since 1970, autos have been banned from the Ginza, Shinjuku, Ikebukuro, and Asakusa shopping districts of Tokyo. The ban is in effect on Sunday, the busiest shopping day in Japan. Counts of carbon monoxide concentration indicated reductions of up to 80 percent; AFZ counts averaged around 2.5 ppm (2.875 mg/m^3). Although median noise levels reportedly were reduced by 5 to 7 dBA (8) these results may have been based on an inadequate sample size.

Vienna, Austria

An AFZ has been in effect in Vienna since 1971; only buses and service vehicles are allowed to enter the central area between 10:30 a.m. and 7:00 p.m. Measurements indicated CO reductions of 45 to 65 percent, to about 9.1 ppm (10.465 mg/m^3). Noise has decreased by 3 to 6 dBA although a slight increase in noise has been reported on adjacent streets during delivery hours (10). Vienna now plans to enlarge the AFZ.

EXTERNAL EFFECTS OF THE AFZ

The many air and noise quality studies of AFZs have concentrated mainly on the immediate effects on the streets in which autos have been banned. Very little information is available on the environmental effects outside the AFZ.

For example, the establishment of an AFZ might simply divert large volumes of traffic from the closed-off streets to adjacent roadways, causing noise and pollution levels to rise in those areas. An AFZ might attract so much new traffic that pollution levels for the surrounding area would rise. Also, the elimination of direct paths of travel might cause increases in total vehicle-miles of travel (VMT) and thus compound the pollution problem. Or, an AFZ might induce many travelers to change to low polluting nonautomobile modes. The magnitude and nature of these problems remain conjectural, until further empirical data are collected. It seems obvious, though, that to determine the total environmental effects of an AFZ will require an analysis of the external effects as well as the internal ones. The following hypothetical situation shows how an analysis might proceed.

An AFZ is being considered for the central business district (CBD) of a small city. Changes in travel behavior are likely to result from this depending on the size of the AFZ in relation to the size of its affected area. Certain people may be attracted to the AFZ from peripheral shopping areas because of improved transit access or other such amenities, or others who formerly shopped in the CBD may be diverted to competing areas because of the AFZ's less convenient automobile access. There will also be a large group of trip-makers, such as workers in the area, who will continue to travel to the CBD whether or not an AFZ is established. If planners wish to estimate the overall effects on air pollution that these changes in travel behavior will generate, they might use the following procedure.

1. Establish the size of the area to be affected.
2. Calculate the trips generated in the affected area for present conditions, some future year with an AFZ, and the same future year with no AFZ. The estimation of

travel in the affected area can be based on existing models of trip generation and assignment. But because changes in travel behavior may be accompanied by shifts in the mode of transport used, modal split should be carefully calculated.

3. Translate trip information into noise and pollution emission data. The emissions for the three alternatives can then be compared to show the net increase or decrease in noise and air pollution in the affected area resulting from the establishment of the AFZ. The conversion of trip information into pollution emission data is fortunately not as formidable as might be expected. Computer simulation packages are available for predicting air pollution effects for alternative development plans. These require such data inputs as the traffic volume on each link of the roadway network, the characteristics of each link in terms of speed and congestion at various times of the day, and a set of emission factors. The outputs can be in kilograms of each pollutant emitted in the study area. When these models are combined with background emission and diffusion models, the actual concentrations of pollutants in particular subareas can be estimated (although at the present time this is only possible for carbon monoxide).

Similar models are available for predicting noise levels. They require the same types of data and produce a listing of links where the L_{10} noise level exceeds a specified dBA.

4. Summarize the information and calculate the net changes in pollution attributable to the AFZ according to quantity and types of pollutants and their distribution by area and time period.

AUTOMOBILE-FREE ZONES AND NONAUTOMOBILE TRANSPORTATION

The preceding section assumed that AFZs are more accessible to nonautomobile modes of travel than are conventional areas; that they encourage the use of nonautomobile modes; and that nonautomobile modes cause less environmental damage than do automobiles. This section will examine these assumptions in greater detail and will focus on mass transit.

Accessibility to Nonautomobile Modes

A flat statement cannot be made about the accessibility of AFZs to nonautomobile modes of transportation unless the circumstances relating to market area and site location are known. For example, an AFZ located at a junction point of transit lines that serve its market area is obviously much more accessible than if it were in a peripheral location. If the AFZ has a city- or region-wide market area, its accessibility is increased in or near the central core, because transit networks of American cities generally radiate from this point. Thus, only if an AFZ is properly located in relation to the spatial structure and transport network of its market area is its accessibility to nonautomobile modes of transit high.

Stimulation of Use of Nonautomobile Modes

If an AFZ is highly accessible by nonautomobile modes, do people use these modes instead of their cars? No simple answer can be given because of the lack of empirical data. Cases in which an AFZ has stimulated transit patronage have usually been complicated by realignments in transit service and shifts of riders from some routes to others.

In predictions of the overall effects on transit in the future, the following variables might be used as indirect indicators of the influence of an AFZ:

1. The type of transit system serving the AFZ, its level of service (both directly to the AFZ and throughout the affected area), and its marketing efforts;
2. Travel times to the AFZ by transit versus travel times by automobile;
3. Walking distances to destinations in the AFZ from transit stops versus walking distances from automobile parking and drop-off areas; and
4. Transit fares versus automobile parking rates and fines near the AFZ.

Another factor that may be important in stimulating the use of nonautomobile modes is the policy that dictates which modes will be excluded from the AFZ and which modes will be allowed to operate within the AFZ.

Environmental Effects of Nonautomobile Modes

If AFZs are shown to stimulate use of nonautomobile modes of transport, are these modes any better for the environment than automobiles? The answer to this question revolves around transit's effect on air pollution, noise, and resource consumption versus the automobile's effect.

Air Pollution—In a 1972 study by Scheel (11), emission data were collected under a variety of operating conditions for automobiles, buses, commuter trains, and rapid transit trains. These data indicated that the absolute levels of pollution were lower for vehicles with small power plants than for those with large ones (Table 5). Thus, total emissions were lower per vehicle-mile for automobiles than for public transportation modes. However, because public transportation is characterized by higher vehicle occupancy, the emissions of each mode were compared by passenger-miles and weighted by the relative effect of the pollutant being considered, where

$$\text{Relative effect} = \frac{\text{(g/vehicle-mile)(relative effect of air quality stds concentration)}}{\text{person/vehicle}}$$

These comparisons revealed that public transportation modes had lower CO and HC emission rates than automobiles, but higher SO_x and particulate emission rates (Table 6).

Noise—There is a lack of comparative data on noise levels because of the variety of data collection techniques and units of measure used in different studies. A survey taken in London indicated that local streets carrying bus traffic had average noise levels 0.5 to 4 dBA higher than those on local streets without bus traffic (12). Although levels even on the bus streets were well below the 70-dBA level likely to cause complaints, buses have noise characteristics similar to trucks and could be responsible for occasional annoying peaks throughout the day. The sound levels of rapid transit trains typically range from 81 to 110 dBA (4), but trains are generally confined to segregated corridors and would presumably not add significant noise to the street environment. The effect of elevated railways or personal rapid transit (PRT) systems could be more serious, however, depending on the type of system and its location. In any event, ambient noise caused by street traffic is high; if more use of public transit causes a decrease in traffic volume, a decrease could be expected in the level of ambient noise.

Natural Resources—Air and noise quality are not the only environmental factors of importance; energy requirements and resource consumption should be considered in future modal comparisons. Because of the current scarcity of energy sources, interest has focused on the efficiency of each transport mode in terms of fuel consumption. Figure 1 shows that, even with low average occupancy levels, public transport modes are considerably more efficient than automobiles in terms of passenger-miles per gallon (14). Policies that encourage increases of vehicle occupancy can significantly increase the efficiency of all modes but public modes are still likely to be more efficient because of their higher capacities.

Although energy consumption is an important issue, future studies of urban areas and their transportation problems need to examine other relationships of transportation to natural resources. One study that attempted to be more comprehensive concluded that "mass ownership of private automobiles is incompatible with any resource-conserving future, because autos and the industries they create are the predominant energy consumers in Western and Japanese society" (13). With this in mind, we can perhaps make more rational decisions regarding the structure of cities (including the applicability of AFZs) and the priorities to be placed on particular modes of transport. It appears that AFZs can be accessible to nonautomobile transit if they are properly located, but their effect on stimulating the use of nonautomobile modes is presently unknown. As for the nonautomobile modes themselves, they are generally more energy-conserving than autos; they emit less CO and HC per passenger-mile; and their use can

Table 5. Emission rates for various vehicle engines and operations.

Engine and Operations	CO	HC	NO_x	SO_x	Total
Automobile					
1970 standard	47	4.6	6.0	0.27	57.87
1975 standard	3.4	0.41	3.0	0.27	7.08
Bus, diesel					
Arterial street	28.3	1.65	36.3	5.2	78.53
Downtown	50.6	2.76	54.4	5.2	112.96
Bus, gas turbine					
Arterial street	4.0	0.20	10.5	5.2	19.90
Downtown	6.8	1.15	12.2	5.2	25.35
Commuter train					
Roots blown	1,040	80	234	48	1,402
Turbocharged	240	80	235	48	603
Rail transit					
Typical cycle	6.75	2.7	271	1,030	1,310

Note: Amounts are in grams/vehicle-mile, where 1 mile = 1.6 km.

Figure 1. Fuel efficiency of six urban transport modes.

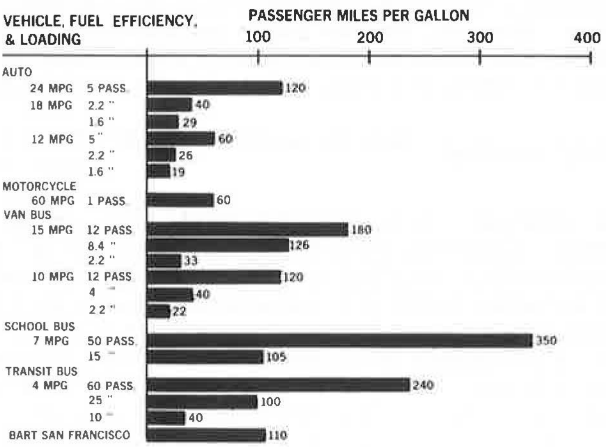

Table 6. Relative effects of emissions from 4 vehicle engines.

Engine and Operations	Gases					Particulates	Total
	CO	HC	NO_x	SO_x	Total		
Automobile							
1970 standard	0.24	1.56	3.27	0.18	5.25	0.25	5.50
1975 standard	0.02	0.14	1.63	0.18	1.97	0.25	2.22
Bus, diesel							
Arterial street	0.02	0.10	3.50	0.52	4.14	2.08	6.22
Bus, gas turbine							
Arterial street	0.003	0.012	0.97	0.52	1.50	2.08	3.58
Commuter train							
Turbocharged	0.004	0.08	0.58	0.10	0.76	0.33	1.09
Rail transit							
Typical cycle	0.00	0.002	0.72	3.40	4.12	1.54[a]	5.66

Note: Amounts are in grams/person-mile, where 1 mile = 1.6 km.

[a]Based on 7,250 g/ton (g/907 kg) of coal, 10 percent fly ash, and 80 percent collection efficiency on control equipment (by person-miles).

lead to lower ambient noise levels. Conversely, public transport modes generate greater emissions of SO_x and particulates and may be responsible for intermittent noise peaks. If it is found that the use of public transportation is stimulated by AFZs or by other resource-conserving strategies, then their ill effects should be made explicit from the start. Then true costs and benefits can be assessed, and appropriate measures applied.

CONCLUSIONS

The creation of an AFZ must be part of a comprehensive plan so that the overall environmental implications and the social and economic benefits can be properly assessed.

There is evidence to demonstrate that definite and often dramatic improvements in noise and air quality can be expected on streets where automobiles are banned. But, an AFZ can improve areawide environmental conditions only if specific conditions are achieved.

First, for regionwide markets, AFZs should be located in a central area because (a) travel distances to other points in the area will be short, resulting in less transport-related noise, air pollution, and resource consumption and (b) access by radially oriented transit systems will be high, encouraging some travelers to use public transit instead of automobiles. Automobile-free zones for neighborhood or district-scale markets should be near the junction of transit lines. This will ensure more transit access than a location along the midpoint of a single transit line would.

Second, the altered traffic patterns in areas adjacent to the AFZ should be anticipated so that traffic flows smoothly. Signal timing, street directions, and intersection geometrics should be adjusted where necessary. Parking should be strictly limited to certain off-street facilities to eliminate "cruising" by drivers looking for curb spaces. Streets used for rerouting traffic should be carefully chosen with respect to land use and existing pollution and noise levels. Increasing the parking supply by creating peripheral parking garages may enhance the economic feasibility of an AFZ but is likely to be counterproductive in terms of air quality and energy consumption.

Third, nonautomobile modes should be allowed to operate within the AFZ to encourage access by these modes. Bicycle lanes, especially, should be considered for access to the AFZ. If it is not feasible to allow public transit within the AFZ, transit stops should not be further away than automobile drop-off and parking areas. Undesirable effects of nonautomobile modes should be calculated in advance, and appropriate remedies applied if warranted.

The overall environmental effect of an AFZ depends entirely on its size and importance in relation to the rest of the region. Because transportation is a major source of noise and air pollution, a large AFZ, which meets the criteria outlined above, may have a significant effect on reducing regionwide environmental hazards. A small AFZ, which meets the same criteria, might have no regional effect at all but may have a significant local effect. Environmental considerations, which have in the past played a small role in urban decision-making, must be included in the planning process.

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