

EXHIBIT W

PROMOTING PHYSICAL ACTIVITY

A GUIDE FOR COMMUNITY ACTION

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Public Health Service
Centers for Disease Control and Prevention
National Center for Chronic Disease Prevention and Health Promotion
Division of Nutrition and Physical Activity

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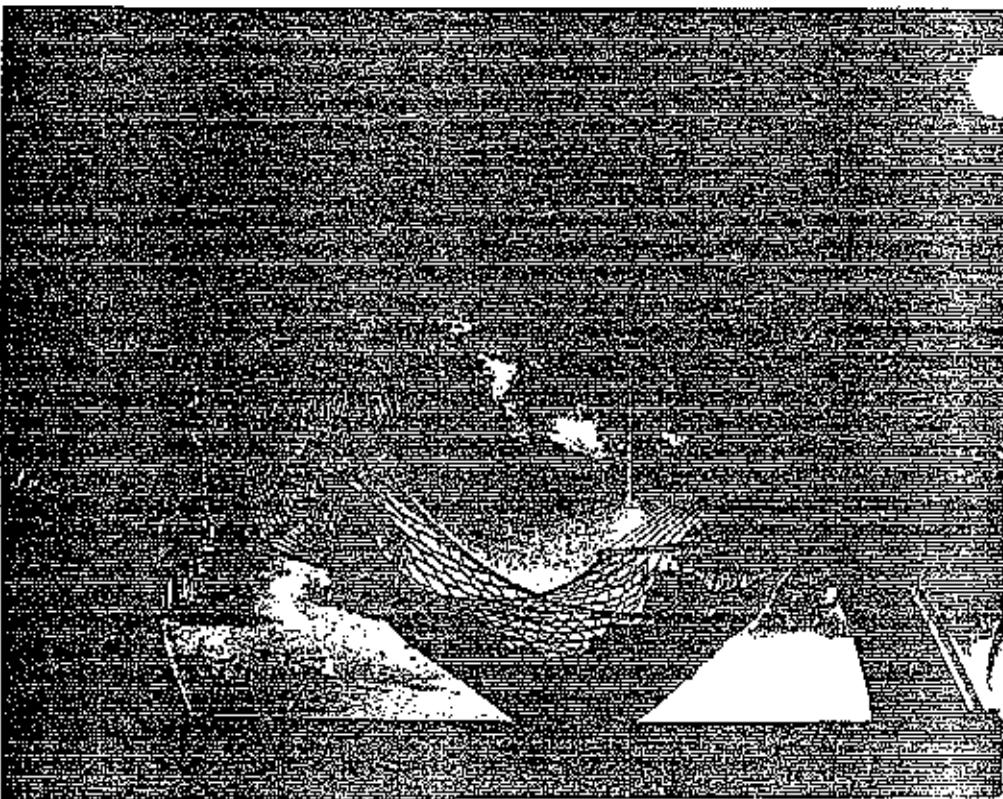
Human Kinetics

Battling the Real American Pastime: Inactivity

Some Americans do participate in daily physical activity, but far too many are less than optimally active. Although Americans have been told over and over that a commitment to regular exercise and a healthy diet can reap health benefits, far too many of them remain sedentary and unmotivated to make a lifestyle change to improve their health and well-being. In your work to promote physical activity, it will help to know what the health risks are to the sedentary population and just how widespread inactivity is. Armed with that information, you'll have a clearer picture of whom to target and the negative consequences of inactivity that you need to communicate to inactive Americans.

Several national data sets have demonstrated that about 30% of American adults report no leisure-time physical activity and an additional 30% are not sufficiently active to achieve health benefits. These data have not changed over the past decade (USDHHS 1996; Jones et al. 1998). State-based Behavioral Risk Factor Surveillance Data 1996 demonstrate that the problem of physical inactivity is widespread throughout the United States, with estimates of no reported leisure-time physical activity ranging from a low of 17.1% in the most active state, Utah, to a high of 51.4% in the least active state of Georgia (CDC 1998).

sedentary lifestyle—
a lifestyle characterized by little or no physical activity. In scientific literature, *sedentary* is often defined in terms of little or no leisure-time physical activity.



Inactivity Among Adults

Current research on physical activity and health focuses on leisure-time physical activity. While some adults may have physically demanding jobs, most do not. Because most jobs require minimal amounts of physical activity, the choices made during leisure time represent the majority of health-related physical activity. Health promotion efforts may be effective in changing choices during leisure time, which may incorporate time at work (i.e., during lunch breaks), but are unlikely to be successful in changing the activity level associated with a particular occupation. Because of this, national data sets have collected information on physical activity during leisure time, and have only begun to explore occupation-related activity levels.

Data on adults collected from several sources consistently find that (Jones et al. 1998)

- approximately 60% of adults are not sufficiently active to achieve health benefits and about 30% report no leisure-time physical activity (see figure 1.1);
- participation in leisure-time physical activity decreases as age increases;
- women are less likely than men to engage in moderate or vigorous physical activity; and
- African-American and Hispanic adults are less likely to be physically active than white adults.

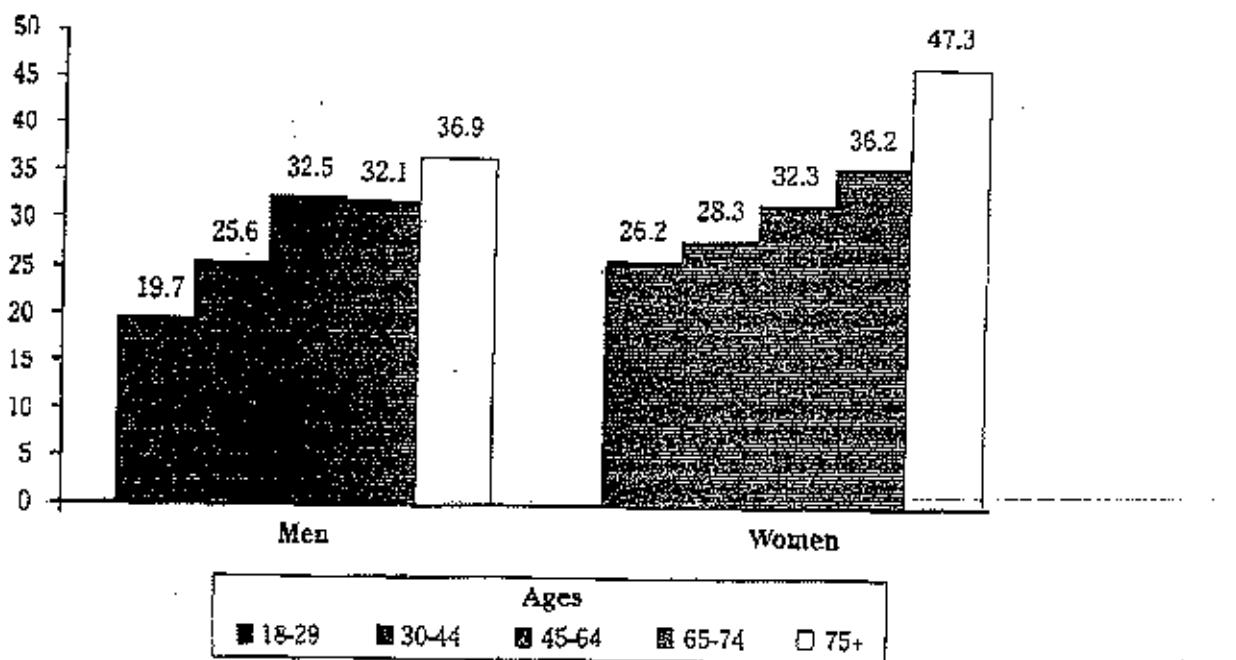


Figure 1.1 Percentage of U.S. adults age 18 and older reporting no leisure-time physical activity during the past month.
Data from BRFSS 1996 (CDC 1998)

Inactivity Among Youth

American youth are also less than optimally active. Results of the 1997 Youth Risk Behavior Surveillance (YRBS) (Kann et al. 1998; USDHHS 1996), a national school-based survey of 9-12th graders, revealed that:

- 36% of youth do not engage in vigorous activity consistently or strenuously enough to maintain or improve cardiorespiratory fitness;
- girls are less likely than boys to engage in vigorous activity;
- African-American and Hispanic youth tend to be less vigorously active than white youth;
- participation in physical activity decreases as grade in school increases (see figure 1.2).

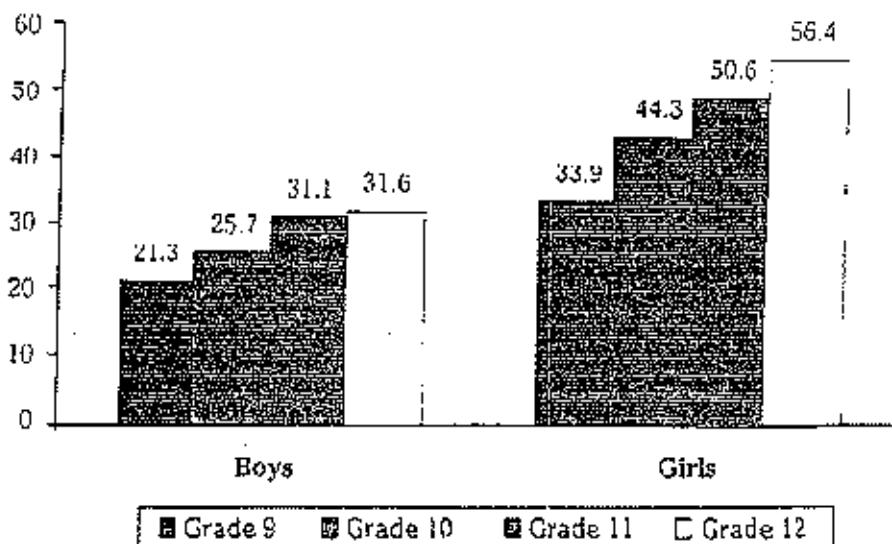


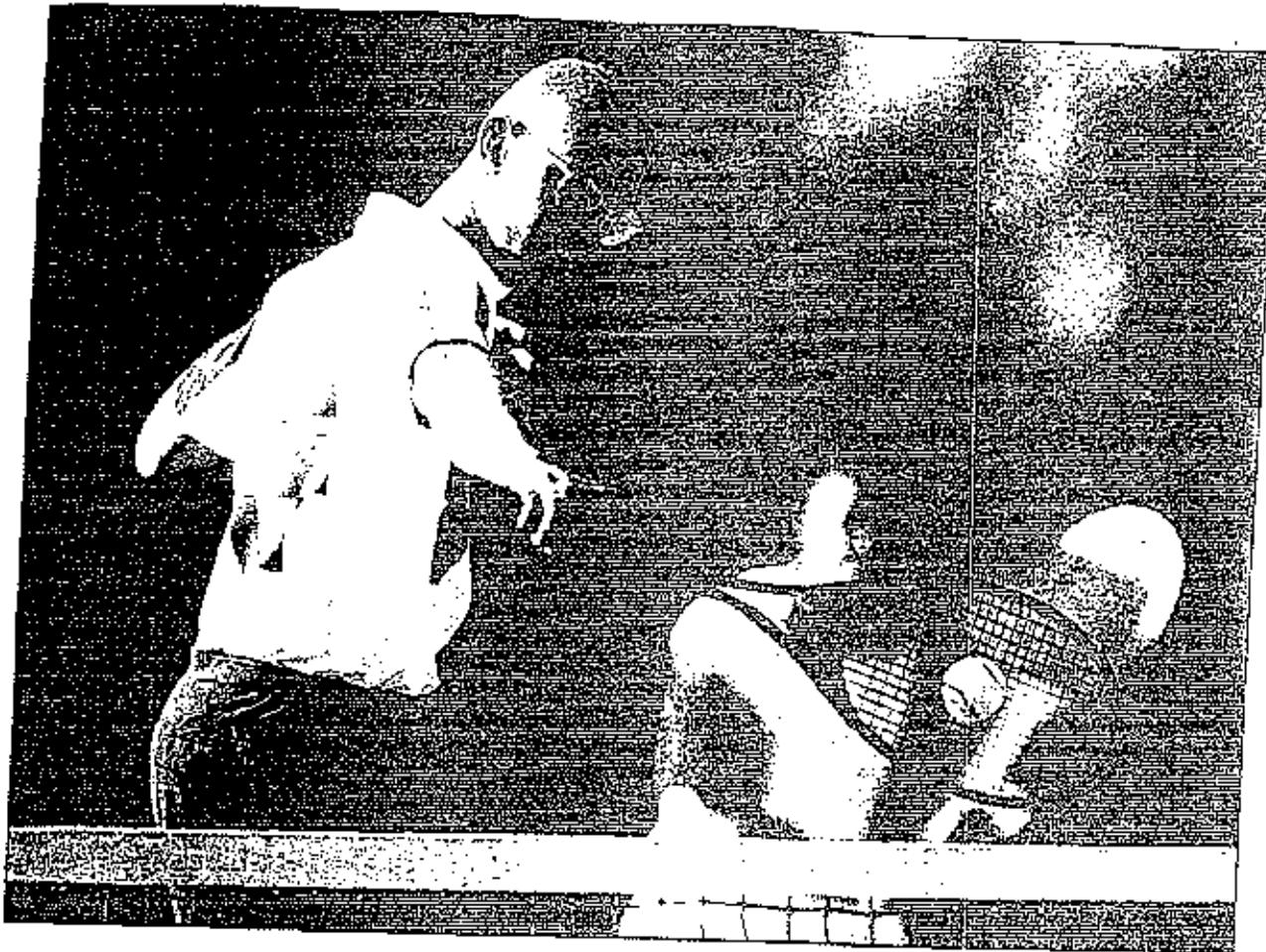
Figure 1.2 Percentage of U.S. high school students reporting no vigorous activity during the previous seven days.
Data from YRBS 1997 (Kann et al. 1998)

Although youth are a more active segment of the U.S. population when compared to adults, the important thing to note about youth activity patterns is the drastic change that takes place in the 11-13 age range. As grade in school increases, a number of factors create personal and environmental barriers to physical activity and make it less likely that adolescents will continue an active lifestyle into adulthood.

Consequences of Inactivity

The closer we look at the health risks associated with physical inactivity, the more convincing it is that the two out of three Americans who are not moderately physically active should become active. Premature death and cardiovascular disease are "complications" of physical inactivity that ought to get Americans to take notice. Studies by Paffenbarger and associates (1993) and Blair and associates (1995) showed that previously sedentary unfit men who became moderately physically active or fit had lower de-

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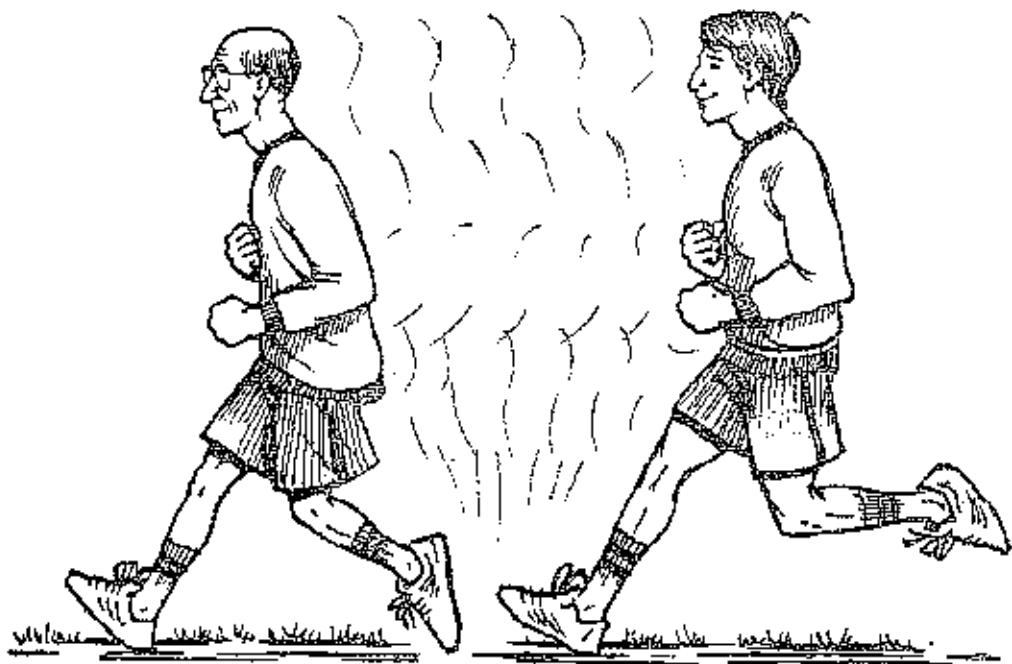


rates than those who remained sedentary or unfit (figure 1.3). Research like that ought to be compelling enough to get Americans to be more physically active!

In a study of 11,130 Harvard University alumni, researchers found that people who expended 1,000 kilocalories per week—the equivalent of walking briskly 30 minutes a day, 5 days a week—had about a 24% reduction in their risk of stroke, a leading cause of disability in the United States. Meanwhile, those expending 2,000 kilocalories each week—the equivalent of a one-hour brisk walk, 5 days a week—had a 46% lower risk of stroke than those who did little or no exercise (Lee and Paffenbarger 1998).

High blood pressure, an important risk factor for both coronary heart disease and stroke, has also been associated with inactivity. A 1984 study by Blair and colleagues reported that people with low cardiorespiratory fitness had a 52% higher risk of later developing high blood pressure than their physically fit peers, and studies by Arroll and Beaglehole (1992) and Kelley and McClellan (1994) have shown that both systolic and diastolic blood pressure are reduced by approximately 6–7 mm Hg through aerobic exercise. If physical activity can reduce elevated blood pressure, thereby reducing the risk of cardiovascular disease, and if physical inactivity puts people at risk for developing high blood pressure, then it seems obvious that physical activity, taken in the right "doses" and at the right intensity, is an important key to preventing cardiovascular disease.

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Paffenbarger and associates (1993) studied men over an 11-year period. Those who were sedentary at the beginning of the study and took up moderately-intense sports activity had a 23% lower death rate than those who remained sedentary.

Blair and associates (1995) found that men who were in the bottom fifth in terms of cardiorespiratory fitness at the beginning of the study and later improved to at least a moderate level of fitness had a 44% lower death rate than those who remained in the bottom fifth for cardiorespiratory fitness.

Figure 1.3 Two large studies provide evidence that changing from lower to higher levels of physical activity or cardiorespiratory fitness has an effect on subsequent mortality.

Suggested Reading

For a list of organizations, agencies, and selected program materials for promoting physical activity see:

Resource A. for general resources

Chapter 6. for environment-related resources

Chapter 9. for worksite-related resources

Chapter 10. for school-related resources

Physical Activity and Health: A Report of the Surgeon General

To obtain a copy of the report: U.S. Department of Health and Human Services. *Physical Activity and Health: A Report of the Surgeon General*. Atlanta: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Chronic Disease Prevention and Health Promotion, 1996. Order forms are available via telefax by calling toll-free 1-888-CDC-4NRG (1-888-232-4674), or set your Internet browser to the following address <http://www.cdc.gov/nccdphp/sgr/sgr.htm>. (Also available: an Executive Sum-

mary, At-A-Glance Summary, and a set of consumer fact sheets. These items are also reproduced in Resource B of this publication.)

NIH Consensus Conference: Physical Activity and Cardiovascular Health

A copy of the summary report of the NIH Consensus Conference is available by calling toll-free 800-NIH-OMAR (644-6627), by visiting the Internet at the following address: <http://www.text.nlm.nih.gov/nih/nih.html>, or by obtaining a copy of the article with the following citation: NIH Consensus Development Panel on Physical Activity and Cardiovascular Health. *Journal of the American Medical Association* July 17, 1996; 276(3):241-246. The full papers have also been compiled into a book, available from Human Kinetics: A. Leon, editor. *Physical Activity and Cardiovascular Health: A National Consensus*. Champaign, IL: Human Kinetics, 1997. To order, call 800-747-4457 or visit <http://www.humankinetics.com>.

For periodic reviews of current research related to physical activity and fitness, review:

Physical Activity and Fitness Research Digest published by:

The President's Council on Physical Fitness and Sports
Department of Health and Human Services
Humphrey Bldg. Room 738H
200 Independence Ave. SW
Washington, DC 20201
202-272-3421

For more information about BRFSS and YRBS

To understand the Behavioral Risk Factor Surveillance System (BRFSS) and how to interpret these survey data, review the specific physical activity-related definitions used for each category of respondents (Caspersen and Morris 1995; USDHHS 1990). To obtain the most current BRFSS statistics for your state, contact your BRFSS Coordinator at your state health department or visit <http://www.cdc.gov/nccdphp/brfss>.

For the most current information on physical activity levels among youth, contact your state Department of Education to determine whether your state participates in Youth Risk Behavior Surveillance (YRBS), a system that collects data on the health behaviors of high school students. To obtain more information about the YRBS, review Kann et al. 1998 or visit <http://www.cdc.gov/nccdphp/dash>.

For more information about the economic impact of physical activity and physical inactivity, read:

Jones, TF and CB Eaton. 1994. Cost-benefit analysis of walking to prevent coronary heart disease. *Archives of Family Medicine* 3: 703-710.

Keeler, EB, WG Manning, et al. 1980. The external costs of a sedentary lifestyle. *American Journal of Public Health* 79: 975-981.

For information about Americans' attitudes toward physical activity read:

Rodale Press Inc. and Parkwood Research Associates. 1995. *Pathways for People II: Americans' Attitudes Toward Walking, Bicycling and Running in Their Communities*. Summary Report. Emmaus, PA: Rodale Press. (May).

EXHIBIT X

Special Communication

Physical Activity and Public Health

A Recommendation From the Centers for Disease Control and Prevention and the American College of Sports Medicine

Russell A. Pate, PhD; Michael Pratt, MD, MPH; Steven N. Blair, PED; William L. Haskell, PhD; Caroline A. Macera, PhD; Claude Bouchard, PhD; David Buchner, MD, MPH; Walter Ehringer, MD; Gregory W. Heath, DHS; Abby C. King, PhD; Andrea Kriska, PhD; Arthur S. Leon, MD; Bass H. Marcus, PhD; Jeremy Morris, MD; Ralph S. Paffenberger, Jr., MD; Kevin Patrick, MD; Michael L. Pollock, PhD; James M. Rippe, MD; James Sallis, PhD; Jack H. Wilmore, PhD

Objective.—To encourage increased participation in physical activity among Americans of all ages by issuing a public health recommendation on the types and amounts of physical activity needed for health promotion and disease prevention.

Participants.—A planning committee of five scientists was established by the Centers for Disease Control and Prevention and the American College of Sports Medicine to organize a workshop. This committee selected 15 other workshop discussants on the basis of their research expertise in issues related to the health implications of physical activity. Several relevant professional or scientific organizations and federal agencies also were represented.

Evidence.—The panel of experts reviewed the pertinent physiological, epidemiologic, and clinical evidence, including primary research articles and recent review articles.

Consensus Process.—Major issues related to physical activity and health were outlined, and selected members of the expert panel drafted sections of the paper from this outline. A draft manuscript was prepared by the planning committee and circulated to the full panel in advance of the 2-day workshop. During the workshop, each section of the manuscript was reviewed by the expert panel. Primary attention was given to achieving group consensus concerning the recommended types and amounts of physical activity. A concise "public health message" was developed to express the recommendations of the panel. During the ensuing months, the consensus statement was further reviewed and revised and was formally endorsed by both the Centers for Disease Control and Prevention and the American College of Sports Medicine.

Conclusion.—Every US adult should accumulate 30 minutes or more of moderate-intensity physical activity on most, preferably all, days of the week.

(*JAMA*. 1995;273:402-407)

REGULAR physical activity has long been regarded as an important component of a healthy lifestyle. Recently, this impression has been reinforced by new

scientific evidence linking regular physical activity to a wide array of physical and mental health benefits.¹⁻¹¹ Despite this evidence and the public's apparent

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Department of Health Research and Policy, Stanford University (Dr Paffenberger); Center for Preventive Medicine, University of California, San Diego, and San Diego State University (Dr Pollock); Departments of Medicine and Exercise Science, University of Florida Gainesville (Dr Pollock); Center for Clinical and Lifestyle Research, Tulane University, New Orleans, Miss (Dr Rippe); Department of Psychology, San Diego State University (Dr Sallis); Department of Kinesiology and Health Education, University of Texas at Austin (Dr Wilmore).

This statement and its recommendations are endorsed and supported by the Committee on Exercise and Cardiac Rehabilitation, Council on Clinical Cardiology, American Heart Association.

Reprint requests to Department of Exercise Science, University of South Carolina School of Public Health, Columbia, SC 29208 (Dr Pate).

acceptance of the importance of physical activity, millions of US adults remain essentially sedentary.⁸

If our sedentary society is to change to one that is more physically active, health organizations and educational institutions must communicate to the public the amounts and types of physical activity that are needed to prevent disease and promote health. These organizations and institutions, providers of health services, communities, and individuals must also implement effective strategies that promote the adoption of physically active lifestyles.

A group of experts was brought together by the Centers for Disease Control and Prevention (CDC) and the American College of Sports Medicine (ACSM) to review the pertinent scientific evidence and to develop a clear, concise "public health message" regarding physical activity. The panel of experts also considered the organizational initiatives that should be implemented to help US adults become more physically active.

The focus of this article is on physical activity and the health benefits associated with regular, moderate-intensity physical activity. Physical activity has been defined as "any bodily movement produced by skeletal muscles that results in energy expenditure."¹² Moderate physical activity is activity performed at an intensity of 3 to 6 METs (work metabolic rate/resting metabolic rate)—the equivalent of brisk walking at 3 to 4 mph for most healthy adults. Physical activity is closely related to, but distinct from, exercise and physical fitness. Exercise is a subset of physical activity defined as "planned, structured, and repetitive bodily movement done to improve or maintain one or more components of physical fitness."¹³ Physical fitness is "a set of attributes that people have or achieve that relates to the ability to perform physical activity."¹⁴

This article summarizes the work of an aforementioned expert panel and has two purposes. First, we recommend the amounts and types of physical activity that are needed by adults for good health and summarize the scientific basis for this recommendation. Second, we recommend the ways that public health organizations, educational institutions, health care providers, communities, and individuals can effectively promote physical activity through more effective educational programs and the creation of programs and facilities that make it easier for people to become and remain more active. This article builds on existing recommendations, including *Healthy People 2000*,¹⁰ the Guide to Clinical Preventive Services,¹¹ the ACSM's "Position Stand on the Recommended Quality and Quantity of Exercise for Developing and Maintaining Cardiorespiratory and Muscular Fitness in Healthy Adults,"¹² and the American Heart Association's recent "Statement on Exercise."¹³ This article is not meant to be a definitive review of the many health aspects of physical activity; a thorough discussion can be found elsewhere.¹⁴

RELATIONSHIP BETWEEN PHYSICAL ACTIVITY AND HEALTH

Cross-sectional epidemiologic studies^{15,16} and controlled, experimental investigations¹⁷ have demonstrated that physically active adults, as contrasted with their sedentary counterparts, tend to develop and maintain higher levels of physical fitness. Epidemiologic research has demonstrated protective effects of varying strength between physical activity and risk for several chronic diseases, including coronary heart disease (CHD),^{14,17,18} hypertension,^{19,20} non-insulin-dependent diabetes mellitus,^{21,22} osteoporosis,^{23,24} colon cancer,²⁵ and anxiety and depression.²⁶

Other epidemiologic studies have shown that low levels of habitual physical activity and low levels of physical fitness are associated with markedly increased all-cause mortality rates.^{12,27} A midlife increase in physical activity is associated with a decreased risk of mortality.²⁸ It has been estimated that as many as 250,000 deaths per year in the United States, approximately 12% of the total, are attributable to a lack of regular physical activity.²⁹

The conclusions of these epidemiologic studies are supported by experimental studies showing that exercise training improves CHD risk factors and other health-related factors, including blood

lipid profile,³⁰ resting blood pressure in borderline hypertensives,^{31,32} body composition,³³⁻³⁵ glucose tolerance and insulin sensitivity,^{36,37} bone density,³⁸ immune

function,^{39,40} and psychological function.⁴¹

Epidemiologic criteria used to establish causal relationships can be applied to the association between physical activity and CHD.⁴² The following principles of causality appear to have been met: Consistency: The association of physical inactivity and risk of CHD is observed in a number of settings and populations, with the better-designed studies showing the strongest associations. Strength: The relative risk of CHD associated with physical inactivity ranges from 1.5 to 2.4, an increase in risk comparable with that observed for hypercholesterolemia, hypertension, and cigarette smoking.⁴³ Temporal sequencing: The observation of physical inactivity predates the diagnosis of CHD. Dose response: Most studies demonstrate that the risk of CHD increases as physical activity decreases. Plausibility and coherence: Physical activity reduces the risk of CHD through a number of physiological and metabolic mechanisms. These include the potential for increasing the level of high-density lipoprotein cholesterol; reducing serum triglyceride levels; reducing blood pressure; enhancing fibrinolysis and altering platelet function, thereby reducing the risk of acute thrombosis; enhancing glucose tolerance and insulin sensitivity; and reducing the sensitivity of the myocardium to the effects of catecholamines, thereby reducing the risk of ventricular arrhythmias.⁴⁴⁻⁴⁸

DESCRIPTIVE EPIDEMIOLOGY OF PHYSICAL ACTIVITY

Physical activity recommendations in *Healthy People 2000*¹⁰ are to "[i]ncrease to at least 30 percent the proportion of people aged 6 and older who engage regularly, preferably daily, in light to moderate physical activity for at least 30 minutes per day." However, only about 22% of adults are active at this level recommended for health benefits, 54% are somewhat active but do not meet this objective, and 24% or more are completely sedentary (ie, reporting no leisure-time physical activity during the past month). Participation in regular physical activity gradually increased during the 1960s, 1970s, and early 1980s, but seems to have plateaued in recent years.⁴⁹

Patterns of physical activity vary with demographic characteristics (Table 1). Men are more likely than women to engage in regular activity,⁵⁰ in vigorous exercise, and sports.⁵¹ The total amount of time spent engaging in physical activity declines with age.^{52,53} Adults at retirement age (65 years) show some increased participation in activities of light to moderate intensity, but, overall, physical activity declines continuously as age increases.^{54,55} African Americans

Table 1—Proportion of Adults Reporting No Leisure-Time Physical Activity Within the Last Month, 1991 Behavioral Risk Factor Surveillance System*

Demographic Group	Sedentary, % (95% CI)
Sex	
Male	27.69 (27.18-28.50)
Female	31.48 (30.55-32.11)
Race	
White	27.75 (27.24-28.26)
Nonwhite	37.92 (36.27-38.77)
Age, y	
18-34	23.77 (23.01-24.53)
35-54	29.50 (28.70-30.30)
≥55	30.00 (27.10-30.99)
Annual income, \$	
≤14,999	30.46 (29.06-31.22)
15,000-24,999	32.00 (30.90-33.10)
25,000-59,999	33.78 (32.63-34.93)
≥60,000	28.64 (17.50-19.62)
Education	
Some high school	38.08 (40.75-40.37)
High school	33.57 (32.79-34.36)
Tech school graduate	
Some college	
College graduate	20.16 (19.35-20.77)

*A population-based random-digit-dial telephone survey with 67,433 respondents aged 18 years and older from 47 states and the District of Columbia. Data are weighted, and point estimates and confidence intervals (CI) are calculated using the FBBUPWATT procedure to adjust for the complex sampling frame.⁵⁶

and other ethnic minority populations are less active than white Americans,^{57,58} and this disparity is more pronounced for women.⁵⁹ People with higher levels of education participate in more leisure-time physical activity than do people with less education.⁵⁹ Differences in education and socioeconomic status account for most, if not all, of the differences in leisure-time physical activity associated with race/ethnicity.⁵⁹

DETERMINANTS OF PARTICIPATION IN PHYSICAL ACTIVITY

Physiological, behavioral, and psychological variables are related to physical activity.⁶⁰⁻⁶² A lack of time is the most commonly cited barrier to participation in physical activity,⁶³ and injury is a common reason for stopping regular activity. Cigarette smoking is only weakly inversely related to participation in physical activity, but smokers are more likely than nonsmokers to drop out of exercise programs.⁶⁴ Body composition (percentage of body fat) is not a powerful predictor of physical activity habits; however, persons who are obese are usually inactive.⁶⁵

An intention to exercise and awareness of the benefits of exercise are weakly related to participation in physical activity.⁶⁶ Confidence in the ability to be physically active, perceived barriers to activity, and enjoyment of activity are strongly related to participation.⁶⁷ Low- to moderate-intensity physical activities are more likely to be continued than high-intensity activities.⁶⁸ Self-regulatory skills, such as goal set-

Table 2—Examples of Common Physical Activities for Healthy US Adults by Intensity of Effort Required in MET Scores and Kilocalories per Minute*

Light (<3.0 METs or <4 kcal·min ⁻¹)	Moderate (3.0–6.0 METs or 4.7 kcal·min ⁻¹)	Hard/Vigorous (>6.0 METs or >7 kcal·min ⁻¹)
Walking, slowly (strolling) (1–2 mph)	Walking, briskly (3–4 mph)	Walking, briskly uphill or with a load
Cycling, stationary (<35 W)	Cycling for pleasure or transportation (<10 mph)	Cycling, fast or racing (>10 mph)
Swimming, slow treading	Swimming, moderate effort	Swimming, fast treading or crawl
Conditioning exercise, light stretching	Conditioning exercise, general calisthenics	Conditioning exercise, static ergometer, ski machine
Racket sports, table tennis	Racket sports, singles tennis, racketball	
Golf, power cart	Golf, pushing cart or carrying clubs	
Bowling		
Fishing, sitting	Fishing, standing/leisure	Fishing at distance
Boating, power	Camping, leisurely (2.0–3.5 mph)	Camping, rapidly (24 mph)
Home care, carpet sweeping	Home care, general cleaning	Moving furniture
Mowing lawn, riding mower	Mowing lawn, power mower	Mowing lawn, hand mower
Home repair, carpentry	Home repair, painting	

*Data from Ainsworth et al.,¹² Leon et al.,¹³ and MacFarlane et al.¹⁴ The first 1.5 work metabolic rate (resting metabolic rate) are multiples of the resting rate of oxygen consumption during physical activity. One MET represents the approximate rate of oxygen consumption of a seated adult at rest, or about 3.5 mL·min⁻¹·kg⁻¹. The equivalent energy cost of 1 MET in kilocalories·min⁻¹ is about 1.2 for a 70-kg person, or approximately 1 kcal·kg⁻¹·hr⁻¹.

ting, self-monitoring progress, and self-reinforcement, contribute to continued physical activity.¹⁴

A number of physical and social environmental factors can affect physical activity behavior.¹⁵ Family and friends can be role models, provide encouragement, or be companions during physical activity. The environment often presents important barriers to participation in physical activity, including a lack of bicycle trails and walking paths away from traffic, inclement weather, and unsafe neighborhoods.¹⁶ Excessive television viewing may also deter persons from being physically active.¹⁷

PHYSICAL ACTIVITY RECOMMENDATION FOR ADULTS

The current low-participation rate may be due in part to the misperception of many people that to reap health benefits they must engage in vigorous, continuous exercise. The scientific evidence clearly demonstrates that regular, moderate-intensity physical activity provides substantial health benefits. After review of physiological, epidemiologic, and clinical evidence, an expert panel formulated the following recommendation:

Every US adult should accumulate 30 minutes or more of moderate-intensity physical activity on most, preferably all, days of the week.

This recommendation emphasizes the benefits of moderate-intensity physical activity and of physical activity that can be accumulated in relatively short bouts. Adults who engage in moderate-intensity physical activity—ie, enough to expend approximately 200 calories per day—can expect many of the health ben-

efits described herein. To expend these calories, about 30 minutes of moderate-intensity physical activity should be accumulated during the course of the day. One way to meet this standard is to walk 2 miles briskly. Table 2 provides examples of moderate-intensity physical activities.

Intermittent activity also confers substantial benefits.^{18–20} Therefore, the recommended 30 minutes of activity can be accumulated in short bouts of activity: walking up the stairs instead of taking the elevator, walking instead of driving short distances, doing calisthenics, or pedaling a stationary cycle while watching television. Gardening, housework, raking leaves, dancing, and playing actively with children can also contribute to the 30 minute-per-day total if performed at an intensity corresponding to brisk walking. Those who perform lower-intensity activities should do them more often, for longer periods of time, or both.

People who prefer more formal exercise may choose to walk or participate in more vigorous activities, such as jogging, swimming, or cycling for 30 minutes daily. Sports and recreational activities, such as tennis or golf (without riding a cart), can also be applied to the daily total.

Because most adults do not currently meet the standard described herein, almost all should strive to increase their participation in physical activity that is of at least moderate intensity. Those who do not engage in regular physical activity should begin by incorporating a few minutes of increased activity into their day, building up gradually to 30 minutes per day of physical activity. Those who are active on an irregular

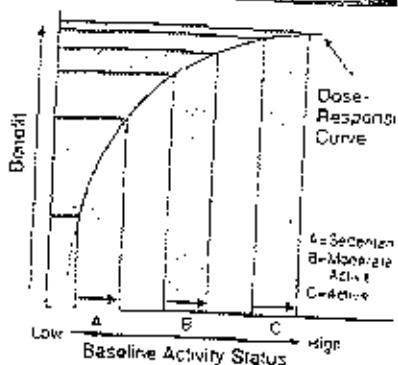


Figure 1.—The dose-response curve represents the best estimate of the relationship between physical activity (dose) and health benefit (response). The lower the baseline physical activity status, the greater will be the health benefit associated with given increase in physical activity (arrows A, B, and C).

basis should strive to adopt a more consistent activity pattern.

The health benefits gained from increased physical activity depend on the initial activity level (Figure 1). Sedentary individuals are expected to benefit most from increasing their activity to the recommended level. People who are physically active at a level below the standard would also benefit from reaching the recommended level of physical activity. People who already meet the recommendation are also likely to derive some additional health and fitness benefits from becoming more physically active.

Most adults do not need to see their physician before starting a moderate-intensity physical activity program.²¹ However, men older than 40 years and women older than 50 years who plan a vigorous program (intensity >60% individual maximum oxygen consumption, Table 1) or who have either chronic disease or risk factors for chronic disease should consult their physician to design a safe, effective program.²²

PREVIOUS EXERCISE RECOMMENDATIONS

The recommendation presented in this article is intended to complement, not supersede, previous exercise recommendations. In the past, exercise recommendations (including those from the ACSM) were based on scientific studies that investigated dose-response improvements in performance capacity after exercise training, especially the effects of endurance exercise training on maximal aerobic power (maximum oxygen consumption). The recommendations usually involved 30 to 60 minutes of moderate- to high-intensity endurance exercise (60% to 90% of maximum heart rate or 50% to 85% of maximal aerobic power) per-

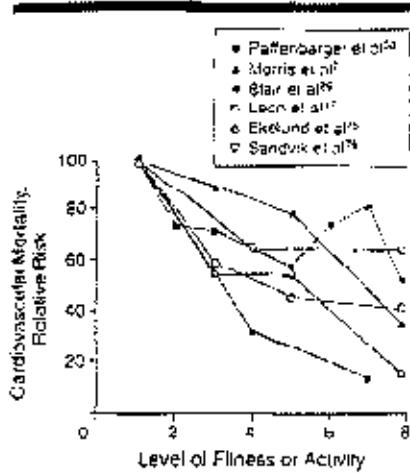


Figure 2.—The relationship between level of physical activity (Paffenbarger et al.,²² Morris et al.,²³ and Leon et al.²⁴) or exercise capacity (Blair et al.,²⁵ Ekelund et al.,²⁶ and Sandvik et al.,²⁷) and coronary heart disease mortality. Values for more active or fit persons are expressed as the ratio of the event rate for more active or fit divided by the event rate for least active or fit.

formed three or more times per week.

Although the earlier exercise recommendations were based on documented improvements in fitness, they probably provide most of the disease prevention benefits associated with an increase in physical activity. However, it now appears that the majority of these health benefit can be gained by performing moderate-intensity physical activities outside of formal exercise programs.

UNIQUE ASPECTS OF THE NEW RECOMMENDATION

The new recommendation extends the traditional exercise-fitness model to a broader physical activity-health paradigm. The recommendation is distinct in two important ways. First, the health benefits of moderate-intensity physical activity are emphasized. Second, accumulation of physical activity in intermittent, short bouts is considered an appropriate approach to achieving the activity goal. These unique elements of the recommendation are based on mounting evidence indicating that the health benefits of physical activity are linked principally to the total amount of physical activity performed. This evidence suggests that amount of activity is more important than the specific manner in which the activity is performed (ie, mode, intensity, or duration of the activity bouts).

The health benefits of physical activity appear to accrue in approximate proportion to the total amount of activity performed, measured as either caloric expenditure or minutes of physical activity (Figure 2). For example, observational studies have shown a signifi-

cantly lower death rate from CHD in people who perform an average of 47 minutes vs 15 minutes of activity per day,²² and in men who expend an estimated 2000 or more calories per week vs those who expend 600 or fewer calories per week.²⁵ Five of the six studies shown in Figure 2 included men only; however, the relationship between physical fitness and cardiovascular disease mortality was identical for men and women in the one study that included both.²⁷

There is a clear association between total daily or weekly caloric expenditure and cardiovascular disease mortality. In most of the epidemiologic studies that have demonstrated this association, physical activity was assessed by questionnaires, and total activity was summed during periods ranging from 1 day to 1 year and then reported as average daily or weekly levels of physical activity. For example, among Harvard alumni the summed activity consisted of blocks walked, flights of stairs climbed, and moderate and vigorous sports play.²² In the Multiple Risk Factor Intervention Trial,²⁸ the most frequently reported activities were lawn and garden work (80% of men), walking (65%), and home repairs (50%). It is not possible to ascertain with certainty whether the activity reported in these studies was performed in single, continuous daily bouts or was accumulated in multiple episodes. However, the nature of the most frequently reported activities suggests that it is unlikely that most of the activity was performed continuously. It is more likely that the daily or weekly caloric expenditures reflect accumulation of activity, most of which was performed intermittently. Also, the activities most commonly reported in these studies (eg, walking, lawn work, and gardening) typically are performed at moderate intensity (Table 2).

Two published experimental studies have addressed the effects of continuous vs intermittent activity on fitness.^{29,30} DeBush et al.²⁹ examined the effects of three 10-minute bouts of moderate to vigorous activity daily compared with a single 30-minute daily period of exercise of equal intensity in men. Ebisuzaki studied the effects of running on fitness and blood lipids in three groups of men. Subjects were divided into three exercise groups and one inactive control group. Each exercise group ran the same total distance, but in one, two, or three sessions daily. In both studies, fitness (measured as maximal oxygen uptake) increased significantly in all exercise groups, and the differences in fitness across the exercising groups were not significant. In the latter study, high-density lipoprotein cholesterol levels in-

creased significantly only in the group that exercised three times per day.³⁰

Although more research is needed to better elucidate the health effects of moderate- vs high-intensity activity and intermittent vs continuous activity, clinicians and public health practitioners must rely on the most reasonable interpretation of existing data to guide their actions. We believe that the most reasonable interpretation of the currently available data is that (1) caloric expenditure and total time of physical activity are associated with reduced cardiovascular disease incidence and mortality; (2) there is a dose-response relationship for this association; (3) regular moderate physical activity provides substantial health benefits; and (4) intermittent bouts of physical activity, as short as 6 to 10 minutes, totaling 30 minutes or more on most days provide beneficial health and fitness effects.

MUSCULAR STRENGTH AND FLEXIBILITY

The preceding recommendation addresses the role of endurance exercise in preventing chronic diseases. However, two other components of fitness—flexibility and muscular strength—should not be overlooked. Clinical experience and limited studies suggest that people who maintain or improve their strength and flexibility may be better able to perform daily activities, may be less likely to develop back pain, and may be better able to avoid disability, especially as they advance into older age. Regular physical activity also may contribute to better balance, coordination, and agility, which in turn may help prevent falls in the elderly.³¹

CALL TO ACTION

Successfully changing our sedentary society into an active one will require effective dissemination and acceptance of the message that moderate physical activity confers health benefits.

Public Health Agencies

The public health community will need to strengthen its leadership role if improvement in population levels of physical activity is to occur. The CDC, the ACSM, the President's Council on Physical Fitness and Sports, and the American Heart Association have been leaders in promoting physical activity and will continue to be crucial in this effort. However, new partners must also be enlisted. State and local health departments, departments of public transportation and planning, parks and recreation associations, state and local councils on physical fitness, environmental groups, and the sports and recreation

industry all have interests that coincide with the public health goal of making our society more active.

Health Professionals

Physicians and other health professionals should routinely counsel patients to adopt and maintain regular physical activity. Physicians can be effective proponents of physical activity because patients respect physicians' advice and change their exercise behaviors as a result.²⁹ The large number of primary care physicians and the frequency with which Americans visit them³⁰ suggest that even modestly effective physician counseling would have a substantial public health impact.

Inadequate reimbursement, limited physician knowledge of the benefits of physical activity, lack of training in physical activity counseling, and inadequate knowledge of effective referral are barriers to achieving these goals. While policymakers work to improve reimbursement for preventive services, educators of physicians and other health professionals should develop effective ways to teach physical activity counseling and incorporate them into curricula for health professionals. In response to this need, the PACE (Physical Activity Counseling and Evaluation) program was recently developed. This approach relies on providing specific counseling protocols matched to the patient's level of activity and readiness to change.³¹ Preliminary evidence indicates that the PACE program is practical and effective in increasing physical activity among patients counseled in the primary care setting.³²

The personal physical activity practices of health professionals should not be overlooked. Health professionals should be physically active not only to benefit their own health but to make more credible their endorsement of an active lifestyle.

Special Populations

Special efforts will be required to target populations in which physical inactivity is particularly prevalent. These groups include the socioeconomically disadvantaged, the less educated, persons with disabilities, and older adults.

Interventions should be designed with input from the target population. Physical activity promotional efforts targeted to people with disabilities, or chronic disease, or to older adults should emphasize the importance of being physically active by routinely carrying out their daily activities with a minimum of assistance. There is clear evidence demonstrating that physiological and performance capacities can be improved

by regular physical activity in older adults³³⁻³⁵ and in persons with disabilities and/or chronic disease.³⁶

Communities

Institutions such as schools, worksites, and the medical community are specifically targeted in *Healthy People 2000*¹⁰ because they offer the means to reach most of the US population. Facilities in these institutions and the broader community can be used to a much greater extent. Corporate, government, school, and hospital policies should be restructured to encourage individuals to be active by making time and facilities available.

Organized programs emphasizing lifelong physical activity should be promoted in schools, worksites, and community organizations. Efforts should be made to develop walking trails and other exercise facilities, and to encourage walking and bicycling for transportation.

Educators

Schools should deliver comprehensive health and physical education programs that provide and promote physical activity at every opportunity.

Physical education curricula should be developmentally appropriate, provide youngsters with enjoyable experiences that build exercise self-efficacy, provide significant amounts of physical activity, and promote cognitive learning related to lifelong participation in physical activity. These curricula also should acquaint youngsters with physical activity resources in their community. The school environment should encourage physical activity for all students and promote development of physically active lifestyles. Educators at all levels should be good models of physical activity behavior.

Individuals and Families

Individuals can make modest adaptations in their physical and social environment to enhance their participation in physical activity. Parents should be physical activity role models for their children and support their children's participation in enjoyable physical activities.

CONCLUSIONS

If Americans who lead sedentary lives would adopt a more active lifestyle, there would be enormous benefit to the public's health and to individual well-being. An active lifestyle does not require a regimented, vigorous exercise program. Instead, small changes that increase daily physical activity will enable individuals to reduce their risk of chronic disease and may contribute to enhanced quality of life.

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EXHIBIT Y

NEAL PEIRCE

OBESITY

More and more Americans are overweight, and part of blame goes to suburban development styles



An obesity epidemic has seized America. And the suspected villain is none other than America's prized development icon: suburbia.

So far, there's no smoking gun, no irrefutable scientific evidence to prove that our spread-out, overwhelmingly auto-dependent way of living is expanding our paunches — and imperiling our health.

"It's like global warming," says Robert Yaro, executive director of the New York Regional Plan Association. "There's no conclusive proof. But there's enough strong circumstantial evidence that we better take it seriously."

What's indisputable is that we're getting heavier — rapidly. Thirty percent to 50 percent of Americans, depending on how severe the measure, are now overweight. Obesity — defined as roughly 30 pounds or more overweight — swelled 60 percent in the past decade, and now affects 22 percent of us.

One clear reason: almost a third of Americans are basically sedentary, with little or no exercise. Almost three-quarters of adults aren't active enough physically, according to the federal government's Centers for Disease Control and Prevention.

And now kids are falling into the same trap. A quarter of American children aged 6 to 17 are overweight, 11 percent seriously so, says the CDC. Not only have school sports and gym programs declined, but in today's spread-out suburbia of roaring freeways and highways, tiny percentages walk to school.

The implications are serious. Six of every 10 overweight children aged 5 to 10 already have one associated biochemical or clinical cardiovascular risk factor. Almost 80 percent of obese adults have diabetes, high cholesterol, high

Almost a third of Americans are basically sedentary, with little or no exercise.

blood pressure or coronary heart disease.

So why the soaring American Fat Factor? Some people blame couch potato TV-viewing, which is surely a factor. Others finger Big Macs and diet in general.

But none of those, say the experts, explain the magnitude of increased obesity in America. Something more pervasive — and damaging — is at work.

I like the simple explanation of Thomas Schmid, director of the CDC's Active Community Environments working group: "We sit in cars. We don't walk to the store on the corner. We ride the lawnmower instead of pushing it. We've engineered almost any kind of work out of our lives. That's why we're growing bigger."

Look behind most of those reasons and you find lurking an even more persistent, effective culprit — suburban development styles. America's post-World War II streets and community layouts weren't designed for people; they were designed for automobiles.

So what did we get? Residences on curvy, dead-end streets (often culs-de-sac) that feed into high-volume highways leading to segregated uses — shopping malls, office parks, government centers.

Traditional street grids encouraged walking and biking by facilitating shortest-possible travels between two points. Contemporary suburban development does just the opposite. Sidewalks are often missing. Roadways are designed for vehicular "throughput" and make foot or bike traffic downright dangerous.

Small wonder government

studies show that just between 1977 and 1995, trips that Americans made by walking decreased from 25 percent to 10 percent, while trips by auto rose from 84 percent to 90 percent.

There are disturbing international comparisons. In Italy, 54 percent of trips are by walking or bicycling; in Sweden (where it's cold and dark much of the year) 49 percent. In this gloriously hallowed Land of the Free and the Brave, we walk or cycle just 10 percent of the time.

Where's the cure? Maybe in reaching back over a century. In the late 1800s and early 1900s, Yaro notes, modern American city planning was pioneered by figures such as Frederick Law Olmsted, who pushed for major parks in our cities on the theory that getting people out into the fresh air and sunshine would combat tuberculosis and rickets then prevalent in the tenements of industrial workers. The public health and city planning movements developed at the same time.

Just maybe, there's a parallel today — that getting more people out of their cars, walking and biking and re-engaging an active lifestyle, can cut back on the wave of heart diseases, diabetes and associated diseases now afflicting this nation's people.

As long as smoking was an aesthetic issue, notes Yaro, nothing changed. But when it became a public health issue, the public reacted. He predicts the same now: "The correlations are strong; the science will follow shortly. Once the recognition sinks in — that our patterns of mobility and development are killing us and imperiling our kids — we're quite capable of forging a new public ethic about these issues."

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EXHIBIT Z

Diabetes considered 'emerging epidemic'

September 28, 1999

FREE PRESS NEWS SERVICES

Type 2 diabetes accounts for about nine of every 10 cases of diabetes. Medical experts don't know the exact cause of Type 2 diabetes, but its link to genetics is clear. A person can inherit a tendency to get Type 2 diabetes, but it usually takes another factor such as obesity to bring on the disease.

Type 2 diabetes used to be considered an adult form of the disease that typically occurred in overweight people after the age of 40. But a troubling trend has emerged: The disease is showing up with alarming frequency in children and adolescents.

"We consider this to be an emerging epidemic," says Dr. Arlan Rosenbloom, professor of pediatrics at the University of Florida in Gainesville. Medical professionals are blaming an increasingly overweight and sedentary society for the rising incidence of the disease among young people. Data from the National Health and Nutritional Examination Survey support this theory.

In 1963, only 4.1 percent of 6- to 11-year-olds were overweight. By 1994, the number had more than doubled to 10.6 percent, while the number of overweight teens also doubled.

"This problem with physical inactivity and obesity reflects the Big Mac, big screen society," explains Rosenbloom, who is chairman of the American Diabetes Association task force. He says children need to eat less junk food and more nutritious meals containing the five basic food groups and to exercise more.

Type 2 diabetes often develops slowly. Most people who get it have increased thirst and an

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increased need to urinate. Many also feel edgy, tired and sick to their stomach. Some people have an increased appetite, but they lose weight.

Other signs and symptoms are:

Repeated or hard-to-heal infections of the skin, gums, vagina or bladder.

Blurred vision.

Tingling or loss of feeling in the hands or feet.

Dry, itchy skin.

These symptoms can be so mild that you don't notice them. Older people may confuse these symptoms with signs of aging and may not go to their health care practitioner.

Type 1 diabetes, which the Centers for Disease Control estimates to be 5-10 percent all diagnosed cases of diabetes in the United States, is caused by a lack of insulin production by the pancreas. It typically starts in children or young adults who are slim, but can start at any age.

People with Type 1 diabetes give themselves at least one shot of insulin every day. Insulin must be injected through the skin and into the body fat for it to work. It cannot be taken in pill form because stomach juices destroy the insulin before it can become effective.

The causes of Type 1 diabetes appear to be much different than those for type 2 diabetes. The appearance of Type 1 diabetes is suspected to follow exposure to an "environmental trigger," such as an unidentified virus, stimulating an immune attack against the beta cells of the pancreas in some genetically predisposed people.

Treatment requires a strict regimen that typically includes a carefully calculated diet, planned physical activity, home blood glucose testing several times a day, and multiple insulin injections daily.

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FRIDAY

Jan. 26,
2001

ON THIS DAY In 1962, the United States launched Ranger 3 to land scientific instruments on the moon. Because of a series of malfunctions, it missed the moon by about 22,000 miles.

Diabetes is rising across the board

*CDC blames obesity,
says epidemic possible*

By ERIN McCORMACK
ASSOCIATED PRESS

ATLANTA — Diabetes in the United States rose in 1999 in what the government called evidence of an unfolding epidemic.

Cases rose sharply across almost every demographic category, the Centers for Disease Control and Prevention said. The rise is blamed largely on obesity, which was up a startling 57 percent from 1981.

"The message is out there: lose weight by increasing your physical activity and changing your diet," CDC epidemiologist Ali Mokdad said. "But nobody is doing it."

The share of the adult population diagnosed with diabetes jumped from about 6.5 percent in 1998 to 6.9 percent in 1999, the CDC said. The obesity rate increased to nearly one in five Americans — up from one in eight in 1991.

Last August, the CDC reported that diabetes jumped 33 percent nationally, to 6.5 percent, between 1990 and 1998. The rise crossed race and age groups but was sharpest — about 70 percent — among people ages 30 to 39.

CDC director Jeffrey Koplan said the effect on the nation's health care costs will be overwhelming if the trends continue.

The statistics, to be released today by the CDC, appear in the February issue of the journal *Diabetes Care*. The report is based on a telephone survey of 150,000 people in the United States.

At least 16 million people in the United States have diabetes, which prevents the body from regulating blood sugar. The number is expected to rise to 22 million by 2020.

EXHIBIT AA

How Land Use and Transportation Systems Impact Public Health:

A Literature Review of the Relationship Between Physical Activity and Built Form¹

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Active Community Environments (ACEs) Working Paper #1

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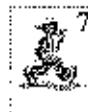


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Executive Summary

This review discusses how urban form affects public health, specifically through the ways in which the built environment encourages or discourages physical activity levels. The questions raised illuminate fundamental quality of life considerations including residential preferences, time use, space requirements, security, and convenience, which collectively shape the built environment. The relative costs and benefits of the locational and travel choices that are currently available have resulted in a built environment designed to accommodate the car -- at the measurable expense of the ability to move about under human power. Although the institutional and attitudinal changes that need to take place to enable, let alone promote, physical activity in our towns and cities today appear to be daunting, we can take some comfort from Benjamin Franklin, who stated in 1791:

"To get the bad customs of a country changed and the new ones, though better introduced, it is necessary first to remove the prejudices of the people, enlighten their ignorance, and convince them that their interests will be promoted by the proposed changes; and this is not the work of a day."

This report is organized around an urban form - public health model, as conveyed in Figure X-1. Land development and transportation investments are interactive processes that collectively have a tremendous influence in shaping the built environment. The location of transportation investments impact where growth occurs, and the mode in which the investment is made (e.g., highway, transit, sidewalks, and bikeways) impacts the form of the growth that follows. Conversely, the location of new development impacts the location of transportation investments, while the character of that development (transit- and pedestrian-friendly versus auto-oriented) determines the viability of alternative transportation scenarios. These two urban form processes, land

development and transportation investments, are hypothesized to influence public health by affecting the relative convenience and viability of pedestrian travel and biking for both recreational and utilitarian (trip) purposes, and thus they influence the levels of physical activity.² Figure X-1, therefore, shows that the built environment influences activity patterns, which impact health. However, one's culture, age, income, genetics, and even health influence activity patterns. Consequently, activity patterns serve as a bridge that interfaces the built environment with public health. Our review employs a classification of studies that emphasizes the interfaces between

1. physical activity and health;
2. transportation systems and physical activity; and
3. land development patterns and physical activity.

² The authors note that there are other means through which the built environment influences public health. These include the direct impacts of land use decisions including harmful exposure to toxics (Bullard 1990) and the indirect impacts of land use on travel choice and air quality (Frank, Stone, and Bachman 2000).

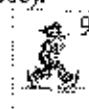
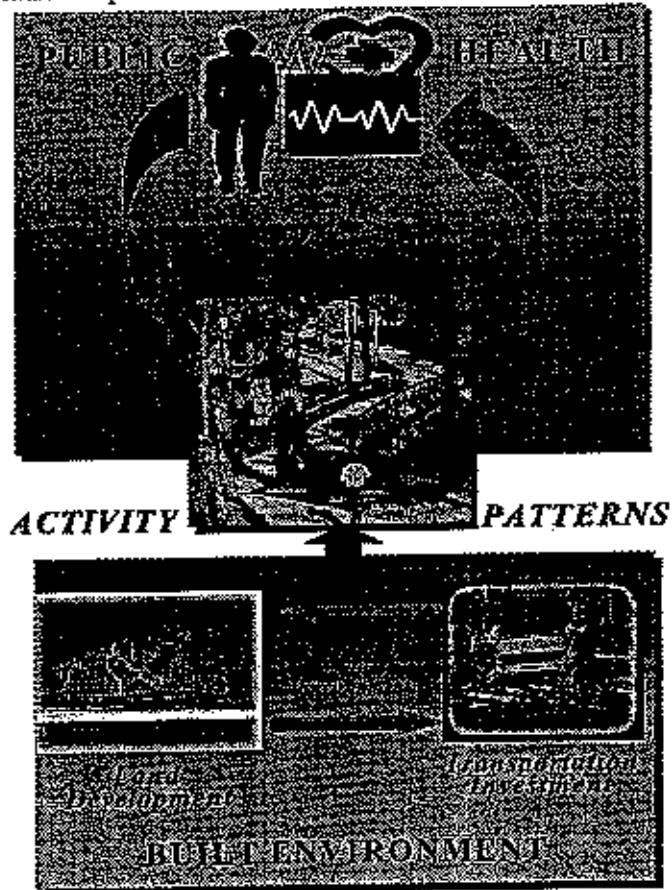


Figure X-1 Relationships Between Urban Form, Physical Activity, and Public Health



A. Physical Activity and Health

Public health research links physical activity to public health. On balance, the literature shows that regular physical activity

- decreases the risks of cardiovascular disease, colon cancer, and diabetes mellitus;
- maintains muscle strength and joint structure and function;
- is necessary for normal skeletal development during childhood;
- may relieve depression, anxiety, and other mental illnesses;
- along with appropriate dietary patterns, may lower obesity levels.

One review estimated that improper diet and inactivity patterns was the root cause of some 300,000 deaths in the United States in 1990, second only to tobacco (McGinnis and Foege 1993). Another estimated that between 32% and 35% of all deaths in the United States attributable to coronary heart disease, colon cancer, and diabetes could be prevented if all persons were highly active (Powell and Blair 1994). The economic cost to the UNITED STATES economy of coronary heart disease from physical inactivity is estimated to be around \$5.7 billion per year (Francis 1997).

Physical inactivity levels in the United States are worrisome. According to annual statistics gathered by the Centers for Disease Control and Prevention and other health organizations, only 30% to 40% of the American population engage in regular, sustained exercise, while another 30% are completely inactive. Physical inactivity is greater for females, minorities, the elderly, the less educated, and those with lower incomes (Mokdad et al. 1999). Physical inactivity starts during childhood. Only about half those aged 12 to 21 years engage in regular, vigorous physical activity, and preschool children spend the majority of their playtime in sedentary activities (U.S. Department of Health and Human Services 1996; Strauss 1999). In a study of physical activity patterns in wealthy countries, the United States was at about the midpoint for moderate physical activity levels and was near the bottom for vigorous physical activity levels (Sallis and Owen 1999).

The public health literature widely accepts the hypothesis that significant health benefits can be achieved through moderate forms of physical activity. Walking on a regular basis, for example, is believed to generate health benefits. Structured, vigorous forms of exercise such as running or aerobics are not the only way to achieve health benefits of physical activity. As a result of this understanding, public health studies have begun to focus on interventions designed to change lifestyles. Many public health professionals believe that lifestyle intervention programs, which aim to increase daily levels of walking and bicycling through changes in the environment in which people live and work, may be more effective in changing long-term activity patterns than interventions centered on



structured activities such as aerobics classes. This belief is based on the assumption that the ability to sustain an active lifestyle may partially hinge on the characteristics of the built environment in which we live, work, and play.

B. Physical Activity in the Built Environment

In wealthy countries, the automobile is the primary mode of transportation. But, the variation in automobile use varies significantly across countries. According to one study (Pucher and Lefevre 1996), automobile use for all trips in urban areas ranged from a low of 36% in Sweden to a high of 84% in the United States. Walking and bicycling levels roughly correlated in an inverse fashion with auto usage: in Sweden, the Netherlands, Switzerland, Denmark, Italy, and Austria, the modal share of trips occupied by walking and bicycling was at or above 40%, while the share occupied by the auto was near or below 40%. Conversely, in high auto-usage countries such as the United States, Great Britain, and Canada, the percentage of walking and bicycling trips was below 20%. The figures generated by this study had the United States ranked last, with walking and biking accounting for only about 10% of all trips.

The Nationwide Personal Transportation Survey (NPTS), conducted by the U.S. Department of Transportation every few years, has consistently reaffirmed this pattern for the United States. The NPTS has shown that private vehicle-based travel dominates urban transportation in the United States. In the 1995 survey, travel by motorized vehicle accounted for 86% of all person trips and 91% of all person miles. Walking accounted for only 5% of trips and less than 1% of miles. Furthermore, NPTS data show that the private vehicle has been increasing its share of personal transportation over time.

As currently reported, data suggest that walking and bicycling trips are mostly for recreational travel. According to the 1995 NPTS, only 7% of all walking trips and 8% of all bicycling trips were to work. Part of the reason for this is distance. Most walking and bicycling trips are short, with walking trips generally limited to about a kilometer and bicycling trips generally limited to a few kilometers.

Children, the poor, the disabled, and the elderly are especially vulnerable in auto-dominated transportation systems. For a variety of reasons, members of these groups often cannot drive and must rely upon others to drive them to destinations, or they must use nonmotorized or public means of transportation. There are two consequences. First, overall mobility is restricted. Transportation systems in the United States generally do not facilitate pedestrian and bicycle travel, while accompanying low-density, single-use land development patterns increase distances between trip origins and destinations. Second, safety becomes a major problem. Different studies suggest that safety issues result in not only more injuries and deaths for members of these groups but also a reduction in nonmotorized travel. Parents, for example, may be increasingly worried about traffic safety for their children, resulting in their refusal to let their children walk or bike to destinations.

There are two sets of variables believed to negatively influence the decision to walk or bike: personal barriers and environmental barriers. Personal barriers are subjective considerations that operate on an individual level, whereas environmental barriers are objective considerations that hinder the individual's ability to act (Table X-1). In surveys of why people do not walk or bike more frequently, both sets of barriers show up in the results. The public health literature has begun to focus on the creation of walking- and bicycling-supportive environments as a way of reducing or eliminating environmental barriers to physical activity.

Table X-1: Examples of Personal and Environmental Barriers to Physical Activity in the Built Environment

<i>Personal Barriers</i>	<i>Environmental Barriers</i>
<ul style="list-style-type: none"> • Lack of motivation • Perceived lack of time 	<ul style="list-style-type: none"> • Lack of exercise facilities • Lack of sidewalks, bike lanes on roads, nearby public parks, or hiking/biking trails.

<ul style="list-style-type: none">• Weather• Family obligations• Fatigue	<ul style="list-style-type: none">• Topography• Perceived low levels of safety of one's neighborhood
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C. Urban Form and Nonmotorized Travel

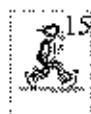
The urban planning literature focuses on two sets of variables believed to be relevant to travel behavior: transportation system characteristics and land development variables.

Transportation systems influence travel behavior in at least three ways. First, street networks influence mode choice and trip frequency through the ways in which trip origins and destinations are connected. Traditional street networks such as the grid pattern reduce trip distances and increase route choices, factors believed to increase walking and biking. Most contemporary suburban development, in contrast, minimizes the degree of connectivity between trip origins and destinations through the heavy use of T intersections, cul-de-sacs, and reduced access to subdivisions. Second, streets can be designed to facilitate either automobile travel or nonmotorized travel. Streets that are wide, smooth, and straight encourage automobile travel at fast speeds and discourage travel by foot or bicycle. Conversely, streets that are narrow and irregular discourage automobile travel at high speeds. Additionally, streets that incorporate pedestrian and bicycle facilities (bike lanes, sidewalks, crosswalks, etc.) and that are calmed (i.e., streets that contain traffic-slslowing obstacles and devices) are believed to facilitate more walking and bicycling. In the United States, street design has been dominated by the desire to facilitate the smooth flow of automobile traffic, resulting in design standards for streets that encourage driving and discourage walking and biking. Third, transportation systems can increase walking and biking through separate, dedicated bicycle and pedestrian facilities such as bike paths and walking trails. While these systems are increasingly popular, it is generally not feasible to create dense networks of them in existing urban areas.

Land development patterns influence travel behavior in at least four ways:

- Low density can increase distances between origins and destinations. Its relationship to travel is intuitive – higher density levels reduce trip distances, theoretically increasing the incentive to walk and bike – and its measurement is simple. For these reasons, density is perhaps the most-studied land development variable. Much of the research on density and travel has centered on motorized travel modes.
- The relative mix of land uses in a given area also affects the distances between trip origins and destinations. The separation of uses into residential, commercial, and industrial zones increases travel distances, with similar dampening effects on nonmotorized travel behavior. While its relationship to travel is easily conceptualized, land use mix is not as easy to measure as density. Still, a body of scholarly literature on the effects of land use mix on travel has emerged .
- Motorized travel is encouraged if trip destinations are widely dispersed at the regional level. For example, if jobs are located far from housing, commuting by bicycle or on foot will be nearly impossible. While recognition is widespread that regional development patterns such as the mixture of jobs and housing are important, this particular measure has difficulties. Among other problems is the limited availability of data accurately portraying the number and types of jobs and households in subregional locations.
- Site design impacts travel patterns in much the same way as street design. Building design, orientation, and setback, along with other aesthetic considerations, will create environments that are either attractive or unattractive for nonmotorized travel. Not been many empirical studies have attempted to isolate the effects of site design on travel behavior.

D. Impediments to Capturing the "Land Use Effect"



Scholars have had a difficult time isolating the effects of urban form variables on nonmotorized travel. There are three major reasons for this:

- Though motorized travel has been the subject of a much research, nonmotorized travel has not. This disparity reflects a research and cultural bias that conceptualizes travel as an automobile-dependent phenomenon. Much of the work in transportation focuses on congestion and emissions reductions. The resulting data collection regime has therefore generated much information on automobile transportation and relatively little on nonmotorized modes.
- Travel is a complex phenomenon, with many variables influencing how often, and by what means, people travel. A host of demographic and socioeconomic variables influence travel patterns, including nonmotorized travel. Urban form variables are just one set of variables believed to be influential in this regard.
- Urban form variables themselves are difficult to disentangle. Those believed to influence the propensity to walk and bike, such as high density levels and grid street patterns, are often located in the same areas, making it difficult to determine which urban form factor is the more important.

As a result of these difficulties, there is no universally accepted methodology in the scholarly literature for disentangling the influences of individual urban form variables on travel behavior: some studies utilize quasi-experimental designs, others regression analysis, and still others generate conclusions by means of temporal data from case studies. Much of the information is based on ecological comparisons and thus vulnerable to misinterpretation. This lack of methodological uniformity stems from disagreement over how best to conceptualize and model the effects of urban form on travel behavior and from data limitation.

Despite these problems, on balance the literature supports the hypothesis that urban form variables influence levels of walking and bicycling. Higher densities, a greater mixture of

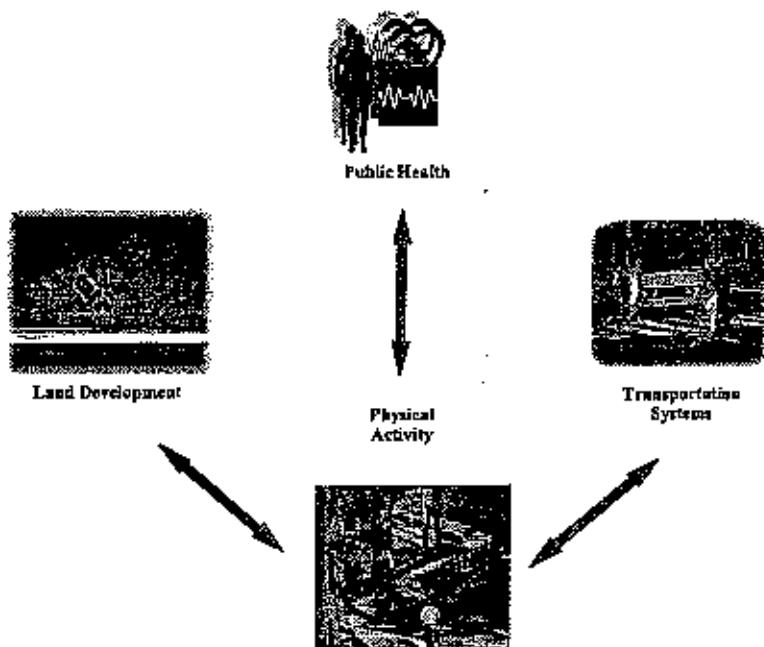
land uses, a balance between housing and jobs, pedestrian- and bicycle-friendly site and street design, grid street networks, and the presence of separated facilities for bicycles and pedestrians have all been shown to increase walking and biking. The findings are not uniform, however. Individual studies often extract data from a relatively few neighborhoods in one or a few metropolitan areas, making analyses across studies difficult. Demographic, economic, and socioeconomic influences are alternatively found to be more important or less important than urban form variables; this inconsistency results in continuing debate over whether urban form is primary or secondary in importance. Different studies yield competing results with respect to which urban form variables are the most important in determining nonmotorized transportation. Most often, due to the complexity inherent in studying urban travel patterns and the generally poor availability of good data on all relevant variables, studies incorporate only a fraction of all the major urban and nonurban form variables believed to impact nonmotorized travel.

Amid all of these complexities, this review concludes that some very precise strategies could be articulated in the form of *interventions* within the public health arena. These *interventions* would be targeted at retrofitting existing communities and shaping emerging communities in a manner that enables, and even promotes, physical activity.

Chapter I: Purpose and Structure of This Literature Review

The central question to be addressed in this review is how urban form affects public health through the mechanism of physical activity. Given the increasing body of evidence that suggests that sustained levels of moderately intense physical activity can positively influence health, this review asks whether land use patterns and transportation investments impact daily physical activities, specifically the propensity to walk or bike. Figure 1-1 provides the model of the relationship between urban form and public health that structures this review.³ This paper examines the state of research into the three linkages in Figure 1-1: between public health and physical activity, between land usage patterns and physical activity, and between transportation systems and physical activity.⁴

Figure 1-1
The Review's Structure



³ Please refer to Figure X-1 which illustrates more complex interactions between the components identified in Figure 1-1.

⁴ Urban form impacts public health in a number of ways and along several dimensions, one being physical activity patterns. One important example of a different dimension of the urban form/public health connection is the link between the concentration of industrial and chemical plants and waste treatment facilities in poor and minority communities and inequitable health impacts on members of those communities. See Bullard (1990).

Chapter two addresses the linkage between physical activity and public health (for chapter structure, see Figure 1-2). A review of the literature shows that the public health community has long recognized the critical role played by physical activity in reducing risk factors for many chronic diseases and conditions, including coronary heart disease, colon cancer, hypertension, diabetes, obesity, osteoporosis, anxiety, and depression. Unfortunately, data show that more than 60% of all adults in the United States do not engage in the recommended amounts of physical activity, and 28% are completely sedentary. The impact of physical inactivity on public health in the United States is significant, due to the interconnectedness of physical inactivity with other variables important in influencing chronic disease. High blood pressure and obesity, for example, are believed to be connected to sedentary lifestyles. Overweight and obesity levels have been increasing for years in the United States.

Figure 1-2: Design of Chapter 2

- Discussion of the state of research into the health benefits of physical activity
- Review of statistics regarding physical activity levels in the United States
- Discussion of the state of research into the merits of different strategies for increasing levels of physical activity and health

Public health research recognizes the importance of lifestyle interventions in changing physical activity patterns and, by extension, public health levels. Increases in moderate forms of physical activity such as walking and bicycling have the potential to significantly improve public health levels. Short, daily, moderate bouts of physical activity are believed by many scholars to be as effective in promoting public health as more structured physical activities such as jogging.

Chapter three reviews literature on travel patterns (Figure 1-3). Travel statistics by modal choice (motorized versus nonmotorized travel) are reviewed, and they show that a

Active Community Environments

What are Active Community Environments?

Active Community Environments (ACES) are places where people of all ages and abilities can easily enjoy walking, bicycling, and other forms of recreation. These areas:

- Support and promote physical activity.
- Have sidewalks, on-street bicycle facilities, multi-use paths and trails, parks, open space, and recreational facilities.
- Promote mixed-use development and a connected grid of streets, allowing homes, work, schools, and stores to be close together and accessible by walking and bicycling.

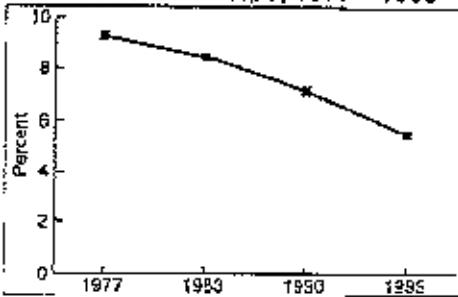
Most communities today were designed to favor one mode of travel—the automobile—and usually do not have many sidewalks or bicycle facilities. Building roads, schools, shopping centers, and other places of interest only for convenient access by cars often keeps people from safely walking around town, riding bicycles, or playing outdoors. This is one important reason why people in the United States are not as active as they used to be.

- Between 1977 and 1995, trips made by walking declined while driving trips increased.¹ (See charts at right.)
- One-fourth of all trips people make are one mile or less, but three-fourths of these short trips are made by car.¹
- Children between the ages of 5 and 15 do not walk or ride their bicycles as much as they used to (40% less from 1977 to 1995).² For school trips one mile or less, only 31% are made by walking; within two miles, just 2% of school trips are made by bicycling.²

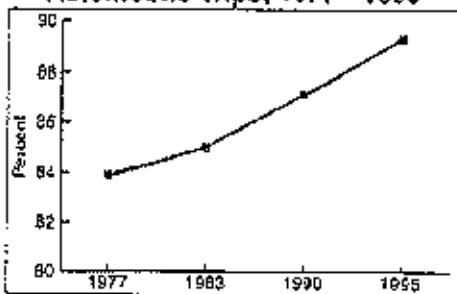
These trends pose an important public health problem when the effects of physical inactivity and excess weight are considered.

- Physical inactivity and unhealthy eating are risk behaviors that contribute to at least 300,000 preventable deaths each year.³
- Almost a third (29%) of adults get little or no exercise (they are sedentary), and almost three-fourths (73%) are not active enough.⁴ (Engaging in 30 minutes of physical activity at least 5 days per week is recommended.)
- More than 3 in 10 adults are overweight.⁴
- More than a third (36%) of young people in grades 9-12 do not participate in vigorous activities 3 or more days a week,⁵ and one-fourth (25%) of those aged 6-17 are overweight.⁵

Walk and Bike Trips, 1977—1995



Automobile Trips, 1977—1995



U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES

Centers for Disease Control and Prevention

National Center for Chronic Disease Prevention and Health Promotion



What are the benefits of Active Community Environments?

ACES have the potential to help people be more physically active. This is because they give people more (and safer) places to walk, ride bicycles, and enjoy other recreational activities.

- People are more active in neighborhoods that are perceived as safe. Of those who report living in unsafe neighborhoods, about half of women and the elderly are inactive.⁴
- In neighborhoods with square city blocks, people walk up to three times more than in neighborhoods with cul-de-sac streets or other features that keep streets from connecting.⁵
- Up to twice as many people may walk or cycle in neighborhoods that are transit-oriented than in neighborhoods that are auto-oriented.^{6,7}
- People are more likely to be physically active if they have recreational facilities close to their homes.⁸

What is CDC doing to promote Active Community Environments?

CDC and its Division of Nutrition and Physical Activity are taking the lead in promoting ACES.

Their activities include:

- Development of a guide (KidsWalk-to-School) to promote walking and bicycling to school
- Collaboration with public and private agencies to promote National and International Walk-to-School Day (www.walktoschool-usa.org and www.walktoschool.org)
- Development of an ACES manual to help state and local public health workers develop similar initiatives.
- A partnership with the National Park Service's Rivers, Trails, and Conservation Assistance Program to promote the development and use of close-to-home parks and recreational facilities (www.nrcrp.nps.gov/rteca/index.htm).
- Collaboration on an Atlanta-based study to review the relationships of land use, transportation, air quality, and physical activity.
- Collaboration with the Environmental Protection Agency on a national survey to study attitudes of the American public toward the environment, walking, and bicycling

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For more information...

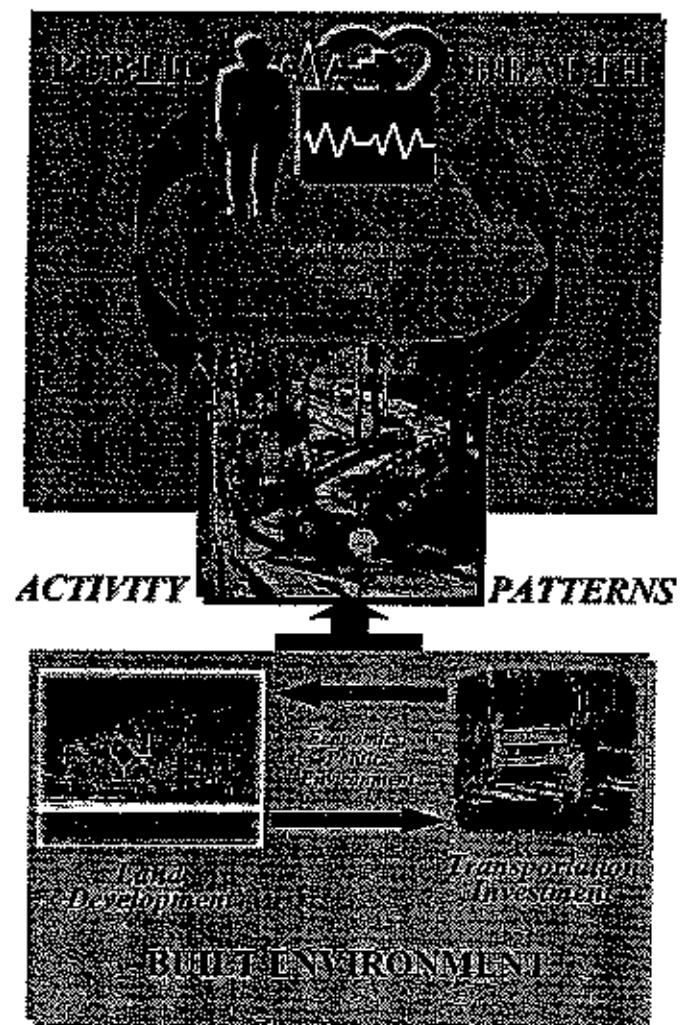
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Physical Activity and Health Branch
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How Land Use and Transportation Systems Impact Public Health:

*A Literature Review of the Relationship Between Physical
Activity and Built Form*



ACES Working Paper #1

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Special Report 245

EXPANDING METROPOLITAN HIGHWAYS

*Implications for
Air Quality and Energy Use*

Committee for Study of Impacts of
Highway Capacity Improvements on
Air Quality and Energy Consumption

TRANSPORTATION RESEARCH BOARD
National Research Council

National Academy Press
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2

Contribution of Motor Vehicle Transportation to Air Pollution and Energy Consumption

Motor vehicles run on fossil fuels, emitting pollutants that are a major cause of poor air quality in metropolitan areas and consuming a large fraction of the nation's petroleum resources. In this chapter, the impacts of motor vehicle transportation on air quality and energy consumption are described and the models that are commonly used to analyze these impacts are introduced.

TRANSPORTATION AND AIR QUALITY

The four principal sources of polluting emissions from man-made sources are transportation (primarily highway vehicles), stationary fuel combustion (especially electrical utilities), industrial processes such as chemical refining, and solid waste disposal (Horowitz 1982, 2-1). Emissions that either directly cause or combine to form pollution (called primary and secondary pollutants, respectively) may also be classified as stationary, area, or mobile, depending on the magnitudes and geographical distributions of their emissions (DOT and EPA

1993, 2).¹ Pollutants from motor vehicle transport, the focus of this study, are commonly referred to as mobile source emissions.

To comply with the requirements of the 1970 Clean Air Act, the Environmental Protection Agency (EPA) developed national ambient air quality standards (NAAQS) that set allowable concentration and exposure limits for six pollutants considered harmful to public health. The NAAQS are expressed as average concentrations of pollutants over some period of time (see box).² EPA tracks both the emissions or flows of harmful materials from polluting activities, such as factories and transportation, on the basis of the best available engineering and modeling estimates, and the accumulation of these emissions in the air as concentrations of pollutants, which are directly measured at selected sites throughout the country (Curran et al. 1994, 20; Horowitz 1982, 3-4). Regulatory activities are directed toward attainment of NAAQS (i.e., concentration standards), because health effects are directly related to public exposure to pollutants at specific concentrations.

Transportation-Related Pollutants

According to current estimates, transportation sources account for about 45 percent of nationwide emissions of EPA's six criteria pollutants. The range is considerable for each pollutant source (Table 2-1) and there is a high degree of uncertainty with respect to many of the estimates. Ground-level ozone is the most pervasive of the transportation-related pollutants; in 1993 approximately 51 million persons lived in counties that did not meet the carbon monoxide (CO) standard in the same year (Curran et al. 1994, 15).

Highway vehicles are the largest source of transportation-related emissions for nearly every type of pollutant (Table 2-1). In total, they contribute slightly more than one-third of nationwide emissions of the six criteria pollutants.

Formation of Motor Vehicle Emissions

The primary sources of motor vehicle emissions are exhaust emissions from chemical compounds that leave the engine through the tail pipe system and the crankcase and evaporative emissions from the fueling

National Ambient Air Quality Standards (NAAQS) in Effect in
1991 (Curran et al. 1994, 19)

POLLUTANT	PRIMARY (HEALTH RELATED)		SECONDARY (WEAVER RELATED)	
	TYPE OF AVERAGE	STANDARD LEVEL CONCENTRATION ^a	TYPE OF AVERAGE	STANDARD LEVEL CONCENTRATION
CO	8-hr ^b	9 ppm (10 mg/m ³)	No secondary standard	
	1-hr ^c	35 ppm (40 mg/m ³)	No secondary standard	
Pb	Maximum quarterly average	1.5 $\mu\text{g}/\text{m}^3$	Same as primary standard	
NO _x	Annual arithmetic mean	0.053 ppm (100 $\mu\text{g}/\text{m}^3$)	Same as primary standard	
O ₃	Maximum daily 1-hr average	0.12 ppm (235 $\mu\text{g}/\text{m}^3$)	Same as primary standard	
PM-10	Annual arithmetic mean ^d 24-hr ^e	50 $\mu\text{g}/\text{m}^3$ 150 $\mu\text{g}/\text{m}^3$	Same as primary standard	
SO ₂	Annual arithmetic mean 24-hr ^f	80 $\mu\text{g}/\text{m}^3$ 3.65 $\mu\text{g}/\text{m}^3$ (0.14 ppm)	3-hr ^g 1300 $\mu\text{g}/\text{m}^3$ (0.50 ppm)	

Note: CO = carbon monoxide; Pb = lead; NO_x = nitrogen dioxide; O₃ = ozone; PM-10 = particulate matter; SO₂ = sulfur dioxide; ppm = parts per million; $\mu\text{g}/\text{m}^3$ = micrograms per cubic meter; $\mu\text{g}/\text{m}^3$ = milligrams per cubic meter.

^aParticulate value is an approximately equivalent concentration.

^bNot to be exceeded more than once a year.

^cThe standard is attained when the expected number of days per calendar year with maximum hourly average concentrations above 0.12 ppm is equal to or less than 1, as determined according to Appendix H of the Ozone NAAQS.

^dParticulate standards use PM-10 (particulates less than 10 μm in diameter) as the indicator pollutant. The annual standard is attained when the expected annual arithmetic mean concentration is less than or equal to 50 $\mu\text{g}/\text{m}^3$; the 24-hr standard is attained when the expected number of days per calendar year above 150 $\mu\text{g}/\text{m}^3$ is equal to or less than 1, as determined according to Appendix K of the PM NAAQS.

TABLE 2-1 Transportation Contribution to Emissions of Major Air Pollutants in the United States, 1992
(Millions of Short Tons) (Nitich et al. 1994, 3-11-3-16)

SOURCE	CO	NO _x	VOC	PM-10	Pb	SO ₂	Total
Transportation							
HIGHWAY vehicle share	60.0	74	83	0.6	0.6	1.6	96.9
Fuel combustion	5.4	7.4	6.1	0.2	0.2	1.4	75.5
Industrial processes	5.2	11.7	0.9	0.6	0.6	1.2	38.7
Miscellaneous	1.8	0.9	3.1	0.1	0.4	1.9	14.0
All transportation	77	44	36	1	33	3	45
Highway vehicles	62	32	26	0.4	29	2	35
Share of total (percent)							
Total	97.2	23.4	23.3	45.5	4.9	21.9	216.2
Industrial processes	9.5	0.3	0.9	42.8	0	0	53.5
Miscellaneous	1.8	0.9	3.1	0.4	0.5	1.9	13.1
All transportation	77	44	36	1	33	3	45
Highway vehicles	62	32	26	0.4	29	2	35

SC₂ = sulfur dioxide.
NOTE: CO = carbon monoxide; VOC = volatile organic compounds; NO_x = oxides of nitrogen; PM-10 = particulate matter; Pb = lead.

system [mainly volatile organic compounds (VOCs)] (NRC 1992, 69). For most motor vehicles (i.e., those powered by gasoline), exhaust emissions are formed in a two-stage process: emissions originate as a result of the combustion of fuel in the engine (engine-out emissions) and are then reduced by passing through a catalytic converter (tail pipe or exhaust emissions). For diesel-powered vehicles, the process of producing exhaust emissions is simpler, because there is presently no aftertreatment (i.e., catalytic converter).

Carbon monoxide and VOCs are the product of incomplete combustion of motor fuels and, in the case of VOCs, of fuel vapors emitted from the engine and fuel system (NRC 1991, 257). Oxides of nitrogen (NO_x) are formed differently; they are the product of high-temperature chemical processes that occur during the combustion process itself (NRC 1991, 261). Particulates, another compound mainly found in diesel exhaust, are formed primarily from incomplete combustion of diesel fuel and lubricating oil (Weaver and Klausmeier 1988, 2-7; Come 1990, 58).

The air/fuel (A/F) ratio, which is controlled by the carburetor or fuel injection system, is the most important variable affecting the efficiency of catalytic converters and thus the level of exhaust emissions (Johnson 1988, 40). Because concentrations of key emissions are not at a minimum at the same A/F ratio (CO and VOCs are highest under fuel-rich conditions and NO_x is highest under fuel-lean conditions), manufacturers must optimize catalytic converter operation within a narrow A/F ratio range, known as stoichiometry, to achieve the greatest control efficiency for all three pollutants (Figure 2-1).

Major Pollutants by Type

Transportation is the dominant source of U.S. CO emissions, and highway vehicles contribute nearly two-thirds of the total (Table 2-1). Carbon monoxide is an odorless gas that forms from incomplete combustion of motor fuels. The higher the share of fuel in the air-fuel mixture, the more CO is produced (NRC 1992, 69). Fuel-rich operations occur under cold-start conditions, when the vehicle has been turned off for some time and the catalytic converter is cold, or under heavy engine loads (e.g., during rapid accelerations, on steep grades, or at high speeds). CO concentrations tend to be high on and near con-

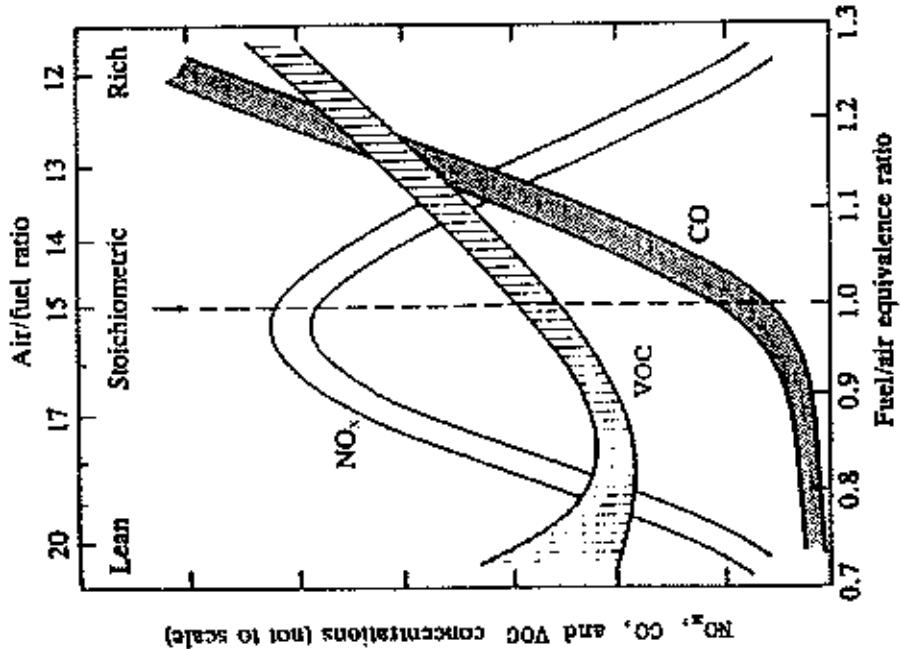


FIGURE 2-1. Variation of CO , VOC , and NO_x concentration in the exhaust of a conventional spark-ignition engine with fuel/air equivalence ratio. Adapted from J. B. Heywood, *Internal Combustion Engine Fundamentals*, McGraw-Hill, 1988, p. 571. Reproduced with permission of McGraw-Hill, Inc.

HIGHWAYS

ways and at other locations where traffic densities are ^{6,11}. These concentrations are often referred to as CO hot spots. However, CO can also be viewed as a regional problem, with frequent reported exceedances of the 8-hr average concentration standards (Gordon 1991). CO contributes indirectly to greenhouse gas emissions (Gordon 1991, 60).¹²

Motor vehicles are also a major contributor to smog, the haze that hangs over many large urban areas, which has harmful health effects, contributes to the greenhouse problem, and adversely affects crops and vegetation (MacKenzie and Walsh 1990, 7). Ground-level ozone, an important constituent of smog, is not emitted directly into the atmosphere. Rather it is formed as a secondary pollutant through a chemical reaction between the ozone precursors, VOCs and NO_x, which is stimulated by heat and sunlight (Gordon 1991, 62). Highway vehicles account for about one-quarter of total VOC emissions and about one-third of total NO_x emissions (Table 2-1). EPA's estimates of VOC emissions, in particular, have been challenged in a National Research Council report as understating actual emission levels by a factor of 2 to 4 (NRC 1991, 7).¹³ Because it is a chemically reactive pollutant, ozone behaves quite differently from CO. The relation between ozone concentrations and VOC and NO_x emissions is both nonlinear and synergistic; thus, changes in VOC and NO_x emissions can have impacts on ozone that are difficult to predict. For example, ozone concentrations often are lower near large sources of motor vehicle emissions, because exhaust emissions of nitrogen oxide (NO) break down the ozone molecule.¹⁴ This is referred to as ozone scavenging. Also, spatial variations in ozone concentrations tend to be much more gradual than in CO concentrations (Horowitz 1982, 63).

The role of NO_x in urban ozone pollution has received attention recently from the scientific and regulatory communities. NO_x emissions from motor vehicles consist of a mixture of NO and nitrogen dioxide (NO₂) (NO being the dominant constituent), which is formed by high-temperature chemical processes during the combustion of fossil fuels (Horowitz 1982, 17; NRC 1991, 261). High concentrations of NO₂, which are responsible for the yellowish-brown color of the sky in many smoggy areas, are caused primarily by the oxidation of NO from engine exhaust and other sources to NO₂ through the chemical

processes that produce ozone (Horowitz 1982, 77). The NRC report (1991) argued that it is the balance between ambient levels of VOCs and NO_x that determines ozone levels in a particular area, and that efforts to reduce NO_x may be the most effective ozone abatement strategy in many of the nation's most polluted urban areas (NRC 1991, 7).¹⁵ In its final conformity regulations following the Clean Air Act Amendments of 1990 (CAA), EPA requires that transportation improvement programs proposed by metropolitan planning organizations (MPOs) show reductions in NO_x as well as VOCs from a 1990 baseline scenario (Federal Register 1993, 62,226).¹⁶

Particulates from diesel-fueled vehicles, primarily trucks and buses, contribute to pollution from inhalable particulate matter (PM-10). Overall, tail pipe emissions of highway vehicles account for less than 1 percent of total PM-10 emissions (Table 2-1). The major source of particulates is road dust, which is a function of vehicle traffic, wildfires, and agricultural activity (Curran et al. 1994, 53). Particulate emissions are raising renewed concern because of medical evidence of their contribution to lung cancer (Dockery et al. 1993, 1753).

Transportation no longer accounts for a large share of pollution

from lead; use of unleaded gasoline has resulted in a 99 percent reduction in total lead emission levels from highway vehicles since 1970

(Neitzel et al. 1994, 3-16).

Finally, transportation is not a major contributor to sulfur dioxide (SO₂) (Table 2-1). Although heavy trucks and buses emit oxides of sulfur because of the high sulfur content of diesel fuel, coal-fired electric utilities are the dominant source of SO₂ emissions (Curran et al. 1994, 12).

Pollutants by Vehicle and Fuel Type

Emissions of specific pollutants vary by vehicle and fuel type. The primary emissions of gasoline-powered, passenger vehicles—the most common vehicle on the road—are CO, followed by much smaller emissions of VOCs and NO_x. Most heavy-duty diesel vehicles—commercial trucks and buses—use diesel fuel.¹⁷ Their primary emissions are NO_x, followed by smaller emissions of CO, PM-10, SO₂, and VOCs (Figure 2-2).

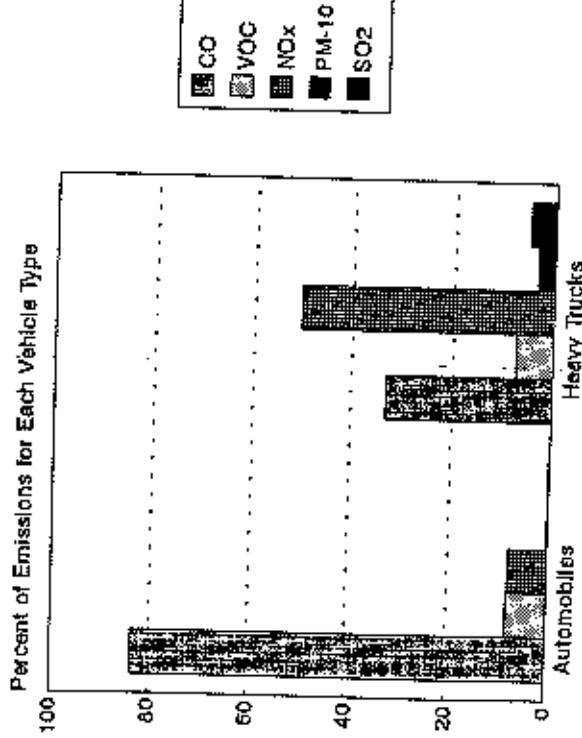


FIGURE 2-2 Comparison of national emission estimates (measured in short tons) for gasoline-powered, light-duty automobiles and diesel-powered heavy-duty vehicles (Nizich et al. 1994, A-4, A-8, A-13, A-19, A-24).

Heavy-duty diesel vehicles produce about 5 percent of total emissions from all highway vehicles, roughly proportional to their share of highway travel but small compared with the emissions of gasoline-powered passenger vehicles, which represent nearly two-thirds of total emissions from highway vehicles.¹⁰ Diesel-powered vehicles, however, contribute a disproportionate share of total highway vehicle emissions of PM-10, SO₂, and NO_x: 72, 47, and 27 percent, respectively (Nizich et al. 1994, A-8, A-19, A-24).

High levels of NO_x emissions from heavy-duty vehicles are caused by the characteristics of diesel engines. Diesel engines typically run at higher combustion chamber pressures and temperatures than gasoline engines (Lilly 1984 in Guensler et al. 1991, Appendix A). Both conditions are conducive to high NO_x emission levels.

PM-10 and SO₂ emissions are also higher for heavy-duty diesel vehicles than for gasoline-powered automobiles. Catalytic converters

have not been used with diesel engines because of particulates and concentrated sulfur gases in the exhaust gas, which could clog or deactivate the catalyst (Guensler et al. 1991, Appendix A).

Particulates in diesel exhaust originate mainly from unburned fuel and oil (Weaver and Klausmeier 1988, 2-7; Conte 1990, 59, 61).¹¹ However, introducing higher combustion temperatures to burn the fuel more completely and reduce particulates leads to higher NO_x emissions. The challenge facing diesel engine manufacturers is to reduce emissions of both pollutants at the same time to meet NO_x and particulate standards.

Emissions of SO₂ are also substantially higher for diesel than for gasoline engines because of the high sulfur content of diesel fuel. However, mandatory use of low sulfur or "clean" diesel fuel, which began in October 1993, should substantially reduce SO₂ emissions as well as PM-10 emissions,¹² from heavy-duty diesel powered vehicles.

Factors Affecting In-Use Emission Levels

Actual emission levels from transportation sources are a function of several variables that can be grouped under four main categories: travel-related factors, driver behavior, highway network characteristics, and vehicle characteristics. Highway projects that add capacity and smooth traffic flows should affect emissions related to travel, driving patterns, and physical characteristics of the highway itself.

Travel-Related Factors

Trips and Vehicle Use

Emissions are a function of trip taking as well as distance traveled. Trips matter because emissions vary depending on the share of the trip associated with different vehicle operating modes. Exhaust emissions, one of the major sources of emissions from motor vehicle operation, include vehicle start-up emissions (start-ups are classified as cold or hot starts depending on how long the vehicle has been turned off) and running emissions, which occur when the vehicle is warmed up and operating in a hot stabilized mode (Sierra Research 1993, 18, 19). Evaporative emissions, the other major source, consist entirely of

VOCs. They include running losses, which occur when the vehicle is operating in a hot stabilized mode; hot soak emissions, which result from fuel evaporation from the still-hot engine at the end of a trip; and diurnal emissions, which result from evaporation of fuel from the gasoline tank whether the vehicle is driven or not (Sierra Research 1993, 19, 20).¹⁴

Vehicle technology improvements have been focused primarily on reducing running emissions, which are a function of vehicle miles traveled (VMT). However, vehicle emissions from a cold start when the catalytic converter is not functioning at optimal temperatures, which are a function of trip making rather than VMT, can account for more than half of total CO and VOC emissions (FHWA 1992, 6).¹⁵ The importance of trips relative to VMT is most evident for VOC emissions as illustrated by the following example of a prototypical 32-km (20-mi) trip (Figure 2-3). In this example, vehicle start-up contributes approximately one-third of total VOC emissions and trip end contributes one-sixth. Neither of these emissions is a function of VMT, but together they account for about half of the total VOCs emitted.¹⁶ Thus, the impact of highway capacity additions on trips as well as VMT is of interest in assessing the effect on emissions.

Speed, Acceleration, and Load

Emission levels depend not only on the number of trips taken and VMT but also on the speed and acceleration of the vehicle and the load on the engine over the distance of the trip.¹⁷ In current emission models, vehicle speed and acceleration are combined into a single average speed for various trip types (i.e., drive test cycles) so that emission levels vary with average trip speed. The severe limitations of this approach are discussed in Chapter 3. Engine loads are generally not varied to reflect different vehicle operating or highway conditions (e.g., road grade) in modeling emission estimates.¹⁸

Figures 2-4 through 2-6 show current model estimates of emission factors for key pollutants expressed in grams per mile for light-duty gasoline-powered automobiles representing the 1990 fleet mix, for a range of average trip speeds.¹⁹ The data are based on the most recent emission models—MOBILE5a developed by EPA and EMFAC7F developed by the California Air Resources Board (CARB) and approved

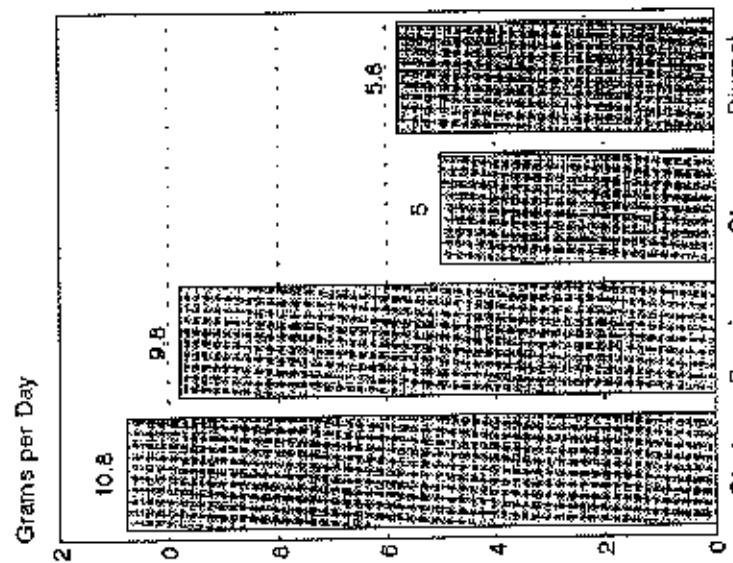


FIGURE 2-3 Sources of VOC emissions by type for a prototypical trip (Ourwater and Loudon 1994, 17). Based on a 32-km (20-mi) round-trip in 1990 for a light-duty automobile traveling in the Bay Area of California at an average speed of 64 kph (40 mph).

by EPA for use in that state. A more detailed discussion of the test procedures and models used to estimate emissions is included in the final section of this chapter and in Chapter 3.

According to the estimates, emissions are generally highest in low-speed, congested driving conditions. In intermediate-speed, free-flowing traffic conditions, emissions fall. They rise again at high

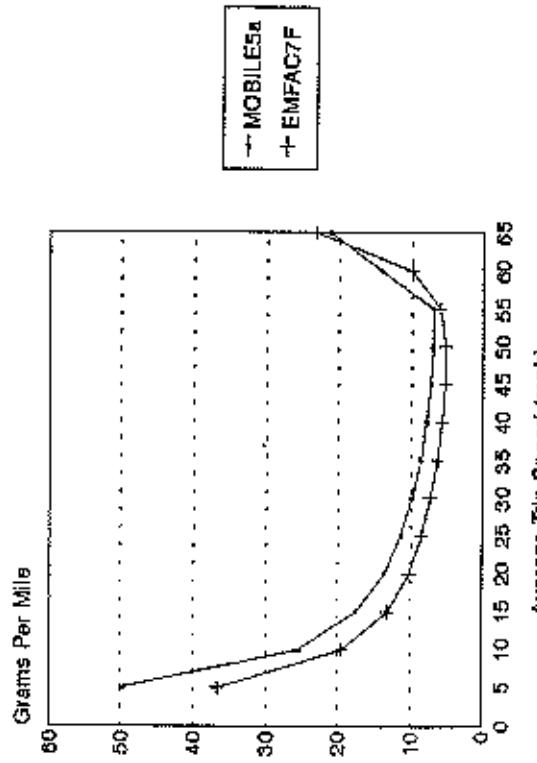


FIGURE 2-4 Comparison of MOBILE5a and EMFAC7F emission factors for carbon monoxide as a function of average trip speed, 1990 fleet average for light-duty gasoline vehicles (data from Sierra Research, June 1994). Note: confidence intervals around point estimates may be large and encompass positive and negative values. See discussion of uncertainty about emission estimates from EMFAC by Guensler (1994, Chapter 13) and in Chapter 3. 1 mi = 1.6 km.

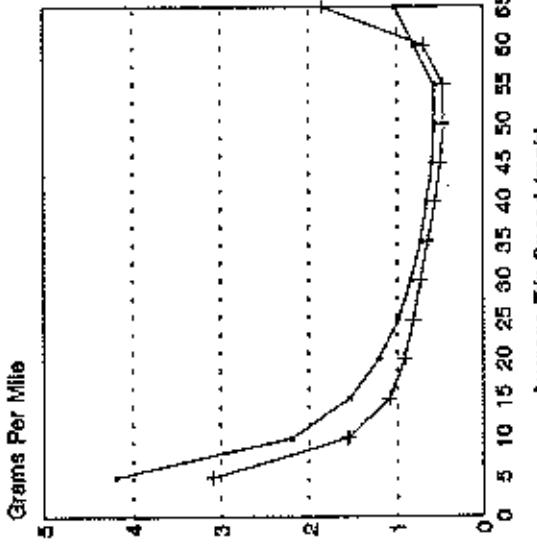


FIGURE 2-5 Comparison of MOBILE5a and EMFAC7F emission factors for volatile organic compounds as a function of average trip speed, 1990 fleet average for light-duty gasoline vehicles (data from Sierra Research, June 1994). Note: confidence intervals around point estimates may be large and encompass positive and negative values. See discussion of uncertainty about emission estimates from EMFAC by Guensler (1994, Chapter 13) and in Chapter 3. 1 mi = 1.6 km.

speeds, but not to initial levels. NO_x emissions are the exception; they rise at relatively low speeds and are highest at high speeds. Confidence in current speed-emission relationships, however, is severely limited by test data that poorly represent urban driving conditions and large variances in emission rates for a wide range of changes in average trip speeds. These topics are discussed further in Chapter 3.

Emission factors for heavy-duty diesel vehicles (also representing the 1990 fleet mix) as a function of average trip speed are shown in Figures 2-7 through 2-9. The data show emissions of CO and VOC falling as speeds rise, but at high speeds they remain relatively constant (Figures 2-7 and 2-8). Emissions of NO_x have the same characteristic U-shaped curve as for automobiles (Figure 2-9). Esti-

mates for particulate emissions as a function of speed are not available. Particulate emissions are believed to follow the same trend as VOC emissions because both result from incomplete combustion of motor fuels (see Appendix A). However, the behavior of diesel particulates at high speeds is not well understood (see Appendix A). The final section on modeling describes the test procedures for estimating diesel emissions; the certainty of these estimates is discussed in Chapter 3.

Because highway capacity additions will increase average vehicle operating speeds, at least initially, they will have a direct effect on emission levels. However, the applicability of current average speed-emission relationships to assessing the emission effects of specific

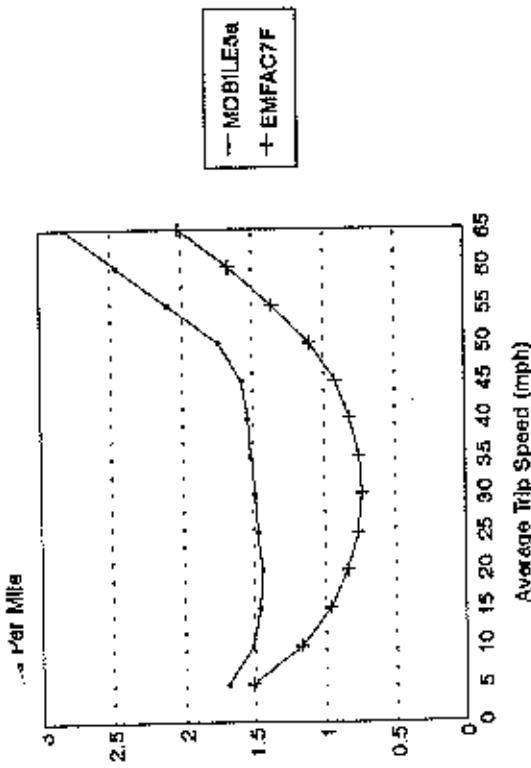


FIGURE 2-6 Comparison of MOBILE5A and EMFAC7F emission factors for oxides of nitrogen as a function of average trip speed, 1990 fleet average for light-duty gasoline vehicles (data from Sierra Research, June 1994). Note: confidence intervals around point estimates may be large and encompass positive and negative values. See discussion of uncertainty about emission estimates from EMFAC by Guenstler (1994, Chapter 13) and in Chapter 3. 1 mi = 1.6 km.

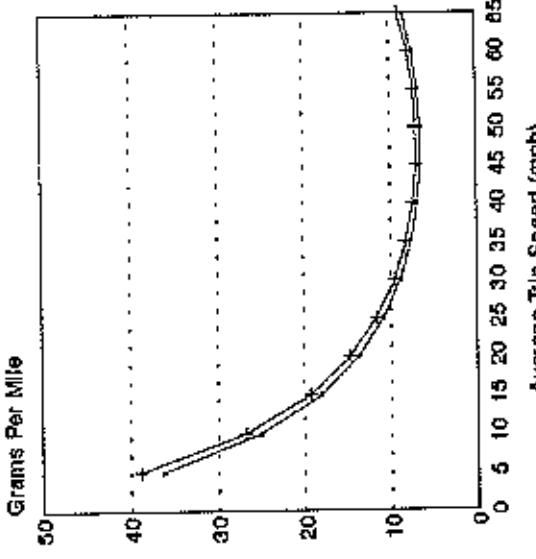


FIGURE 2-7 Comparison of MOBILE5a and EMFAC7F emission factors for carbon monoxide as a function of average trip speed, 1990 fleet average for heavy-duty diesel vehicles (data from Sierra Research, June 1994). Note: confidence intervals around point estimates may be large and encompass positive and negative values. See discussion of uncertainty about emission estimates from EMFAC by Guenstler (1994, Chapter 13) and in Chapter 3. 1 mi = 1.6 km.

capacity-enhancing projects is problematic. The emission factors relate to average trip speed, not to the portion of the trip on which the speed improvement is being made. Furthermore, by focusing on average speed, many of the variables of interest, such as the emission effects of traffic flow smoothing from a capacity project, cannot be analyzed directly. These limitations will be addressed more fully in the following chapter.

Driver Behavior

Recent research suggests that emissions are also affected by smoothness and consistency of vehicle speed, which are heavily affected by

driving behavior and traffic conditions. Sharp accelerations from passing or changing lanes, merging onto a freeway from a ramp, or leaving a signalized intersection impose heavy loads on the engine that result in high emission levels. Vehicle accelerations produce emissions because of an engine operating strategy called power enrichment. When heavy loads are placed on the engine by acceleration, vehicles are designed to operate with a richer fuel-to-air mixture (more fuel than air) to prevent engine knock and damage to the catalytic converter (EPA 1993, 19). This provides good driving performance but causes the catalytic converter to be overridden (there is insufficient oxygen for efficient performance of the catalyst), thereby producing high levels of emissions (EPA 1993,

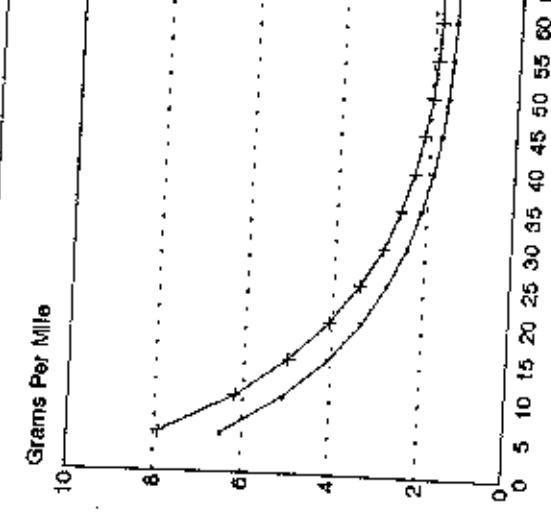


FIGURE 2.8 Comparison of MOBILE5a and EMFAC7F emission factors for volatile organic compounds as a function of average trip speed, 1990 fleet average for heavy-duty diesel vehicles (data from Sierra Research, June 1994). Note: confidence intervals around point estimates may be large and encompass positive and negative values. See discussion of uncertainty about emission estimates from EMFAC by Guensler (1994, Chapter 13) and in Chapter 3. 1 mi = 1.6 km.

- 19). Carbon monoxide emissions are most affected, followed by VOCs; there is little effect on NO_x emissions.²⁰ Research is under way to measure the effects of accelerations on emission levels. Although widespread testing of a range of vehicle ages and model years has not been completed, testing of individual vehicles suggests that the effects can be large. The staff of CARB, for example, have reported that for some vehicles, one heavy acceleration may produce more VOC emissions than the remainder of a 16-km (10-mi) trip (FHWA 1992, 29). Sierra Research has reported that aggressive driving (with many accelerations) results in CO emission levels 15 times higher, and VOC levels 14 times higher, than those resulting from "average" driving. These results were obtained by

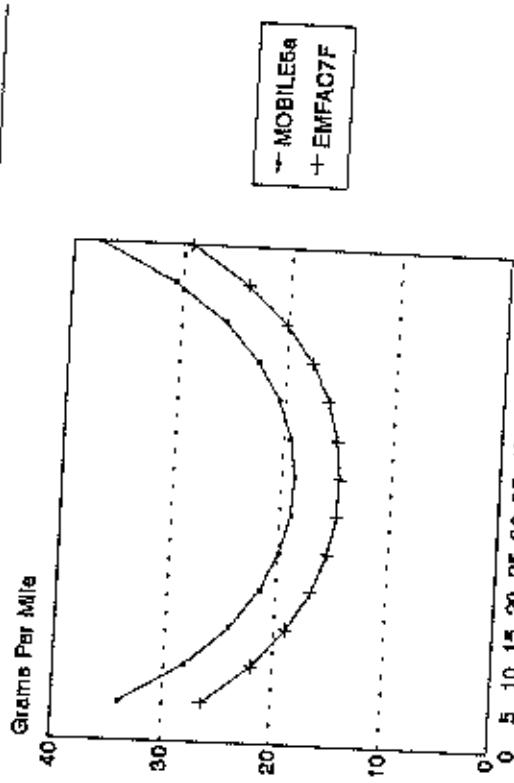
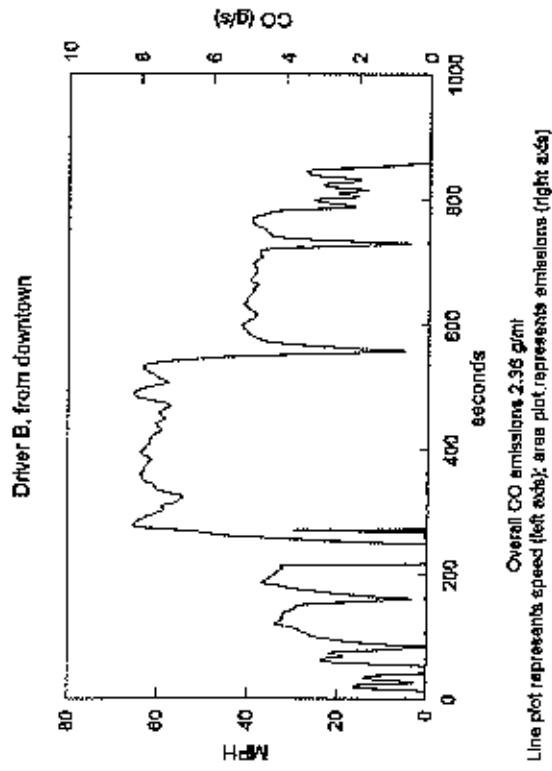


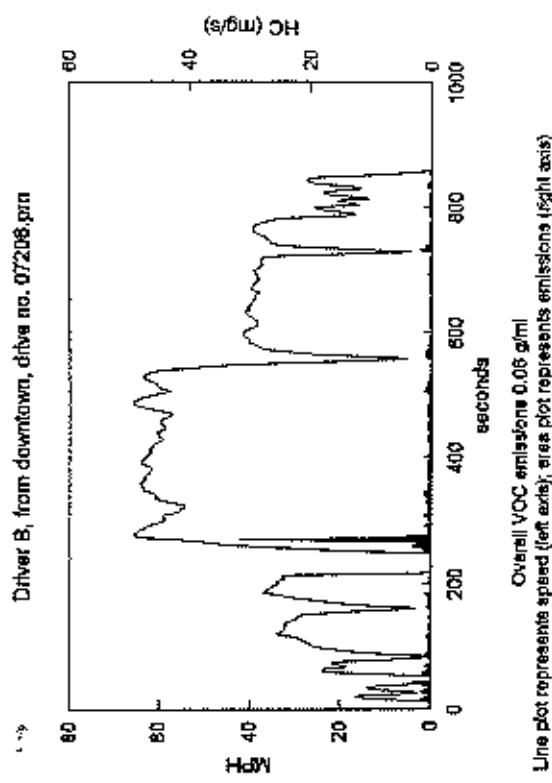
FIGURE 2.9 Comparison of MOBILE5a and EMFAC7F emission factors for oxides of nitrogen as a function of average trip speed, 1990 fleet average for heavy-duty diesel vehicles (data from Sierra Research, June 1994). Note: confidence intervals around point estimates may be large and encompass positive and negative values. See discussion of uncertainty about emission estimates from EMFAC by Guensler (1994, Chapter 13) and in Chapter 3. 1 mi = 1.6 km.

comparing time-speed-emission traces for the same 11-km (7-mi) trip from downtown to an outlying area (Figures 2-10 and 2-11). Highway capacity additions should initially smooth traffic flows; researchers have found reductions in heavy accelerations and greater frequency of cruise-type driving at higher speeds (Etta and Larsen 1993, 3). Capacity additions should thus reduce emissions from accelerations. In the long run, it is likely that extreme impacts from power enrichment will gradually be ameliorated as new emission standards are established. Both EPA and CARB are presently working on certification test cycles for new vehicles that will include heavy accelerations. However, these new standards are not expected to be in place until the late 1990s.

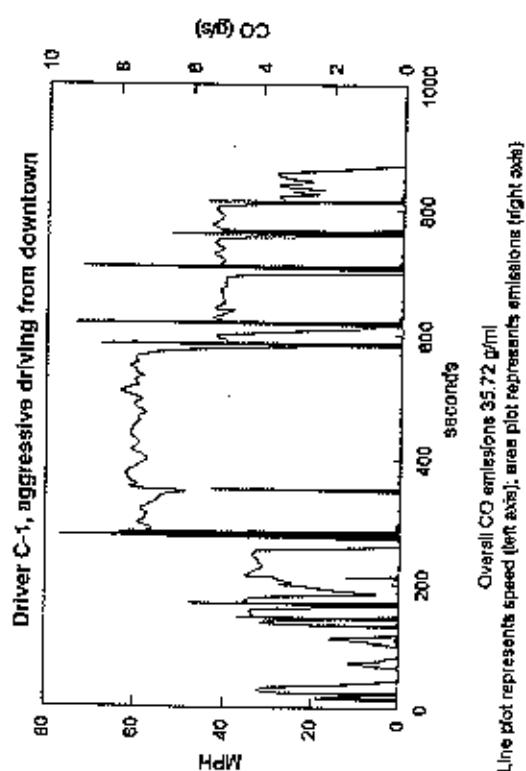
Driver B, from downtown



Driver B, from downtown, drive no. 07208.prt



Driver C-1, aggressive driving from downtown



Driver C-1, aggressive driving from downtown, drive no. 072012.prt

FIGURE 2-10 Time-speed emission traces for carbon monoxide for an "average" and aggressive driver in an 11-km (7-mi) trip from downtown (data from Sierra Research, September 1993). Note: 1 mi = 1.6 km.

FIGURE 2-11 Time-speed emission traces for volatile organic compounds for an "average" and aggressive driver in an 11-km (7-mi) trip from downtown (data from Sierra Research, September 1993). Note: 1 mi = 1.6 km.

Highway-Related Factors

The physical characteristics of the highway network itself can affect emission levels. The presence of highways with long grades, freeway ramps, signalized intersections, major arterials with numerous driveways and significant volumes of traffic entering the traffic flow, and rough pavement are all network conditions that can increase emission levels primarily because of engine enrichment from accelerations as described above (Meyer et al. 1993, 227). Certain highway capacity additions—including improvements to freeway ramp geometry, intersection reconstruction, grade separation of major crossings, synchronization of traffic signals, and other measures to improve traffic flow such as the application of intelligent transportation system technologies—should reduce these emission-creating situations.

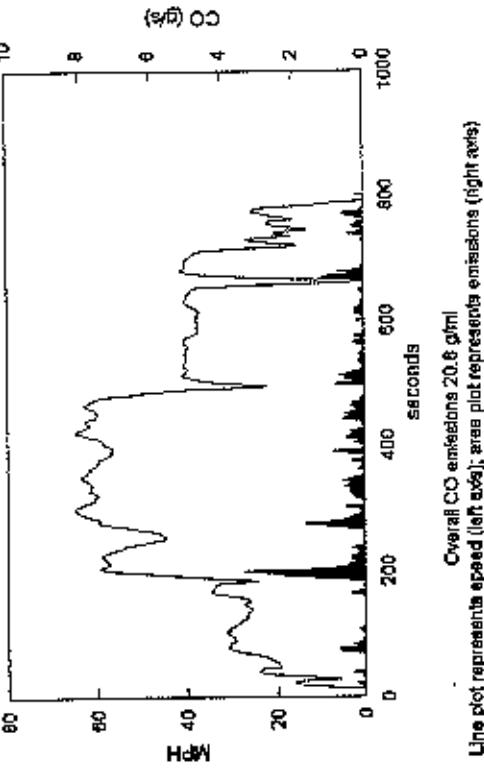
Vehicle-Related and Other Factors

Although not directly affected by highway capacity additions, other factors such as vehicle characteristics, fuels, and temperature can interact with changes in highway capacity and alter their effect on emissions. Future changes in vehicle technologies, fuels, and inspection and maintenance programs to reduce emissions will also reduce the emissions impact of traffic flow pattern changes due to highway capacity additions.

Emissions vary with vehicle age. Older carbureted vehicles have less precise fuel control than newer fuel-injected vehicles, resulting in higher average emissions during normal operation and vehicle starts and a greater incidence of malfunctions (Enns et al. 1993, 7–8). In addition, older vehicles have not met the more stringent emissions standards for the newer vehicle fleet. For example, 1990-model vehicles emit VOCs and CO at only one-third the rate of 1975-model vehicles (DOT and EPA 1993, 33).

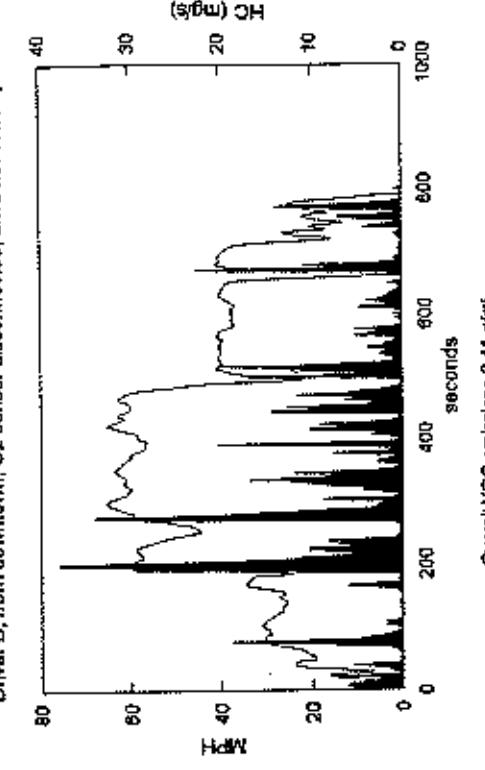
Vehicle condition—whether the vehicle is well maintained, whether the catalytic converter has been tampered with or is malfunctioning—is even more critical than vehicle age in determining total emission levels. In conducting surveys of vehicle condition, researchers have documented the extent of tampering, particularly in areas without inspection and maintenance programs, and its effect on

Driver B, from downtown, O₂ sensor disconnected, drive no. 07233, ppm



Overall CO emissions 20.8 g/mi
Line plot represents speed; area plot represents emissions (right axis)

Driver B, from downtown, O₂ sensor disconnected, drive no. 07233, ppm



Overall CO emissions 20.8 g/mi
Line plot represents speed; area plot represents emissions (right axis)

FIGURE 2-12. Time-speed-emission traces for carbon monoxide (top) and volatile organic compounds (bottom) for an 11-km (7-mi) trip from downtown with the catalytic converter disconnected (data from Sierra Research, September 1993). Note: 1 mi = 1.6 km.

emission levels (Greco 1985 in Johnson 1988, 50–51). More recently, using a roadside measuring device, researchers have been able to test the emissions of vehicles in operation, confirming that a few vehicles, commonly known as superemitters, account for a large share of emissions of CO and VOCs (Sedman 1991; Naghavi and Stroper 1993, 9–10).²¹ Two additional speed-time-emission traces from Sierra Research (Figure 2-12), which can be compared with Driver B in Figures 2-10 and 2-11, show the effect on CO and VOC emissions of driving with the catalytic converter disconnected: emissions are approximately 7 to 10 times larger, respectively. The CAAA requirements for enhanced vehicle inspection and maintenance programs in areas that do not meet air quality standards—annual or biennial high-technology emission testing supplemented with on-the-road testing—should help reduce the number of vehicles that are out of compliance with emission standards.²² Because emissions of superemitters are always high, however, their emission levels are generally less sensitive to changes in speed and sharp accelerations than are those of other vehicles.

As discussed earlier, the mix of vehicles, particularly the amount of heavy truck traffic, affects the types of pollutants emitted. Substantial truck traffic can affect the behavior of other vehicles and their emission levels. For example, slower-moving trucks, particularly in locations with grades, can contribute to more frequent accelerations and decelerations by passenger vehicles as they attempt to navigate around the trucks.

The type of fuel used also has important ramifications for emission levels. The nearly universal use of lead-free gasoline has effectively eliminated lead as a pollutant from transportation sources. The use of reformulated and oxygenated fuels as well as low-sulfur diesel fuel, and the introduction of clean fuels programs for vehicle fleets required by the CAAA in the nation's most polluted areas, will also help reduce emission levels.

Finally, ambient temperature affects both exhaust and evaporative emissions. Exhaust emissions increase below 24°C (75°F); at colder temperatures the engine and emission control system take longer to warm up, increasing cold start emissions (Sierra Research 1993, 122). Evaporative emissions increase above about 24°C, with higher emissions

sion rates the higher the maximum temperature (Sierra Research 1993, 125).²³

Translating Emissions into Air Quality

Examining the changes in vehicle emissions that will result from highway capacity additions is only the first step in understanding how these emissions are likely to be dispersed in the atmosphere and affect the air quality of a metropolitan area.

Meteorological conditions (e.g., wind and temperature) have a major effect on the transport and dispersion of emissions and hence their concentration in a region, which is the primary criterion of concern from a public health perspective (Horowitz 1982, 39). For example, the highest concentrations of CO generally occur in the winter, when atmospheric conditions tend to be more stable and wind speeds are lower, causing reduced dispersion and increased concentrations of CO (Horowitz 1982, 45). Because the chemical reaction that creates ozone is stimulated by heat and sunlight, ozone concentrations tend to be higher from midspring to midfall than during the rest of the year (Horowitz 1982, 74). The atmospheric mixing and transport of ozone concentrations long distances from the sources of the precursors is a well-known phenomenon (Horowitz 1982, 74).

Local topography—both man-made (e.g., tall buildings near a highway) and natural (e.g., mountains)—can also affect the rate of dispersion of emissions from their source.

TRANSPORTATION AND ENERGY CONSUMPTION

The dominant energy source for the transportation sector is petroleum (96.6 percent), and nearly two-thirds of the petroleum consumed in the United States is in this sector (Davis 1994, 2-7, 2-10). The highway mode accounts for nearly three-fourths of total transportation energy use with about 80 percent from automobiles, light trucks, and motorcycles and about 20 percent from heavy trucks and buses (Davis 1994, 2-16). Petroleum energy users are heavily dependent on imported oil; nearly half of all petroleum consumed in the United States comes from foreign sources (Davis 1994, 2-5).

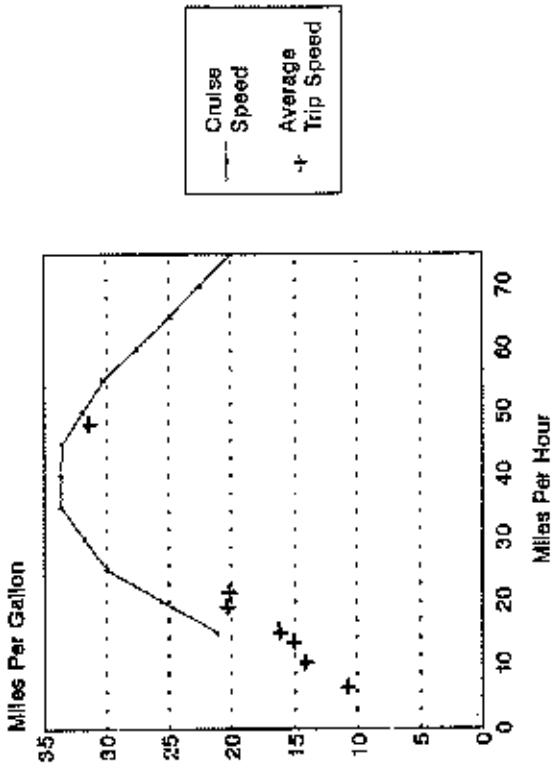


FIGURE 2-13 Fuel economy as a function of cruise speed (Davis 1994, 3-56) and average trip speed (An and Ross 1993b, 76). Note: 1 mi = 1.6 km; 1 gal = 3.8 liters.

Travel-Related Factors

Fuel consumption is a function of different traffic characteristics. Fuel efficiency under steady state, cruise-type driving conditions, measured in miles per gallon for a sample of automobiles and light trucks, peaks at speeds of 56 to 72 kph (35 to 45 mph) and then rapidly declines at higher speeds (Figure 2-13). At lower speeds, engine friction, tires, and accessories (e.g., power steering and air conditioning) reduce fuel efficiency; at high speeds the effect of aerodynamic drag on fuel efficiency, which increases exponentially as a function of speed, dominates (An and Ross 1993a, Figure 2).

Fuel efficiency under start-and-stop traffic conditions shows somewhat different patterns. The data points in Figure 2-13 show modeled estimates of fuel economy as a function of the average trip speed of various drive-test cycles, which are based on different trip

Energy and the Environment

In addition to energy dependence, concerns about global warming have stimulated interest in improving motor vehicle fuel efficiency. Global warming occurs from the emission of carbon dioxide (CO_2) and other gases into the upper atmosphere, which trap heat and warm the earth, hence the term greenhouse effect (Gordon 1991, 55; Greene et al. 1988, 215). Although there is great uncertainty about the likely climatic changes from the greenhouse effect and the timing of these changes, transportation's contribution to the problem is well understood. Carbon dioxide, the principal greenhouse gas, is a by-product of any engine that burns carbon-based, fossil fuels. The U.S. fleet of gasoline-powered automobiles and light trucks contributes about one-fifth of total U.S. CO_2 emissions (NRC 1990 in NRC 1992, 71). Improvements in fuel economy will result in reduced CO_2 emissions. For example, a 10 percent reduction in the fuel consumption of the vehicle fleet will result in an estimated 2 percent reduction in total U.S. emissions of CO_2 (NRC 1992, 71).

Improved fuel economy could also reduce other automotive emissions, such as VOC emissions, which affect ground-level pollution. Improvements in fuel economy may or may not reduce tail pipe VOC exhaust emission levels, depending on corresponding manufacturer changes to emission control systems (DeLuchi et al. 1993, 8).²⁴ If demand for gasoline is reduced, total VOC emissions are likely to be lower because of reduced motor vehicle evaporative emissions and reduced emissions from fuel extraction, refining, processing, distribution, and vehicle refueling (DeLuchi et al. 1993, 3).

Factors Affecting In-Use Fuel Economy

The primary factors affecting fuel economy fall into the same categories as those affecting emissions. Highway projects that add capacity, increasing average vehicle speeds and smoothing traffic flows, will have the greatest effect on those fuel economy factors related to travel conditions, driver behavior, and the physical characteristics of the highway.

types, locations, and traffic conditions (An and Ross 1993b, 76). Fuel economy is somewhat poorer at lower average trip speeds, reflecting greater amounts of acceleration and stopping. At higher average trip speeds, the modeled estimates tend to converge with the cruise speed results, reflecting more cruise-type driving and less acceleration and stopping at these speeds. The results confirm earlier research findings that of all the travel-related factors affecting fuel economy, average vehicle speed explains most of the variability in fuel consumption and is a good predictor of fuel economy for most urban trips (Evans et al. 1974, 16; Murrell 1980, 132). The effect on fuel economy of highway capacity additions, which initially raise average vehicle speeds, depends on average traffic speeds before and after the project. The modal operation of the vehicle also affects fuel consumption. Vehicles get lower fuel efficiency when started cold than when fully warmed up (Murrell 1980, 142).

Driver Behavior

Fuel economy is sensitive to driving behavior, including accelerations (Murrell 1980, 156), braking, and gear shifting. Aggressive braking and accelerations are both associated with reduced fuel economy. Energy is lost from braking as it is dispersed into heat. Repeated braking can account for as much as 15 percent of fuel use in an urban driving trip (An et al. 1993, 5). Aggressive accelerations result in higher engine speeds and greater fuel consumption than constant "cruise" driving.³⁵ Researchers have estimated that, in a congested urban setting, aggressive driving with rapid accelerations will result in a 10 percent increase in fuel use (An et al. 1993, 4). This is a considerably smaller impact, however, than the impact on emissions (Figures 2-10 and 2-11).

Thus, highway capacity additions that smooth traffic flows, reducing the incidence of sharp accelerations and rapid braking, should improve fuel economy initially.

Highway-Related Factors

The characteristics of the highway itself can affect fuel economy. For example, steep grades and rough roads reduce fuel efficiency; the former from increased fuel use as a function of heavy loads on the en-

gine and the latter from increased rolling resistance and aerodynamic drag (Murrell 1980, 119, 121). To the extent that highway capacity additions improve these conditions, fuel efficiency can be gained.

Vehicle-Related and Other Factors

The primary vehicle-related factors affecting fuel economy are vehicle weight and technology. In general, larger and heavier passenger vehicles, vehicles with automatic transmissions, and vehicles with more power accessories (e.g., power seats and windows, power brakes and steering, and air conditioning) all consume more fuel on the average (Murrell 1980, 126, 199, 202).

Vehicle maintenance is also a factor. For example, wheels that are out of alignment and tires that are underinflated increase rolling resistance and hence degrade fuel economy (Murrell 1980, 176, 179). Out-of-tune engines as well as inadequate lubrication to reduce engine friction also take their toll on fuel economy (Murrell 1980, 94, 180).

The mix of vehicles, particularly the amount of heavy truck traffic, affects total fuel consumption. The fuel economy for the U.S. fleet of heavy combination trucks currently averages about 2.4 kpl (5.6 mpg), whereas the fuel economy for the population of passenger vehicles averages about 9.2 kpl (21.6 mpg) (Davis 1994, 3-24, 3-39). However, relative to their weight, heavy-duty diesel-powered trucks are very fuel efficient (O'Rourke and Lawrence 1993, 11).³⁶

Finally, climate is a factor. Fuel economy is poorest at low temperatures (Murrell 1980, 107) and with high winds, which result in aerodynamic losses (Murrell 1980, 114).

MODELING AIR QUALITY AND ENERGY IMPACTS

A range of models are available to estimate the effects of motor vehicle transportation on air quality and energy use. However, many of them are not well suited to the more specific task of estimating the effects of facility-specific highway capacity enhancement projects.

An introduction to the key models of interest, an overview of the state of the practice, and a brief discussion of the key limitations of current modeling practice are provided in this section. More detailed discussions of the problems with individual modeling approaches

as well as recommendations for improvements in practice, including research, are included in each of the following three chapters.

Introduction to Modeling Requirements and Approaches

Modeling the effects of additions to highway capacity on air quality and energy use requires a chain of different models—from land use and travel demand models used to generate trip and traffic volume data to emission, dispersion, and energy models used to estimate the impacts of changes in travel activity on emission levels, regional air quality, and energy use, respectively (Figure 2-14).

Many of these models were not developed to provide the type of analysis required of them today. For example, travel demand models were originally developed to help size and locate highway and transit facilities in a region. Travel volume forecasts could be approximate for estimating capacity requirements, but such forecasts are inadequate for providing the facility- and time-specific travel volume and speed data necessary to estimate the emission impacts of specific projects (Harvey and Deakin 1993, 3–6; DeCorla-Souza 1993b, 6). Similarly, mobile emission models were designed to predict macro-level emissions for input into emissions inventories,²⁷ not to provide precise estimates of emission rates for vehicles traveling on individual highway links (Guensler 1993, 12).

Land Use and Travel Demand Models

Land use and travel demand models are critical to forecasting changes in travel demand from capacity additions to the highway network in a regional area. Only a few MPOs have developed fully integrated, state-of-the-art, land use–transportation models that would enable them to model the impacts of highway supply changes on travel demand and land use. More MPOs are expressing interest in developing this capability as a result of the CAAA and ISTEA (Putman 1994, 2).

Land Use Models

A growing number of metropolitan areas have formal land use modeling capabilities; however, their use is still restricted to a minority of

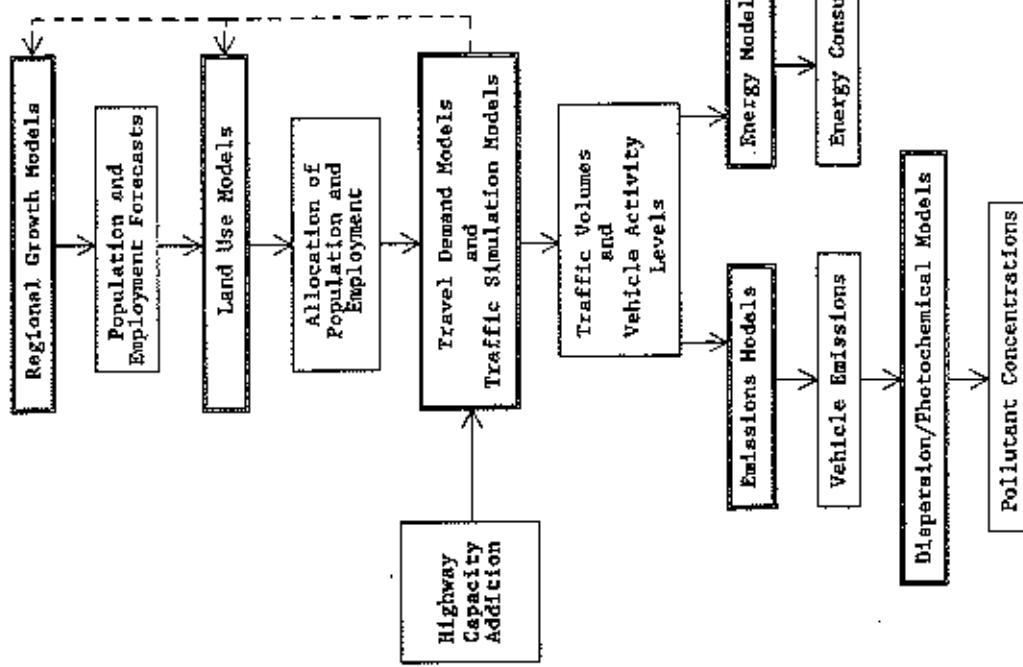


FIGURE 2-14 Modeling chain for estimating impacts of changes in travel activity on emissions and pollutant concentrations and energy use (adapted from DeCorla-Souza 1993a, 1).

regions in the United States (Harvey and Deakin 1993, 3-14-3-15). The available models generally use time series data on population, employment, household income, land availability,³³ and accessibility to allocate regional population and employment forecasts to geographic subareas of a region (Harvey and Deakin 1993, 3-15).

The main allocation modeling approach in use in the United States³⁴ is the DRAM-EMPAL (Disaggregated Residential Allocation Model-Employment Allocation Model) components of the Integrated Transportation and Land Use Package (ITLUP) (Putman 1991).³⁵ The DRAM-EMPAL models allocate projected employment and households in a region on the basis of the current distribution of jobs and population, travel times, and multivariate measures of the attractiveness of various locations (Putman 1993). For example, the attractiveness of specific household locations depends on such factors as the amount of vacant developable land and the characteristics (e.g., income range) of households already living in specific areas (Putman 1993). The DRAM-EMPAL models can be used alone or linked to a travel demand model. A variety of other land use models have been developed and used overseas, many of which are complex and data intensive, but none are currently in use in the United States (Cambridge Systematics, Inc. 1991, 9; Wegener 1994).

One criticism of DRAM-EMPAL is that it does not describe all of the major factors (e.g., housing and land values, tax rates, and crime rates)³⁶ that determine the location decisions of firms or households (Harvey and Deakin 1993, 3-15). This limits the precision of its predictions. However, sensitivity tests of the DRAM-EMPAL models demonstrate the models' ability to reproduce large regional patterns (Putman 1993). Thus, the models should be able to provide a sense of the direction and magnitude of locational changes from major additions to regional highway capacity.

Travel Demand Models

Many MPOs have a travel demand modeling capability.³⁷ Figure 2-15 provides an overview of the typical four-step sequential approach used to forecast regional travel demand; each step is a model representing a different aspect of the traveler's decision (Shunk 1992, 109). The first step in the process, trip generation, is a function of exogenously

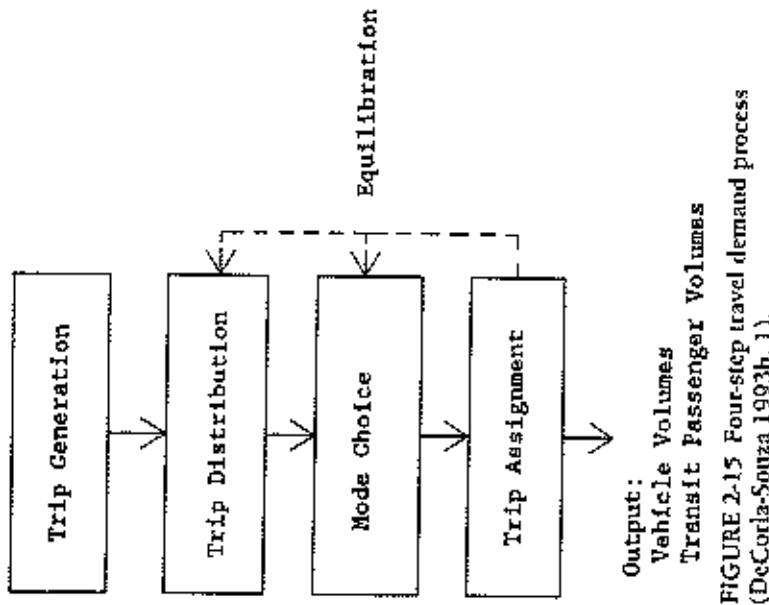


FIGURE 2-15 Four-step travel demand process (DeCorla-Souza 1993b, 1).

determined demographic patterns and economic activity in a region (DeCorla-Souza 1993b, 3). The remaining three steps, which are followed sequentially, simply allocate the trips among alternative destinations in trip distribution, alternative modes of travel in mode choice, and alternative highway (and transit if appropriate) routes in trip assignment (DeCorla-Souza 1993b, 2). Trip assignment is based primarily on minimizing travel time through an iterative process that feeds back to mode choice, and sometimes to trip distribution, in an effort to equate initial with final travel time estimates (Harvey and Deakin 1991, 10-11). The outputs of the process are vehicle and passenger volumes on highway and transit routes, respectively (DeCorla-Souza 1993b, 2) (Figure 2-15).

A primary limitation of current travel demand modeling practice is the lack of integration with land use models. With few exceptions,³³ the models do not provide feedback loops so that analysis can examine the long-term impact of changes in the transportation network and network performance on travel demand and land use patterns and the trips generated by these effects. Because trip generation is exogenously determined in most conventional travel demand models, few MPOs can examine how highway additions might affect the regional distribution of population and economic activity, or regional growth in general (Deakin 1991, 11). In fact, there are no operational models that formally analyze the impact of transportation improvements on aggregate regional growth, in part because of lack of a theoretical basis for determining the relationship between transportation improvements and population and economic growth (Deakin 1991, 11).

In addition, conventional travel demand models do not provide the level of accuracy or detail on vehicle or travel activity by time of day that is needed for accurate emission and air quality modeling of the impacts of additions to highway capacity. The reliability of data on speed and traffic volume forecasts is poor,³⁴ and other detailed data needed for emission and air quality analyses—such as temporal distribution of travel volumes and trips, vehicle type, and vehicle operating mode—are not direct outputs of the models.³⁵

Traffic Simulation Models

Traffic models, as mathematical representations of real-world phenomena, comprise the tools used by traffic engineers to assess the relationships between capacity, levels of service, speed, and delay. Simulation models, as computer implementations of traffic models, provide a more detailed representation of traffic flow, including information on speed, acceleration, and deceleration of individual vehicles.³⁶ Several of the traffic and simulation models in current use have been adapted to provide estimates of emissions and fuel use.

Why are these models then not used more widely to address the questions raised in this study? One reason is that many of the models are extremely data intensive and are thus beyond the data capabilities of many MPOs (Harvey and Deakin 1993, 3-77). Another reason is that, although traffic simulation models provide sophisticated

analyses of the impacts of traffic flow improvements on roadway and vehicle performance, they are not well equipped to make similarly sophisticated assessments of changes in traffic volumes that will accompany these measures (Horowitz 1982, 212). Thus, they fall short in their ability to analyze the longer-term impacts of traffic flow improvements of interest in this study.

Under the auspices of the jointly funded federal Travel Model Improvement Program,³⁷ a multimodal traffic simulation model is being developed at the Los Alamos National Laboratory. The model as planned will provide detailed estimates of household trips and travel and vehicle movements in a metropolitan area, which can then be linked with emissions, airshed, and energy use models (presentation by G. Shunk, fourth study committee meeting, July 11, 1994). Although more detailed estimates of the physical effects of transportation activities on emissions, air quality, and energy use will be available, the model will not have any forecasting capacities to examine behavioral effects; forecasts of land use and trip generation patterns must be prepared separately and input into the model (Shunk, July 11, 1994).

Emission and Atmospheric Dispersion Models

Emission and atmospheric dispersion models are critical to assessing the impacts of motor vehicle travel on pollutant emissions and concentrations.

Emission Models

Two main emission models are currently in use in the United States: (a) the EPA MOBILE model, which is the most widely used emission model, and (b) the CARB EMFAC model, which is used in California. The structure of the models is the same: activity-specific emission rates estimated by the models are multiplied by emission-producing vehicle activities to provide emission outputs by pollutant (i.e., grams per vehicle-mile for MOBILE and, in addition, grams per vehicle-hour and per vehicle trip for EMFAC) (Guensler 1993, 3) (Figure 2-16). In both models, emission rates are a function of vehicle type and age, vehicle speed, ambient temperature, and vehicle operating mode (DeCorla-Souza 1993a, 2).

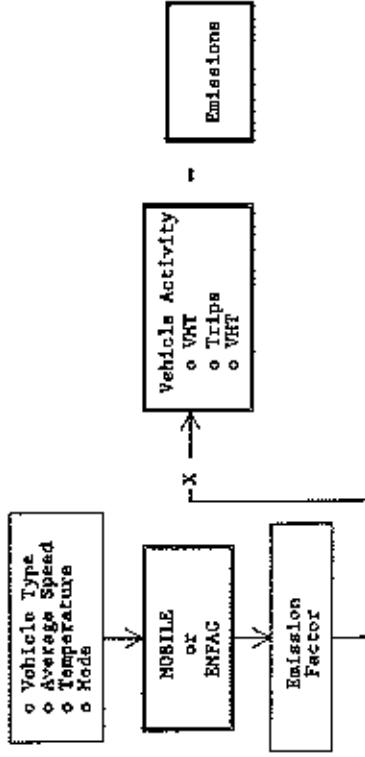


FIGURE 2-16 Emission modeling process (DeCorla-Souza 1993a, 1).

Baseline emission rates are derived from a laboratory test procedure known as the Federal Test Procedure (FTP), which has been used to determine compliance of light-duty vehicles and light-duty trucks with federal emission standards since the 1972 model year (EPA 1993,). The FTP driving cycle consists of a sequence of accelerations, decelerations, cruise speeds, and idles based on actual home-to-work minute trips in the 1960s on Los Angeles freeways and surface arterials. A review of the FTP required by the AAA has found that it underrepresents the high-speed driving and high acceleration rates that are common features of today's driving patterns and are key causes of high emissions (EPA 1993,).³⁸ Several of the 11 other driving cycles used to develop speed correction factors, which adjust emissions rates for vehicles traveling at average speeds other than the FTP baseline speed, are also not considered to be adequately representative of today's urban driving conditions.

Procedures for determining heavy-duty vehicle emissions differ significantly from those for determining light-duty vehicle emissions. Heavy-duty vehicle testing is generally performed on an engine dynamometer³⁹ rather than the full chassis dynamometer, which is used for light-duty vehicles, with the result that conversion factors must be used to produce emission rate data on a grams per vehicle-mile basis equivalent to light-duty vehicles. However, the speed correction fac-

tors for emissions of heavy-duty diesel vehicles, which are embodied in the MOBILE model, are based on chassis dynamometer testing of 22 1979-vintage heavy-duty diesel trucks conducted in the early 1980s (see Appendix A).

Emission models have several shortcomings as analytic tools for assessing the impacts that are of interest in this study. Among these are reliance on a limited number of drive cycles that do not adequately represent current driving on urban highways and underestimate key sources of high emissions; limited testing of passenger vehicles at high speeds and of heavy-duty vehicles at all speeds; and emission rates that reflect average trip speeds rather than average link speeds. These shortcomings are critical because emission estimates from current models are sensitive to assumptions about average vehicle speeds and the underlying drive cycles on which they are based.

Atmospheric Dispersion Models

Atmospheric dispersion or diffusion models translate emission levels into atmospheric concentrations of pollutants. Regional models take input data on grid-based rates and locations of emissions in a region and on the region's topography and meteorology (i.e., wind speeds and directions) to determine the atmospheric transport, diffusion, and chemical reactions of pollutants. Data on concentrations of pollutants at particular locations and times are the result (Horowitz 1982, 31; NRC 1991, 303).

Under the CAAA, ozone nonattainment areas designated as extreme, severe, serious, or multistate-moderate are to use photochemical, grid-based air quality models, such as the Urban Airshed Model, to demonstrate attainment of NAAQS (NRC 1991, 81). These models require detailed travel activity data that are spatially and temporally allocated (e.g., by grid, by season, month, and weekday or weekend day) to reflect the episode being modeled⁴⁰ (DeCorla-Souza 1993a, 1).

Dispersion models are also used to estimate concentrations of pollutants near particular facilities, such as intersections. For example, air quality intersection models estimate CO concentrations using data on traffic, intersection geometry, vehicle characteristics, emission fac-

tors generated from emission models, and meteorological conditions (O'Connor et al. 1993, 1). The CAL3QHC model, which is recommended by EPA guidance for intersection modeling, is used in most states except California, where use of the CALINE 4 model is recommended (O'Connor et al. 1993, 1).

Model uncertainties about chemical mechanisms, wind field modeling, and removal processes as well as problems with input data—difficulties in obtaining accurate measures of VOC emissions and detailed spatial and temporal data on travel activity from conventional travel demand models—limit the effectiveness of dispersion modeling for ozone (NRC 1991, 10-11). Similar data gaps as well as placement and location of receptors are problems for CO modeling. For example, a recent survey on current practices in intersection air quality modeling (O'Connor et al. 1993, 29) found that critical determinants of predicted concentrations of CO, such as data on queuing, vehicle operating modes, fleet age and composition, speeds in highly congested flows, accelerations, and turning movements, are not commonly available for specific intersections.

Energy Models

A major source of highway vehicle fuel economy estimates is the simulation model developed by the Oak Ridge National Laboratory for the Federal Highway Administration in the mid-1980s. The model, which is based on on-road vehicle tests (12 gasoline-powered and 3 diesel-powered light-duty vehicles) and laboratory (dynamometer) testing, estimates fuel consumption as a function of vehicle speed and acceleration (McGill 1985, 3). The simulation model provides a good approximation of actual fuel use. The variance in individual vehicle performance, particularly the effect of speed variation at lower speeds, is less for fuel economy than for emissions. At high speeds, the test results converge, reflecting more steady-state, cruise driving (McGill 1985, 49). More recently, simplified analytic models have been developed that can estimate fuel economy within a 5 percent error range on the basis of vehicle parameters that specify the make and model of vehicle and driving patterns that reflect the level of traffic congestion (An and Ross 1993a, 1).

Limitations of Current Modeling Practice

The key limitations of current models can be summarized under three broad categories. More in-depth discussion, particularly of the uncertainties of the models, can be found in the following chapters.

- **Appropriateness of the models:** The models are being used to solve problems for which they were not originally designed. Many are ill suited to provide the detailed analyses of the impacts of link-specific highway capacity additions on travel behavior and vehicle performance that are the focus of this study.
- **Validity of the models:** There are large uncertainties in the models themselves, which are manifested in wide variances around some model estimates. These reflect the limited state of the knowledge of the underlying phenomena the models are attempting to capture. A better understanding is needed of travel and driving behavior, which are critical to accurate travel demand and emission modeling, respectively. Models are validated, that is, a comparison of estimated with actual measured data is made, when sufficient survey data are available.⁴⁰ Too often the information is dated or limited.
- **Links between the models:** There is a mismatch of detail between the outputs generated and the inputs required by several of the models in the modeling chain. Lack of adequately detailed data from travel demand models for input into emission and atmospheric dispersion models is a particular problem for accurate estimation of the impacts on air quality of highway capacity additions.

SUMMARY

Motor vehicles are a major source of air pollution in the nation's metropolitan areas, and they are major users of petroleum. According to currently available estimates, transportation sources account for about 45 percent, and highway vehicles slightly more than one-third, of nationwide emissions of EPA's six criteria pollutants. However, the range is considerable for each pollutant source and for different vehicle and fuel types. Moreover, there is a high degree of uncertainty with respect to many of the estimates.

Gasoline-powered passenger vehicles—the most common vehicle on the road—are the primary source of CO highway vehicle emissions and contributors to the ozone precursor emissions from highway vehicles (VOCs and NO_x). Heavy-duty diesel vehicles contribute a disproportionate share of total highway vehicle emissions of PM-10, SO₂, and NO_x.

The transportation sector accounts for nearly two-thirds of the petroleum consumed in the United States. The highway mode accounts for about three-quarters of the transportation total. The gasoline-powered motor vehicle fleet also contributes about 20 percent of total U.S. CO₂ emissions, the principal greenhouse gas.

Vehicle emission levels are a function of trip taking as well as distance traveled, because emissions vary depending on whether the vehicle is warmed up. Emission levels are sensitive to average vehicle speed over the distance of the trip and vary as a nonlinear function of average trip speed. In addition, emissions are affected by smoothness and consistency of vehicle speeds, which vary by trip type. Sharp accelerations, in particular, are an important source of CO and VOC emissions, which are not well reflected in current emissions models. Thus, average trip speed alone is not a good predictor of emission levels.

Fuel economy is also sensitive to average vehicle speed but somewhat less so to aggressive accelerations and braking. Thus, average trip speed is a good predictor of fuel economy for most urban trips. Highway capacity additions, which will increase average trip speeds and smooth traffic flows, should directly affect emission levels and fuel economy.

A range of models are available to estimate the effects of motor vehicle transportation on emissions, air quality, and energy use. However, many were developed to predict macro-level, regional effects; they are not well suited to assessing the impacts of link-specific highway capacity enhancement projects at the level of precision that is being required of them today. Nor were the different types of models (e.g., land use models, travel demand models, emission models) designed to be easily integrated in their operations. Data requirements—both the currency of the data and the detail needed for impact analyses—are also problems. Finally, the models are based on a limited understanding of the underlying relationships. Greater knowledge of

travel and driving behavior, in particular, is critical to improved modeling of the travel demand and emission effects of highway capacity enhancement projects.

NOTES

1. A stationary or point source is a large, geographically concentrated emitter, such as a coal-fired electrical power plant, whose emissions rates are large enough to be significant by themselves even if no other emission sources are present (Horowitz 1982, 7). An area source is a collection of small, geographically dispersed emitters that are not significant individually but that are important collectively, such as dry cleaning establishments (Horowitz 1982, 7). A mobile source, such as an automobile, is characterized as not emitting from a fixed location.
2. Short-term (24-hr or less) averaging times were designated for some pollutants, such as CO and O₃, to protect against acute, or short-term, health effects; long-term averaging times (annual average) were established for other pollutants to protect against chronic health effects (Curran et al. 1994, 20).
3. CO contributes to the buildup of tropospheric (ground-level) ozone (the principal ingredient of smog) and methane, both major greenhouse gases. First, CO helps convert nitric oxide to nitrogen dioxide, a crucial step in ozone formation. Second, CO reacts with the hydroxyl radical (OH), which eventually removes CO from the atmosphere; however, OH is also the principal chemical that destroys ozone and methane. Thus, if carbon monoxide levels increase, OH concentrations will fall, and regional concentrations of ozone and methane will rise (MacKenzie and Walsh 1990, 8).
4. After the report was completed, EPA recomputed emissions from highway vehicles using the most recent version of its emission factor model, MOBILE 2a (Curran et al. 1994, 22), but EPA estimates are still thought to be low by many in the scientific community.
5. Nitrogen oxide (NO), the dominant constituent of vehicle exhaust emissions of NO_x, combines with ozone (O₃) to form NO₂ and O₂. However, ozone is subsequently regenerated by further chemical reactions stimulated by the presence of sunlight (see NRC 1991, 168 for a more detailed discussion).
6. The problem is the consistent underestimate of VOC emissions, which leads to estimates of relatively low VOC to NO_x ratios. The nation's ozone reduction strategy has been based largely on the premise that VOC/NO_x ratios in the most polluted areas, where VOC control is more effective, are low (i.e., in the less-than-10 range). An upward correction in VOC emission inventories could indicate the need for a fundamental change

- in ozone abatement strategies to greater use of NO_x controls in many geographic areas (NRC 1991, 7).
7. This regulation, however, is an interim requirement, that is, it applies to all projects contained in new or revised transportation improvement programs until EPA approves state implementation plans. In the latter, a state could choose to accommodate NO_x emissions generated by new transportation projects by reducing emissions from other sectors (NASHTO Journal 1994, 10-11.)
8. In 1987 EPA replaced earlier standards for particulate matter with the more stringent PM-10 standard, which focuses on the smaller particles likely to be responsible for adverse health effects because of their ability to reach the lower regions of the respiratory tract (Curran et al. 1994, 10).
9. The 1987 Truck Inventory and Use Survey reported that 67 percent of combination vehicles used diesel fuel, but most trucks operating only in local areas (96 percent) are fueled by gasoline (Bureau of the Census 1990, 37, 48).
10. In 1993 emissions from all highway vehicles, gasoline and diesel powered, for CO, NO_x, PM-10, SO_x, and VOC were 74,155 thousand short tons. Emissions from diesel-powered, heavy-duty vehicles for the same pollutants were 3,986 thousand short tons, or 5.4 percent of the total; emissions from light-duty passenger vehicles were 46,941 thousand short tons, or 63 percent of the total (Nitzsch et al. 1994, A-4, A-8, A-15, A-19, A-24). In the most recent year for which data are available (1992), all motor vehicles accounted for 2,239,828 million vehicle miles of travel; combination trucks and buses accounted for 104,771 million vehicle miles of travel, or nearly 5 percent of the total, and passenger vehicles accounted for 1,595,438 million vehicle miles of travel, or 71 percent of the total (FHWA 1993, 207).
11. The primary components of diesel particulates are soot formed during combustion (40 to 80 percent of the total); particulate sulfates, which depend on operating conditions and the fuel's sulfur content (5 to 10 percent of the total); and heavy hydrocarbons condensed or adsorbed on the soot from the fuel and lubricating oil and also formed during combustion (the remainder) (Weaver and Klaesener 1988, 2-7-2-8).
12. Even if all fuel were burned in the combustion process, thereby eliminating particulates from incomplete combustion, impurities in the fuel would burn and appear in the exhaust as particulates; the primary off-fender is sulfur (Conte 1990, 61). With lower sulfur levels in fuel, this source of particulates should also be reduced.
13. EPA considers a cold start for a catalyst-equipped vehicle to occur after the engine has been turned off for 1 hr. For noncatalyst vehicles, a cold start occurs after the engine has been turned off for 4 hr (Sierra Research 1993, 18).

14. Refueling losses and crankcase emissions are also generally considered in the evaporative emissions category as is a new category, resting losses.

The latter was previously included under the hot soak and diurnal categories (Sierra Research 1993, 20).

15. VOC and CO emissions are higher when a cold engine is first started, because a fuel-rich mixture must be provided to achieve adequate combustion during warm-up and the excess fuel is only partially burned. In addition, the catalytic converter does not provide full control until the vehicle is warmed up (Sierra Research 1993, 18). It takes between 1 and 3 min for modern, properly operating vehicles to warm up. Catalysts also cool off faster than engines and are completely cold in 45 to 60 min (EPA 1993, 115; Ennis et al. 1993, 3). Preheated catalytic converters may ameliorate the problem. The California Air Resources Board estimates that they would decrease cold-start emissions by half or more but would not eliminate the problem (FHWA 1992, 28).

16. The number would be even larger if running loss evaporative emissions, which are included under running emissions, were separated out.

17. Loads are a function of vehicle operating conditions (e.g., number of passengers, whether a trailer is being towed), whether the air conditioning is on, highway conditions (e.g., road grade), and driver behavior (e.g., aggressive driving with sharp accelerations). The latter two conditions are described in subsequent sections.

18. The exceptions are air conditioning and towing corrections, which can be input by the user in running the emissions models.

19. Emissions were calculated under hot stabilized operating conditions.

20. CO emissions, which are a product of incomplete combustion of motor fuels, are most affected. Engine-out CO emissions increase because of incomplete fuel combustion under fuel-rich conditions and exhaust emissions increase because the catalyst is overridden (personal communication, John German, EPA, Feb. 4, 1994). VOCs are affected but to a lesser extent. They result from unburned fuel in the engine. As fuel is increased with the richer air-fuel mixture, the level of engine-out VOC emissions goes up proportionately; these emissions are not handled by the catalyst, which is overridden under fuel-rich conditions, thereby increasing exhaust emissions (personal communication, John German, EPA, Feb. 4, 1994). NO_x engine-out emissions decrease under rich operation, but NO_x reduction efficiencies in the catalyst also drop (EPA 1993, 19). Overall, there may be a slight increase in exhaust NO_x emissions under rich operation, but the effect is relatively minor and varies from vehicle to vehicle (EPA 1993, 19).

21. From a sample of 24,000 emissions measurements made over a 4-day period, Naghavi and Stopher (1993) found that more than half of the CO was emitted by 6.9 percent of the vehicles and that about half of the VOC was emitted by 20 percent of the vehicles (p. 1).

22. These programs are required in areas designated "serious" or above for ozone and "high moderate" or above for CO. EPA estimates that innovative inspection and maintenance programs could yield a 28 percent reduction in emissions (DOT and EPA 1993, 33).
23. Exhaust emissions of CO and VOC also increase at temperatures above 24°C (75°F), but not as sharply as at lower temperatures. The increase is primarily the result of an increase in vapors purged from the evaporative emission control system, leading to rich operation (Sierra Research 1993, 122).
24. For example, if VOC emission formation in the engine (engine-out emissions) is reduced because less fuel is being delivered to the engine chamber per engine cycle, these gains will show up as lower tail pipe exhaust emissions only if manufacturers do not cut back on catalyst emission control systems (tail pipe emissions) and do not take advantage of some of the savings (Deluchi et al. 1993, 7-8).
25. The problem is not the quick acceleration, but the delay in gear shifting. Drivers with manual transmissions shift later (at higher engine speeds); with automatic transmissions, the system delays shifting up, both with the same result—high engine speeds and high fuel consumption (An et al. 1993, 4).
26. A fully loaded diesel truck realizes 3 to 3.4 kpl (7 to 8 mpg) on the highway, or approximately 108.9 to 123.4 metric ton-km per liter (280 to 320 ton-mi per gal). A car weighing 2268 kg (5,000 lb) can realize 11 to 12.7 kpl (26 to 30 mpg), or 25 to 28.8 metric ton-km per liter (60 to 75 ton-mi per gal) (Duluth 1992 in O'Rourke and Lawrence 1993, 11).
27. Emission inventories contain the relative contributions, current and projected, of emissions and pollution levels from mobile and stationary sources, drawing upon regional models and data (Harvey and Deakin 1993, 2-1-2-2).
28. Population and employment forecasts for a region may be provided by economic models or derived from federal or state sources (Harvey and Deakin 1993, 3-11). Land use data are obtained from local land use plans. Local development policies are important to understanding potential constraints on land availability and development intensity (Shunk 1992, 107).
29. Putman reports, for example, that there are 14 MPOs in various stages of implementing DRAM-EMPALE for regional forecasting and policy evaluation efforts (Putman 1994, 1). Eleven have completed preliminary calibrations of both models using their own region's data and four are working on developing direct linkages between their transportation and land use models (Putman 1994, 2). Other land use models in use in the United States include POLIS in the San Francisco Bay Area, EMPIRIC in Atlanta, and PLUM in Washington, D.C. (Shunk 1992, 107).

30. In the early 1980s the entire UTPS was distributed as a supplement to the Urban Transportation Planning System (UTPS) package, a travel demand modeling system package developed by the Federal Highway Administration (Harvey and Deakin 1993, 3-16).
31. The DRAM model, however, includes the income distribution of residential households, which is a proxy for several of these factors.
32. Many MPOs use the UTPS software package (Harvey and Deakin 1993, 3-5).

33. The MTC of the San Francisco Bay Area and the Puget Sound Council of Governments in the Seattle area have formal land use models, which are integrated into their regional travel demand models in a manner that allows for feedback between transportation and land use over time (Cambridge Systematics, Inc. 1991, 42). Cambridge Systematics, Inc., has been working with the Portland, Oregon, metropolitan area through the Land Use Transportation/Air Quality Connection project to develop this capacity. Finally, the Southern California Association of Governments has recently completed a full test run of an integrated land use (DRAM-EMPALE)-transportation model (Putman 1994, 3).
34. Direct estimates of travel speed are not an output of travel demand models. Instead, link speeds are adjusted through an iterative process of assigning trips to the shortest network path to arrive at travel volume estimates (Meyer and Ross 1992, 6). Traffic volumes are often calibrated with actual traffic counts, but no attempt is made to check travel speeds or travel time against observed speeds (DeCorla-Souza 1993b, 5-6), with the result that model-derived speeds tend to overestimate actual link speeds, particularly under congested conditions (Meyer and Ross 1992, 6; Harvey and Deakin 1993, 3-63). Estimated traffic volumes on specific links may be in error by as much as 15 to 50 percent, depending on the total traffic volume on the link (DeCorla-Souza 1993b, 2).
35. Travel demand models provide no information on cold starts, because trips are not chained and travel is not tracked by time of day (Duca 1993, 3). Travel demand models typically provide data on average weekday traffic levels by traffic zone. Hourly data on episode days by grid square, however, are needed for photochemical modeling (DeCorla-Souza 1993a, 3; Duca 1993, 3). Information on vehicle type and age and vehicle operating mode cannot be directly obtained from travel demand model output (DeCorla-Souza 1993a, 4-5).
36. Some of the most common models for simulating traffic flows on freeways and estimating the effects of bottlenecks and ramp metering are FREQ, TRAFLO, and INTRAS. NETSIM was designed to simulate traffic changes from traffic signalization and intersection design improvements. TRANSYT and PASSER simulate traffic flows on arterials and changes in performance, such as travel times and delays that result from traffic flow improvement measures (Harvey and Deakin 1993, 3-77).

37. The U.S. Department of Transportation and the Environmental Protection Agency have already authorized \$3 million; Department of Energy support is also being sought for a long-term program total of \$25 million.
38. An analysis of instrumented vehicles driven in the Baltimore area for the FTP review found that about 18 percent of total Baltimore driving time was composed of higher speeds and sharper accelerations than those represented on the FTP [i.e., maximum speeds of 90.7 kph (56.7 mph) and maximum acceleration rates of 5.3 kph/sec (3.3 mph/sec)] (EPA 1993, 3-4).
39. An engine-based test procedure was adopted because engine manufacturers are distinct from truck manufacturers and because the same engine can be used with a wide variety of trucks with different transmissions and axles (see Appendix A).
40. The models are validated for predictive purposes on the basis of their ability to simulate adequately a base-year episode day of high concentrations of ozone (NRC 1991, 308).
41. Validation of emissions data is further complicated, as is discussed in the following chapter, by identifying what actual data (e.g., what drive cycle) to measure.

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- | | |
|------|-----------------------------------|
| DOT | U.S. Department of Transportation |
| FHWA | Federal Highway Administration |
| EPA | Environmental Protection Agency |
| NRC | National Research Council |
| TRB | Transportation Research Board |
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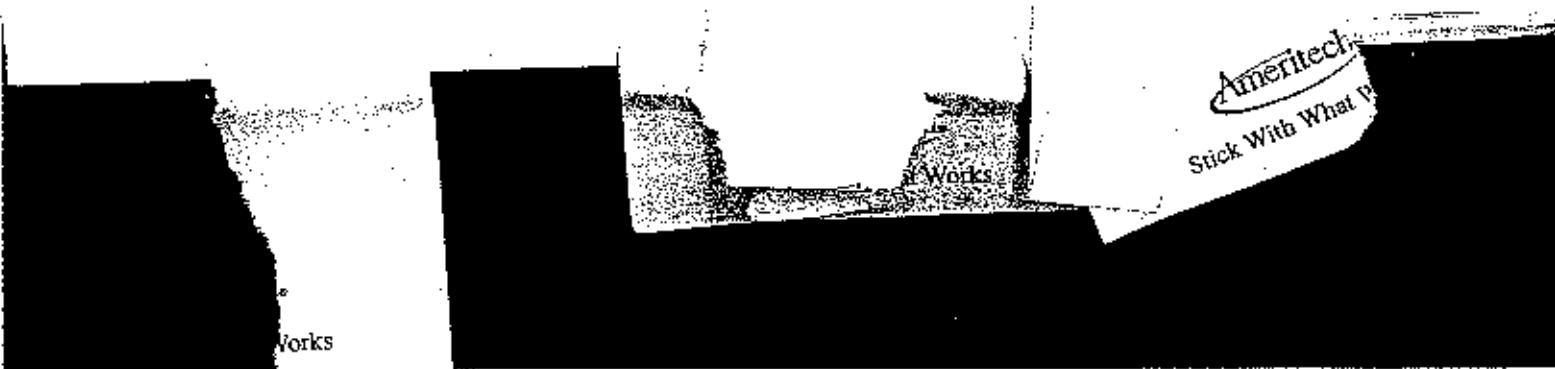


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Special Report 245

EXPANDING METROPOLITAN HIGHWAYS

*Implications for
Air Quality and Energy Use*

Committee for Study of Impacts of
Highway Capacity Improvements on
Air Quality and Energy Consumption

n Officials,
(ex officio)

(ex officio)

TRANSPORTATION RESEARCH BOARD
National Research Council

National Academy Press
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APPR

do not know what the future might bring. Citizens need no experts to know that one does not cure obesity by loosening one's belt nor cure traffic-related problems by simply expanding highways.

Readers of this report should consider two closely related reports issued in 1994 by high-level study commissions in the United Kingdom. These considered a wider range of evidence and drew conclusions and judgments that contrast with the committee report and are generally more consistent with this minority statement. The Standing Advisory Committee on Trunk Road Assessment (SACTRA) report, *Trunk Roads and the Generation of Traffic*, is focused specifically on the strong evidence that highway capacity expansion spurs increased motor vehicle travel demand (SACTRA 1994). In the Royal Commission on Environmental Pollution (RCEP) report, *Transport and the Environment*, an overview is given of the broader challenge of making transportation more sustainable, including extensive discussion and recommendations regarding the role of road investment in contributing to environmental degradation (RCEP 1994).

The committee report does not give appropriate consideration to evidence related to the effects on energy use and the environment caused by a reduction of highway capacity—for example the effects of traffic calming and traffic cells—although such evidence is highly relevant to the issue at hand. While asserting that transportation pricing strategies are more important than changes in highway capacity in determining environmental performance, the report gives only limited consideration to evidence from outside the United States that might isolate the effects of highway capacity changes from the effects of transport pricing, levels of public transportation provision, and alternative land use and urban design patterns. Excluding this evidence, and in a tone that appears to subtly play to one side of current contentious domestic policy debates, the report concludes that our state of knowledge is insufficient to evaluate the effects of added highway capacity to support current federal environmental regulations.

It is intellectually inconsistent for the report to argue that on the one hand, current models cannot evaluate the effects of changes in highway capacity on the environment, while on the other hand asserting that alternative strategies, such as time-of-day tolls, will have known and larger effects on air pollution emissions. If we lack the ability to develop reasoned estimates of likely effects of changes in high-

Appendix E

Minority Statement of Michael A. Replogle

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Stack With What Works

Intermetech

committee charged with evaluating the effects of added highway capacity on the environment and energy use has reviewed extensive literature and conducted numerous meetings in pursuit of consensus. Though I concur with many of the report's findings, some of the findings and much of the report's tone are based on judgments or notions I must reject on the basis of my 18 years of experience as a transportation planning engineer and modeling professional. The committee report is correct in identifying the need to improve our analysis tools, but it errs by asserting that we cannot adapt these tools to meet current regulatory requirements without substantial delay. The problem is not a lack of good science to support analysis, but institutional resistance to the use of good science in transportation analysis that would challenge entrenched and powerful pro-highway expansion interests. One might hope that the report will contribute to increased investment in improved analysis and transportation/environmental monitoring systems. It would be unfortunate if the report's conclusions are misread as an excuse for inaction, regulatory rollback, and a resurgence of business-as-usual highway policies on the basis that we just

way capacity, we are unlikely to have the ability to estimate the effects of changes in pricing, technology, or other system attributes. However, the report's lead finding in the Executive Summary concludes that "analytic methods in use are inadequate for addressing regulatory requirements [to assess the effects of added highway capacity on air quality]. The accuracy implied by the interim conformity regulations issued by EPA [the Environmental Protection Agency], in particular, exceeds current modeling capabilities . . . The current regulatory requirements demand a level of analytic precision beyond the current state of the art in modeling."

Current traffic and emission models need expeditious improvement and substantially higher levels of research, data collection, development, and dissemination of best-practices techniques. However, significant and steady improvement in operational regional models for evaluating the likely emission, system performance, travel behavior, and developmental impacts of changes in highway capacity, pricing, and policy is possible in both the short and mid-term to meet current regulatory requirements. State-of-the-art modeling methods, if applied with common sense (e.g., considering likely effects of transportation capacity on land development patterns), are adequate to judge the probable direction and approximate magnitude of regionally significant highway capacity additions in transportation plans.

Unfortunately, in the 5 years since passage of the Clean Air Act Amendments of 1990 (CAAAs), metropolitan planning organizations (MPOs) that are typically responsible for evaluating transportation conformity have made only slow progress in improving their analytic tools to respond to new policy requirements. Ironically, much of the resistance to improved transportation and air pollution modeling practices in the past has come from the same parties that have most strongly resisted Clean Air Act implementation and that now seek to weaken or overturn its provisions requiring transportation plans and programs to contribute to air quality attainment. Inappropriate use of the models can be addressed by recognizing their shortcomings and devising incremental improvements (Replogle 1993a; Cambridge Systematics, Inc. 1994; Harvey 1993; U.S. District Court 1990). Rather than devoting adequate resources and methods to accomplish this, many state and regional transportation agencies prefer to question the requirements of the regulatory process, citing the small differences

they find between "build-no-build" scenarios when these are analyzed using deeply flawed models.

The Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) gave states unprecedented flexibility to use federal transportation capital assistance funds for planning, data collection, model development, and investments in different modes of travel. However, many states have been slow to flex funds from traditional highway construction to support improved performance measurement, modeling, and management systems. CAAA and ISTEA require a positive demonstration that transportation plans and programs contribute to public health and other goals, with the potential to cut off federal transportation funds to jurisdictions that fail to address persistent health-threatening air pollution problems related to motor vehicle use. Our scientific knowledge is more than adequate to support the CAAA mandate that transportation spending be consistent with health-based air pollution control plans.

Despite its assertions to the contrary and statement that "the complex and indirect relationship between highway capacity [and] air quality . . . which is heavily dependent on local conditions makes it impossible to generalize about the effects of added highway capacity on air quality . . . even with improved models," this report concludes that "limiting highway capacity . . . is likely to have relatively small effects, positive or negative, on metropolitan air quality by current attainment deadlines." Whether highway capacity will affect emissions over the 20-year life of transportation plans and for the duration of a region's maintenance period, as required by the CAAA, is not judged. The report strays from its assigned scope in implying that current regulations represent a collision of environmental goals and economic objectives likely to lead to delay and reassessment of environmental regulations, and to error and manipulation of the policy process (Executive Summary). The assertions of the report's conclusions ignore strong evidence that restraints on motor traffic growth can be highly supportive of economic development (Hook and Replogle 1995) and reveal the challenge faced by those who would defend the CAAAs mandates for transportation planning. Although the report recommends "a more constructive approach" toward adding new highway capacity, with congestion pricing to mitigate emissions growth, the report does not discuss the likely effects of restraining road

capacity within a road pricing context. It is nonetheless arguable that higher motorist user fees and investments in public transportation and other alternatives would encourage earlier and greater energy and air pollution emissions reductions in a policy environment that limited, rather than accommodated, new highway capacity.

KEY FINDINGS

The effects of added highway capacity on energy use and the environment are complex and vary over time. Although we cannot determine with great precision the effect of an individual project, we can with some confidence determine the general direction and relative magnitude of changes that are likely to accompany substantially different investment programs and policies. We now know that trying to reduce emissions by emphasizing supply-side high-occupancy vehicle (HOV) and single-occupancy vehicle (SOV) highway capacity expansion strategies is at best uncertain and temporary. It often makes the problem worse by spurting greater motor vehicle travel demand and lower-density, automobile-dependent land use patterns and by reducing the relative attractiveness of alternatives to automobile travel. Although technological improvements to vehicles, fuels, and vehicle maintenance promise further cost-effective reductions in air pollution emissions, action is needed to manage the growth of traffic demand to reduce emissions of greenhouse gases and air pollution, curb noise pollution, manage traffic congestion, reduce dependence on foreign energy supply, boost the sustainability of our local and regional economies, and enhance community livability.

Limiting further highway capacity expansion, reducing highway capacity, and calming traffic (especially in central areas) can be effective strategies for reducing energy use, air pollution, and other environmental problems, particularly when done in a context of regional growth management that encourages revitalization of urban and suburban centers instead of further sprawl. Smoothing traffic flows to reduce sharp acceleration and deceleration also offers significant promise for reducing emissions when done within a balanced multimodal transportation policy framework that includes effective demand management tools, such as road and parking pricing. Auto-

rated vehicle speed limitation using intelligent transportation systems may also offer a promising future strategy and merits further investigation.

The best way to ensure that transportation plans and programs contribute to improved air quality is to ensure that they provide expanded opportunities to meet daily needs for access to jobs, shops, services, and recreation with less forced dependence on petroleum-fueled motor vehicles. This means promoting accessibility instead of mobility; using information and communications more effectively to manage community and mobility systems and to provide virtual access, and integrating land use and transportation planning and development with sound urban design for more livable, walkable, and efficient communities. It means explicating the hidden subsidies and tax expenditures that now spur inefficient consumption and investment patterns, charging motorists for these costs, and encouraging a new sense of values about transportation and the responsibilities of individuals in communities.

Much more research, data collection, and model development are necessary to support local and regional planning and policy evaluation and to better ascertain the effects of alternative investments and policies on energy use and the environment. This research, data collection, and development of decision-support systems should be undertaken as a partnership involving local, regional, state, and federal agencies within the ISTEA planning systems framework. The creativity and initiative of the private and nonprofit sectors should be encouraged in developing these new management systems for sustainable regional economies and healthy communities. Special attention should be paid to developing modal motor vehicle emission models and activity-based microsimulation models of travel behavior and surface transportation system performance. The federal government could play an important role by developing an information-based National Transportation System in cooperation with states and regions to strengthen strategic management systems for monitoring transportation system performance against key benchmarks, in addition to the factors that affect travel demand and transportation service quality. These systems are necessary to ensure that transportation investments will contribute to wise expenditure of scarce taxpayer dollars, improved air quality, safety, productivity, and more livable

communities. Performance-oriented federal funding for transportation could also play a useful role.

INDUCED TRAFFIC EFFECTS: FINDINGS FROM A MAJOR UNITED KINGDOM STUDY

The committee's conclusions regarding induced traffic are an improvement over earlier official studies, but are so heavily modified and hedged as to have little meaning. The recent British SACTRA study commission offers more useful guidance on the effect of major road projects (which it calls "schemes") and has far greater confidence than this report in the ability of current scientific knowledge to evaluate these impacts. SACTRA found that:

- ... induced traffic is of greatest importance in the following circumstances:
 - * where the network is operating or is expected to operate close to capacity;
 - * where traveller responsiveness to changes in travel times or costs is high, as may occur where trips are suppressed by congestion and then released when the network is improved;
 - * where the implementation of a scheme causes large changes in travel costs.

This suggests that the categories of road where appraisal needs to be most careful are improvements to roads in and around urban areas, esplanade crossing schemes, and strategic capacity-enhancing interurban schemes, including motorway widening. . . [Studies] we have reviewed demonstrate convincingly that the economic value of a scheme can be overestimated by the omission of even a small amount of induced traffic. We recommend that variable demand methods should now become the normal basis of trunk road forecasts, and these forecasts must be carried through into the operational, economic, and environmental evaluation of schemes in a systematic way. In particular, where networks are operating close to capacity, suitable procedures must be used to represent the constraint of traffic in the base case and the release of traffic growth

in the do-something case as additional capacity is provided. . . . We do not think that continuing to appraise solely at the schematic level using the fixed demand approach is, either intellectually or in practical terms, acceptable. It is this central conclusion which has led us to make the recommendations in this Report. (SACTRA 1994, iii-iv)

The report continues as follows:

Results of published research demonstrate the following important findings, to a reasonable level of confidence: (a) there is an effect of fuel prices on traffic levels, and a larger effect on fuel consumption; (b) the quality and/or price of public transport can have a small effect on car ownership or use, or perhaps both; (c) the length of the motorway network is one of the influences on the amount of traffic using it; (d) some but not all of the time saved on travel when journey speed increases is likely to be used for additional travel; (e) car users do in fact trade off time and money to an extent and a measure of this trade-off is given by the empirical estimation of the value of time savings; (f) journey times can have an influence on depot location and length of haul of freight operations; (g) the land-use changes consequent on improved access are likely, in turn, to lead to changes in the patterns of travel, car dependence, and the volume of travel. (SACTRA 1994, 45)

SACTRA concluded that in the short term, "about half the time saved through speed increases might be used for additional travel . . . the longer-term effect is likely to be greater, with a higher proportion (perhaps all) of the time saved being used for further travel" (SACTRA 1994, 47).

These conclusions are more comprehensive and succinct than the committee report and differ in some key respects, particularly with regard to the potential impact of highway expansion on freight travel, the elasticity of travel demand with respect to time savings, and the prospects for improving plan and project appraisal. It is the position of this minority statement that SACTRA has better stated the current state of scientific knowledge in this area. The "fixed demand" approach (i.e., assuming that building new highway capacity will have no effect on land use and time-of-day of travel or other components of

travel demand), which SACTRA finds unacceptable, is the same approach that in the United States produces differences between scenarios smaller than the error term of the models of which this report is critical. SACTRA prescribes the use of currently available improved analytical methods for project appraisal instead of questioning our ability to perform such analysis to meet regulatory requirements.

DETERMINANTS OF TRAVEL DEMAND

Effects of Subsidies

The committee report implies that growth in traffic is an inevitable function of income and economic growth (Chapter 4) and indeed these are important factors in traffic growth. However, the report generally avoids discussing the effects of hidden subsidies and transport pricing systems in explaining the growth of motor vehicle use, although these too are key determinants that reinforce automobile-dependent lifestyles, consumption trends, and land use patterns. In the United States a major share of the costs of highway construction and maintenance continues to be paid for out of general tax revenues, mostly at the local government level. The large past investment in highway capacity by taxpayers imposes a stream of current and future costs that affect the provision of added capacity.

The recent report by the U.S. Congressional Office of Technology Assessment (OTA), *Saving Energy in Transportation*, provides a good accounting of these elements (OTA 1994, 91–111). OTA identifies \$76.5 billion in 1990 public spending on highway construction, maintenance, and services covered by payments by motor vehicle users, along with hidden private sector expenditures related to motor vehicle use of \$150 to \$400 billion a year in 1990 (or parking). OTA estimates that U.S. taxpayers provided \$33 to \$64 billion in subsidies for highway construction and motor vehicle infrastructure and services in 1990, after accounting for total costs and deducting payments by motor vehicle users. Nonmonetary externality costs related to motor vehicle use are estimated at \$325 billion to \$580 billion per year in 1990. According to OTA, "Approximately 49 to 61 percent of the total monetary and nonmonetary costs of motor vehicle use, excluding the value of time, are efficiently priced [i.e., paid and recognized by motor vehicle users]" (OTA 1994, 109–110). The report continues,

"Motor vehicle users paid openly for 53 to 69 percent of the social (public plus private) costs of motor vehicle use, both monetary and nonmonetary, excluding the value of time... if subsidies were withdrawn, externalities 'internalized,' and hidden costs brought out into the open and directly charged to motor vehicle users, the perceived costs of motor vehicle use would increase substantially (by 14 to 89 percent, depending on whether nonmonetary costs and other factors are included), and people would drive less." Such factors play a major role in influencing the effects of highway capacity changes on energy and the environment, as this committee report implies in its closing discussion of "managed capacity" strategies.

Effects of Added Highway Capacity on Freight Travel Demand

The RCEP report states, "It is clear that where an alternative is available, moving freight by road takes more space, uses more energy, produces more pollution, and is more likely to lead to an accident" (RCEP 1994, 166). The short-term potential to switch freight from road to rail, water, or pipeline transportation is limited by the specialized functional requirements for many types of shipments, as this committee report correctly notes. However, over a period of two or more decades, alternative transportation investment choices could produce profound differences in freight travel demand. Contrast, for example, a program of significant further public investment in freeway capacity expansion with a program of minor highway capacity expansion, conversion of existing HOV and SOV freeway lanes to privately managed toll facilities, and a combination of policies promoting more aggressive private development of intermodal transfer facilities, railways, water- and pipeline-based freight systems, and intelligent intermodal freight management systems. Highway capacity expansion will clearly affect the use of just-in-time shipping, and in the longer term, the location of commercial, warehouse, and industrial activities.

Effects of Added Highway Capacity in Built-Up Areas

The committee report asserts, "Within developed areas, traffic flow improvements such as better traffic signal timing and left-turn lanes

tions are much diluted. Instead of presenting LUTRAQ data on total travel or nonwork travel, which constitutes the vast majority of all trips, the report draws its conclusions principally from changes estimated for work trips. Thus, the report incorrectly states that "The travel demand measures [employee commuter subsidy programs that support transit and charges for parking] increase both transit use and carpooling more than the land use and design measures." In fact, the LUTRAQ analysis indicated that TDM measures accounted for only about 30 percent of the increase in nonautomobile driver mode shares for all trips and about 55 percent of the increase in nonautomobile work trip mode shares, not counting the corrections for under-estimated walking trips, which would further increase the effects of the design measures (T. Ross, Cambridge Systematics, Inc., correspondence, February 8, 1995; LUTRAQ working documents, summer 1992).

The LUTRAQ model incorporated measures of pedestrian friendliness but underestimated the potential to shift short car trips to pedestrian trips. This was due to acknowledged underreporting of walking trips in the 1985 Portland household travel survey data (Cambridge Systematics, Inc., et al. 1992), the assumption that nowhere in the region would pedestrian friendliness be better than it is today in downtown Portland, and the insensitivity of the pedestrian mode choice model to pricing and other TDMs. Clearly Portland neighborhoods could become far more pedestrian friendly than observed today. Market-based pricing strategies and other TDMs would also increase the propensity to satisfy travel needs by walking and bicycling. Despite these shortcomings, the LUTRAQ analysis showed that modest improvement in the quality of the pedestrian environment alone could reduce the VMT in suburban zones by about 10 percent. Variation in building orientation at the zonal level was also found to account for changes of 10 percent or more in VMT per household (Parsons Brinckerhoff Quade and Douglas 1994).

Key LUTRAQ performance measures cited in this report (Table 5-5) do not reflect adjustments made by Cambridge Systematics to correct for known undersampling of pedestrian trips in the 1985 Portland travel survey. Data on travel demand changes estimated for the much larger study region are emphasized instead of the significant travel demand reduction effects noted in relation to TODs versus con-

ventional highway-oriented development. LUTRAQ did not attempt to modify urban design patterns in the entire study area, but only in selected neighborhoods near new transit lines. The LUTRAQ assumptions for the composition and mix of building types for development was also constrained by a market demand forecast that assumed that the housing preferences of recent decades for different demographic segments would persist into the future, which implies continued tax subsidies for housing and automobile transportation, rising real household incomes, and continued high levels of consumer and public debt to finance housing and transportation consumption. Moreover, the LUTRAQ model was unable to reflect potential improvement of bicycle friendliness, bicycle access to transit, or encouraging bicycle use, due to the lack of available local empirical data. However, experience in cities such as Davis, California, and Copenhagen, Denmark, shows that reallocation of street space and development of comprehensive cycling networks can have a profound effect in diverting car trips to bicycles and that bicycle access can promote dramatic expansion of transit catchment areas (Replogle 1993b, Replogle 1994, Replogle and Parcells 1993). Indeed, the Portland regional government (Metro) is moving forward to develop methods for incorporating these additional factors into its long-range planning analyses.

London

Portland, Oregon, is being joined by a growing number of other regions considering such alternatives. A study by the United Kingdom Department of Transport for the greater London region found that a combination of car restraint and improved public transport—with a cordon charge, reduced parking provision, and light rail construction—would likely reduce carbon dioxide emissions by 23 percent compared with the base case for 2000. It was estimated that this combined strategy would reduce traffic entering the central area of London and increase peak period traffic speeds in the central area from 23 to 30 kph (14 to 19 mph). Approximately 15 percent of this increase was projected to be due to the effects of the light rail network and the remainder due to measures to restrain traffic (RCCEP 1994, 1994).

Copenhagen

Some regions have made these kinds of changes real. In Copenhagen, a city of 1.7 million people, road building was abandoned in the early 1970s, large numbers of bus priority lanes were introduced, and a comprehensive network of segregated cycle paths was built. The result was a 10 percent decrease in traffic since 1970 and an 80 percent increase in the use of bicycles since 1980. Approximately one-third of commuters now use cars, one-third public transport, and one-third bicycles. Had Copenhagen embarked on major highway expansions in recent decades, surely energy use and emissions would be far higher than they are today. Is this not relevant evidence that highway capacity expansion in metropolitan regions promotes environmental degradation?

EFFECT OF REDUCED HIGHWAY SPEED AND CAPACITY

Since the 1970s in Europe, Japan, Australia, and increasingly in the United States, traffic calming and traffic cell systems have been and continue to be developed to reduce traffic speed and capacity in central areas and residential neighborhoods. There is empirical evidence that these highway capacity reduction strategies typically also reduce air pollution emissions, noise, and energy use. Although mentioned in the report (Chapter 3), this evidence is not well-considered in the report's findings.

Reducing Road Speed and Capacity with Traffic Calming

Traffic calming encompasses a wide range of techniques for slowing down motor vehicle traffic to provide an environment more supportive of walking and bicycling and safer for children, the elderly, and others. Traffic calming measures include narrowing roadways, reducing speed limits, introducing curvilinear elements in formerly straight streets to slow traffic, and changing the vertical profile of the street with elements such as raised intersection tables for pedestrian and

bicycle path crossings. Although the EPA MOBILE model would indicate that slowing down traffic typically increases emissions, empirical research indicates the opposite in many cases. Research in Germany has shown that the greater the speed of vehicles in built-up areas, the higher is the incidence of acceleration, deceleration, and braking, all of which increase air pollution. German research indicates that traffic calming reduces idle times by 15 percent, gear changing by 12 percent, brake use by 14 percent, and gasoline use by 12 percent (Newman and Kenworthy 1992, 39-40). This slower and calmer style of driving reduces emissions, as demonstrated by an evaluation in Buxtehude, Germany. Table E-1 shows the relative change in emissions and fuel use when the speed limit is cut from 50 kph (31 mph) to 30 kph (19 mph) for two different driving styles. Even aggressive driving under the slower speed limit produces lower emissions (but higher fuel use) than under the higher speed limit, although calm driving produces greater reductions for most emissions and net fuel savings (Newman and Kenworthy 1992, 39-40).

Moreover, by encouraging more use of walking and bicycling and reducing the advantage offered by the automobile for short trips relative to these alternatives, traffic calming usually reduces the number of trips, trip starts, and VMT. Applied on a widespread basis in conjunction with transit improvements and transportation pricing changes, traffic calming may contribute as well to a reduction in household automobile ownership levels, further reducing emissions and travel demand. Thus, even under circumstances in which individual

TABLE E-1 Percentage Change in Vehicle Emissions and Fuel Use with Speed Change from 50 kph (31 mph) to 30 kph (19 mph) (Newman and Kenworthy 1992)

EMISSION TYPE	DRIVING STYLE	
	2ND GEAR AGGRESSIVE	3RD GEAR CALM
Carbon monoxide	-17	-13
Volatile organic compounds	-10	-22
Oxides of nitrogen	-32	-48
Fuel use	+7	-7

individual vehicle emissions per mile traveled increase due to more aggressive acceleration, braking, and use of second gear, traffic calming will likely lead to overall emission reductions due to its influence on travel demand (see Table E-1).

A recent FHWA report discusses the German experience with traffic calming in six cities and towns in the early 1980s:

The initial reports showed that with a reduction of speed from 37 km/h (23 mph) to 20 km/h (12 mph), traffic volume remained constant, but air pollution decreased between 10 percent and 50 percent. The German Auto Club, skeptical of the official results, did their own research which showed broad acceptance after initial opposition by the motorists. Interviews of residents and motorists in the traffic calmed areas showed that the percentage of motorists who considered a 30 km/h (18 mph) speed limit acceptable grew from 27 percent before implementation to 67 percent after implementation, while the percentage of receptive residents grew from 30 percent to 75 percent. (Project for Public Spaces 1992)

This experience of initial skepticism of traffic calming, followed by its widespread popularity after implementation, has been experienced in hundreds of communities across Europe, Japan, and Australia, along with the few U.S. communities that have adopted such strategies, such as Palo Alto, California, and Seattle, Washington.

Reducing Road Capacity with Traffic Cells for Environmental Benefit

Many places in Europe and Japan—cities such as Göteborg, Sweden, Hannover, Germany; and Osaka, Japan; suburban new towns such as Houten, Netherlands; and established automobile-oriented suburban centers such as Davis, California—have successfully implemented traffic cell systems. These typically consist of a set of radial pedestrian, bicycle, and transit-only streets focused on a central area. Whereas pedestrians, bicyclists, and public transportation can freely cross these streets, automobile traffic cannot, but must instead use a ring road around the center. Traffic cell systems are very effective at

eliminating through-traffic in central areas and shifting short automobile trips in the central area to walking, bicycling, and public transportation, significantly reducing cold start and evaporative emissions. Reducing central area traffic and increasing street space dedicated to walking, bicycling, and public transportation makes these alternatives more attractive and diminishes parking requirements in the central area. Success in reducing environmental impacts depends on curbing automobile-oriented peripheral development.

Göteborg, Sweden, introduced traffic cells in the mid-1970s together with priority for public transportation at traffic signals, new suburb-to-downtown express bus service, and central area parking controls. Noise was cut from 74 to 67 dB in the main shopping street, peak carbon monoxide levels dropped 9 percent, 17 percent fewer cars entered the center city, weekday transit trips to the center were up 6 percent, traffic on the inner ring road was up 25 percent, and the costs of running public transport went down 2 percent. Nagoya, Japan, introduced traffic cells in residential areas in the mid-1970s, together with a computer-managed signal system, bus lanes, bus priority at traffic signals, staggered work hours, and parking regulation. This resulted in a 17 percent increase in traffic speeds on main roads covered by the signal system, and a 3 percent increase in bus ridership. Fifteen percent fewer cars entered the central area in the morning peak, and automobile-related air pollution decreased by 16 percent (National League of Cities 1979).

The Downtown Crossing pedestrian zone in Boston, Massachusetts, is a limited traffic cell serving a core area with 125,000 employees. Eleven blocks of the central business district were closed to traffic in 1978 while steps were taken to improve transit service and parking management. In the first year, there was a 5 percent increase in visitors to the area, a 19 percent increase in weekday shop purchases, a 30 percent increase in weekend purchases, an 11 percent increase in Saturday purchases, a 21 percent increase in walking trips to the area, a 6 percent increase in transit trips to the area, a 38 percent decrease in automobile trips to the area, and no increase in traffic congestion on adjacent streets, thanks to the elimination of on-street parking and stricter parking enforcement on nearby traffic streets.

Davis, California, a town of 50,000 people near Sacramento, illustrates a successful full traffic cell system that has cut highway

capacity significantly in the vicinity of the University of California (UC Davis) and the town center to increase walking and bicycle use. Bicycle use grew sharply in the 1960s, leading to election of a pro-bikeway city council in 1956. Demonstration bikelanes proved popular and were quickly extended. In addition to the UC Davis traffic cell and bicycle network, the city of Davis now has 59 km (37 mi) of bicycle lanes and 46 km (29 mi) of bicycle paths in an interconnected network. Parking is limited and costs drivers on the UC Davis campus, bus, van, and commuter rail services offer other alternatives to the automobile. Davis has prohibited development of shopping centers near the freeway, retaining a vibrant pedestrian-oriented downtown commercial area. As a result, 27 percent of UC Davis employees and 53 percent of UC Davis students use bicycles as their primary commute mode, among those who live and work in Davis, 44 percent bicycle to work. The City Planning Department estimates that 25 percent of all person trips in the city are by bicycle. Walk shares in the city are also high—on the order of 10 to 20 percent. Cleanly air pollution has been reduced by restricting and reducing highway capacity in Davis.

EFFECT OF HIGHWAY CAPACITY ADDITIONS ON METROPOLITAN FORM

The report is correct in asserting, "Major highway capacity additions in less developed parts of metropolitan areas, where most growth is occurring, pose a greater risk of increasing emission levels and energy use in those areas. If developable land is available and other growth conditions are present, new capacity is likely to attract more development and related traffic to the location of the improvement. Corresponding increases in emission levels and energy use in these areas are likely" (Chapter 6). Yet the report notes, "Because of the large investment implicit in current metropolitan spatial patterns, it may be years before changes in land use and related traffic patterns induced by the added capacity make a significant difference in regional emission levels and air quality" (Executive Summary), downplaying this potential effect in relation to conformity analysis by following with the statement, "In comparison, . . . EPA predicts further emission

reductions for major pollutants on the order of one-quarter to one-third from 1990 baseline levels by attainment deadlines simply from continued vehicle fleet turnover and implementation of CAAA-required vehicular and fuel standards and enhanced vehicle inspection and maintenance programs. Market-based TCMs [transportation control measures], such as increased parking charges and time-of-day tolls, have greater potential for emission reductions."

Most new highway development is likely to have a significant emission-increasing effect within the 20-year planning horizon for conformity analysis unless the region is experiencing no net economic growth or the region's highway access-dependent periphery is not growing at the expense of its older urban neighborhoods. It is irrelevant whether the highway expansion redistributes growth that would have occurred elsewhere in the region or whether it stimulates productivity gains that result in net new growth (Executive Summary). Most new highway capacity will eventually foster automobile-oriented growth. In either case, increased emissions may break an emissions budget and work against attainment and maintenance of health standards.

In regions undergoing rapid development and significant infrastructure investment, major regional impacts on motor vehicle emissions have been observed in relatively short time horizons. Substantial economic growth has not always been accompanied by proportional growth in traffic. Restrained investment in highways accompanied by enhancements of pedestrian, bicycle, and transit access; economic incentives encouraging alternatives to the automobile; and supportive land use policies have resulted in slower growth of traffic despite rising motorization and dramatic economic growth in many European and Asian metropolitan areas, most notably in cities such as Copenhagen, the Randstadt (Amsterdam-Hague-Rotterdam-Utrecht, Netherlands), and in Japanese and Chinese cities. Indeed, there is evidence that such policies enhance growth and economic development (Replogle 1991).

This evidence is given no mention in the report, which instead emphasizes that accessibility and generalized travel cost changes are only one factor shaping metropolitan development. However, the report appears to overgeneralize its conclusions regarding the 20-year effects of highway capacity changes on land use patterns, drawing evidence

primarily from land use model projections that can be called into question. For example, the committee report discusses the relatively small changes (plus or minus a few percentage points) in regionwide locations of employment and households in built-up metropolitan areas over a 20-year forecast period from systemwide changes in travel time of as much as 20 percent, predicted using commercially available but less-than-state-of-the-art land use models. This is cited as evidence that added highway capacity will have small impacts on regional air quality. However, the land use models cited were generally calibrated on very short time-series data, often 1980–1985 or 1985–1990, when substantial "hot" savings and loan money was diverted into highly speculative and often not economically viable real estate development, leading to drastic over-building in many markets. Indeed, the models used in the United States have mostly failed to represent land and rent values, the variable quality of key public services (education, public safety), and the potential for mixed-use cluster development around nodes of high public transportation accessibility. Moreover, the results of model evaluations have usually been predicated on exogenous constraints related to zoning and limitation of redevelopment, giving little room for differences between transportation investment scenarios to express themselves.

In short, the SACTRA report offers more effective statements of our current state of knowledge in these matters, indicating that added highway capacity indeed frequently leads to changes in development patterns that reinforce motor vehicle dependence and use.

DATA COLLECTION, MODEL DEVELOPMENT, AND RESEARCH NEEDS

There is broad agreement with this report's conclusions regarding the need for improved emission and travel-related data collection and model development. Cost-effective resolution of some of the central questions posed by this study would be well-supported by a cooperative effort of states, local governments, and regions, with federal leadership, to develop broader standards for traffic and travel data collection, the coding of networks and spatial data bases, and

transportation-land use monitoring and performance measurement systems. Dozens of uncoordinated, incompatible data systems now hinder the development of effective benchmarks and comparative evaluation frameworks for local and national strategic planning and for theoretical research. The externality costs of transportation and land use investments, such as hidden subsidies, pollution and congestion costs, and accident and health effects, need to be more widely appraised through local measurement and monitoring. A national household travel panel survey is needed to better comprehend the dynamics of travel and activity patterns, vehicle acquisition and use, residential location choice, and commercial development. States should be encouraged to allocate an increased share of surface transportation capital resources to system management and monitoring, planning, and forecasting, to promote long-term, least-cost strategies for community and regional development. The alternative is to continue to pursue costly taxpayer-subsidized, pork-barrel spending unsuited to an era demanding lean government.

THE BUILD-NO-BUILD TEST AND REGULATORY BACKLASH

New Scientific Uncertainty or Just a New Backlash?

This report challenges the "build-no-build" test that has been a key part of transportation conformity under the federal Clean Air Act. This challenge would respond to the distress expressed by many individuals involved in highway development at EPA's November 1993 final transportation conformity rule. Supporters of highway development were generally satisfied with the science of emission speed factor adjustments during the era of EPA's interim conformity rule 1991–1993 and under earlier versions of conformity. During this era, the conformity rule and the emission speed factor adjustments worked together to ensure that new road capacity would be found to increase average motor vehicle travel speeds and reduce vehicle miles traveled and hence reduce air pollution emissions of carbon monoxide (CO) and volatile organic compounds (VOCs) at least by a slight amount (based

ing have model enhanced air-quality programs. In-time report states about the effects "no de-
veloped test is phased reached . . . build test is introduced as the environment can be build-no-build test has been Air Act
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progress toward highway expansion, attainment and policies.
large-scale highway contribute to investments and policies.
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has gone too far in asserting scientific uncertainty.

The committee report might have highlighted the short- and mid-term fixes available to support better conformity analysis. Good discrete choice models based on recent surveys—including total personal travel rather than just motor vehicle trips, with formal or informal accounting for the effects of highway capacity increases on land development, time of day of travel, mode and destination choice—can be developed in any metropolitan region in the span of a year or two with an investment representing a fraction of the cost of a single freeway interchange. Such "better practices" analysis tools can be used to perform far more policy-sensitive build/no-build tests in the near term, which will not be highly accurate or certain, but at least will be more likely to point in the right direction than current analyses. The state-of-the-art of modeling is advancing rapidly in this area, and data collection and research are warranted today for most metropolitan transportation planning agencies to prepare for the next generation of microsimulation-based analysis tools. The SACTRA panel offers useful recommendations for modeling and analysis, including issuance of general advice on good practice in developing models, the auditing of strategic transport demand models to ensure their satisfactory sensitivity "to estimate all the important demand responses to road provision, including trip frequency and choice of time of travel" (SACTRA 1994, 191).

Emission models are in critical need of redevelopment with support for research at the national level. Recent EPA and California Air Resources Board (CARB) research shows that the federal test procedure and other drive-cycle based emission estimation approaches do not well match current driving conditions. Significant variability exists in emissions between vehicles undergoing similar speed changes and in the same vehicle under different load conditions. There is consensus within the committee that modal-based emissions models need to be developed to improve the evaluation of the effects of changes in speed, acceleration, and traffic system management, such as ITS, and some work is under way, but could be accelerated. As this report notes, "current models significantly underpredict emissions of some pollutants" (Executive Summary). This is yet further reason to place greater emphasis on the analysis of the emissions impacts of growth in travel demand likely to be induced by highway investment, instead of continuing to focus analysis solely or primarily on emissions impacts

related to harder to estimate changes in vehicle speeds that are modified by highway investments.

Performance-based funding that gives states flexibility in expending federal funds contingent on meeting key objectives is in place under CAAA and ISTEA with the transportation conformity and management system requirements. Although evaluation tools like MOBILE 5.1 are imperfect, they should continue to be used with caution as the best analysis models currently available to support ongoing public policy making. When needed, ad hoc project-specific methods should be used to complement these tools until better data and software are available. Sound transportation and environmental policy making should focus air pollution control strategies on cost effective technological controls, such as inspection and maintenance of vehicles and reformulated gasoline, in addition to strategies that reduce the growth in vehicle trip starts, VMT, and motor vehicle dependence. Until we get our emission models more refined, we should focus less on strategies that depend on demonstrating emission reductions on the basis of changes in traffic speed. We should not abandon the analysis of the emissions impacts of alternative transportation investments and policies because of uncertainties about emission changes with respect to speed, accelerations, and other factors. We should improve the quality of performance measurement, analysis, and forecasting systems and expand the range of alternatives considered in the evolving new regional transportation planning process.

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- | | |
|--------|--|
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| RCEP | Royal Commission on Environmental Pollution |
| SACTRA | Standing Advisory Committee on Trunk Road Assessment |
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