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Air Quality Impacts of Intercity Freight

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Notice

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Prepared for

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U.S. Environmental Protection Agency
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Preface

The efficient movement of goods between and within cities and metropolitan areas has major implications for not only for the economy, but on the use and performance of the transportation system. Traffic congestion and air quality are two important impacts that result from this activity. And while "intercity freight" is most often thought of in terms of long-distance shipments by rail, large combination trucks, barge, and to an increasing extent, air cargo, the activities that occur at the ends of the trip may actually be the source of some of the major impacts. To accomplish the connection between shipper and mode, or between modes and terminals, considerable activity must occur within the local transportation system, often on crowded highways and during prime travel hours. The constraints posed by inefficient intermodal connections, operation and management of intermodal facilities, barriers and bottlenecks in the highway network, help contribute to the congestion and freight/passenger vehicle conflicts that result.

States and metropolitan planning organizations traditionally have not directed active planning or project efforts at the freight sector. This is due to both a limited understanding of freight transportation characteristics and issues, and the presumption that the key decisions for freight rest in the private sector. However, the importance of freight transportation to economic development, emphasis on freight and intermodal transportation under ISTEA, and concerns about traffic congestion and troublesome air pollution problems, have greatly raised the level of interest in freight transportation. Also, there is growing acceptance and awareness that actions which address congestion and air quality problems may also address issues of service efficiency and cost to the transportation industry and shippers as well.

In response to these concerns, this report has been developed to provide assistance to planners and decision makers -- public and private -- to improve the understanding of freight transportation, economic and air quality relationships, and to provide some helpful tools for identifying and testing improvement strategies. The focus of the report is on truck and rail/intermodal transportation, and it offers guidance and procedures in assessing the impacts of shifts in the industry and overall traffic levels, capacity enhancements, changes in operational or management practices, policy or pricing initiatives, or changes in vehicle technologies or fuels. To underscore its importance and need, this study and report have been sponsored jointly by the Federal Highway and Federal Rail Administrations of the U.S. Department of Transportation and the U.S. Environmental Protection Agency.

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3

NOTE: Volumes greater than 1000 l shall be shown in m^3.

Symbol	When You Know	Multiply By	To Find	Symbol
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised September 1993)

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Air Quality Issues in Intercity Freight

A Guidebook for Estimating the Travel and Emissions Impact of Intercity Trucks and Rail Intermodal Freight Activity and Effects of Improvement or Control Strategies

appendices

prepared for

Federal Railroad Administration
Federal Highway Administration
Environmental Protection Agency

prepared by

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March, 1997

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A-1: *Freight Activity Forecasting Methods for Existing and New Facilities*

Note To Reader

The material presented in this Appendix, A-1, has been abstracted directly without editing from a recently-completed report by Cambridge Systematics under NCHRP Project 8-30, *Characteristics and Changes in Freight Transportation Demand*. The presented segments are Chapters 3 and 4 from that report, which deal, respectively, with Demand Forecasting for ***Existing*** [Freight/Intermodal] Facilities, and Demand Forecasting for *New* [Freight/Intermodal] Facilities. The factors described and techniques recommended in these Chapters are expected to be of considerable relevance to many agencies or analysis efforts which are concerned about the impact that major changes in freight facilities will have on the overall level, location, and composition of freight activity, and rates of change in those levels over time. The interested reader will probably wish to acquire the complete report from NCHRP.

3.0 Demand Forecasting for Existing Facilities

A significant issue faced by public sector transportation planners is determining the appropriate capabilities for various modal and intermodal facilities. Ideally, these facilities should be able to accommodate the projected demand for them, plus an appropriate amount of spare capacity. The basic information required by these planners is the expected demand for use of these facilities.

This chapter presents an introduction to forecasting freight demand for existing transportation facilities; the more complex subject of forecasting freight demand for new transportation facilities is addressed in the next chapter. Additional information relating to the procedures described in this chapter is presented in Appendices C-E.

Sources of information on historic and current transport activity and facility use are presented in Section 3.1 of this chapter; sources of economic forecasts are discussed in the Section 3.2. Section 3.3 presents a simple procedure for combining an economic forecast with historic data on transport activity to produce a forecast of transport demand; several options for improving the quality of these forecasts also are described in this section. Section 3.4 discusses several regression and extrapolation procedures that can produce forecasts of transport demand from time-series data. Finally, Section 3.5 presents the identification and evaluation of alternative futures that should be considered by planners determining a course of action.

■ 3.1 Current and Historic Data on Facility Use and Transport Activity

The most readily available information about demand for an existing facility is information about past and/or current usage of the facility – that is, about past and/or current demand for the facility under certain price and service conditions. If there are no unusual supply constraints, and demand has not been affected significantly by unusual economic conditions, then this demand information can be used as the basis for forecasting demand under similar "normal" conditions. The procedures presented in this chapter use data on (or estimates of) past or current usage or transport activity as the basis for generating forecasts of demand.

There are three types of sources of data on facility usage and related transport activity:

- Data compiled by the facility operator;
- Data collected and published by Federal agencies and other public and private entities that monitor or analyze transport activity on a regional, state, national or international level; and
- Data collected as part of a special survey designed to supplement data available from other sources.

These data sources are discussed in the following subsections.

3.1.1 Facility Data

Facilities that impose user charges for the use of their services invariably collect usage data that is related to the fees collected. They also may collect additional data, either for their own planning purposes or because the data is required by a governmental agency. Data directly related to user fee collections (e.g., facility usage by vehicles, vessels, containers, etc.) is likely to be quite accurate. However, these data are likely to lack detail on actual freight volumes, commodities, origins and destinations, and, in some cases, whether freight is even being carried; even when such detail is collected, the data may be of lower quality. Special surveys may be necessary if more detailed data are desired for forecasting or planning purposes.

3.1.2 Published and Proprietary Data

Appendix C contains information on approximately 35 compilations of data that are available from public or private sector sources in printed or electronic form. These sources vary with respect to: their level of detail; the modes, commodities and types of movements covered; whether they incorporate information on all movements of a given type or on just a sample of such movements; and, in the case of sample data, the size and structure of the sample. Some of the more significant of these sources are:

- **The ICC Carload Waybill Sample Public Use File** – This contains tons, carloads, trailers, containers, revenue, commodity, and BEA region[1] origin and destination for a sample of rail shipments.

- **Waterborne Commerce and Vessel Statistics** – This contains annual data on tons by commodity, harbor, waterway segment, direction, and type of movement (internal, coastwise, export or import) for all movements using domestic waterways.

- **U.S. Air-Freight Origin Traffic Statistics** – This contains estimates developed by the Colography Group of annual weight, value and number of air-freight shipments for 73 industries by "market area" of origin.

- **The 1993 Commodity Flow Survey** – This is expected to contain estimates of tons and value of shipments by commodity, mode, and origin and destination state or NTAR;[2] eight modes will be distinguished (including private truck, for-hire truck, and air/surface parcel transport).

- **Transearch Database** – This contains estimates of tons by commodity and origin and destination state or BEA region for air, truck, rail and water movements.

3.1.3 Special Surveys

Data from the above mentioned sources may be supplemented by information collected from special surveys conducted (partly or primarily) to contribute to the forecasting process. The type of survey to be used for this purpose depends upon whether or not the firms using the facility in question are known.

When the set of firms using a facility is known (e.g., from information maintained by the facility operator), a survey can be conducted of all or a sample of these firms. Such a survey can be designed to collect data on the annual volume of use by shipment characteristics of interest (e.g., shipment size, commodities, origins and destinations, etc.), as well as information on expected near-term changes in these volumes, use of competing facilities, and factors affecting the choice of facilities. When designing such a survey, it is important to limit the amount of

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[1] The Bureau of Economic Analysis (BEA) has divided the United States into 183 economic areas (or regions), each of which contains one or more cities and the surrounding hinterland.

[2] The National Transportation Analysis Regions (NTARs) are a set of 89 regions, obtained by aggregating the 183 BEA economic areas into larger units.

information requested so that respondents do not find the survey to be burdensome.

When the set of firms using a facility is unknown or only partially known, an unbiased sample of firms using the facility cannot be constructed. Instead, a survey generally is designed to collect information on a sample of movements by interviewing employees who are moving shipments to or from an intermodal facility or who are transporting shipments over a facility serving a single mode (e.g., a road). This approach is commonly used for obtaining information on truck transport, the mode for which the least amount of published data is available. For example, the North American Truck Survey (NATS), described in Appendix C, was performed by interviewing truck drivers at truck stops, and a special survey conducted on behalf of the State of Washington[3] was performed by interviewing truck drivers at weigh stations.

Movement-oriented surveys generally are limited to collecting data on a single movement.[4] The data collected may correspond to the annual shipment data collected from a firm (e.g., shipment size, commodity, vehicle type, origin and destination, etc.), although truck drivers and other carrier employees interviewed for a survey may have somewhat less complete information about these shipments than does carrier management. Also, because the data from such surveys are limited to individual shipments, a much larger sample is required to obtain a reliable indication of the overall use of a facility.

Information on facility usage obtained from movement-oriented surveys is most accurate when the facility is geographically confined (e.g., it is an intermodal facility or a relatively short road segment) and the survey is conducted at the facility. For geographically dispersed facilities (such as roads), the sampling procedure may miss surveying certain types of movement, such as short hauls that do not pass any survey locations, or overweight trucks that use bypasses to avoid weigh stations. Surveys conducted at truck stops are likely to pick up very few short movements because drivers on short trips are less likely to stop at truck stops. Also, if multiple survey locations are used, movements on routes that pass more than one survey location are more likely to be sampled than movements on routes that pass only one such location; however, this is a type of sampling bias for which corrections can be readily developed.

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[3] William R. Gillis, Kenneth L. Casavant and Charles Howard, Jr., "Survey Methodology for Collecting Freight Truck Origin and Destination Data," The Gillis Group, Pitzville, Washington, July 1994. Additional information about the conduct of this survey is contained in Appendix D.

[4] Note that the NATS survey collects data on both the truck's current movement, whether empty or loaded, and its preceding loaded movement.

Additional information on the design and use of special surveys is presented in Appendix D.

■ 3.2 Sources of Economic Forecasts

The most important determinants of transport demand are the volume of goods that are produced and consumed, and the locations of production and consumption. Consequently, forecasts of production and consumption, or of overall economic output, are important sources of information for developing freight demand forecasts.

Because economic forecasts have many applications aside from their use in forecasting transport demand, such forecasts often are available from several sources. Accordingly, most forecasts of demand for freight transport are based to some extent on forecasts of changes in the economy. Potential sources of these forecasts are described below.

Several states fund research groups that monitor the state's economy and produce forecasts of economic change. For example, the Center for the Continuing Study of the California Economy develops 20-year forecasts of the value of California products by two-digit Standard Industrial Classification (SIC) code. Similarly, the Texas Comptroller of Public Accounts develops 20-year forecasts of population for ten substate regions and 20-year forecasts of output and employment by one-digit SIC code and substate region, and a private firm produces 20-year forecasts of output and employment in Texas by three-digit SIC code.

Long-term economic forecasts also are available from two federal agencies. At 2½-year intervals, the Bureau of Labor Statistics (BLS) publishes low, medium and high 12-to-15 year forecasts of several economic variables, including real domestic output, real exports and imports, and employment, for each of 226 sectors generally corresponding to groups of three-digit SIC industries.[5] Also, at five-year intervals, the Bureau of Economic Analysis (BEA) develops 50-year regional projections of population and personal income as well as employment and earnings by industry sector.[6] The BEA forecasts are published by state for 57 industries, and by metropolitan statistical area and BEA economic area for 14 industry groups.

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[5] The most recent BLS forecasts are contained in U.S. Department of Labor, Bureau of Labor Statistics, *American Work Force 1992-2005*, Bulletin 2452, April 1994.

[6] See U.S. Department of Commerce, Bureau of Economic Analysis, *BEA Regional Projections to 2040*, Three Volumes, U.S. Government Printing Office, October 1990.

In addition to the state and federal agencies, short-term and long-term economic forecasts also are available from several private sources. The private firms use government and industry data to develop their own models and analyses. Two of the better known private sources are DRI/McGraw Hill (DRI) and the WEFA Group.

DRI provides national, regional, state, Metropolitan Statistical Area (MSA), and county-level macroeconomic forecasts on a contract or subscription basis. Variables forecast include gross domestic product (GDP), employment, imports, exports, and interest rates. DRI also produces short-term (2½-to-3 year) and long-term (20-to-25 year) industrial input and output forecasts for 250 industries (two-, three-, or four-digit SIC code). Industrial inputs include employment, energy, and materials used in production. These input/output forecasts are updated semiannually. Price and wage indices also are forecast for 650 different industries.

WEFA produces quarterly short-term (2½-to-3½ year) and long-term (10 and 25 year), and annual long-term (25 year), U.S. macroeconomic forecasts. Variables forecast include GDP, employment, price indices, financial indicators, and foreign exchange rates. WEFA also produces short-term (three year) output forecasts for 537 industries (at the four-digit SIC level) on a quarterly basis, and long-term (10 year) input and output forecasts for 480 industries semiannually.

■ 3.3 Economic Indicator Variables

A highly useful and relatively simple procedure for deriving forecasts of transport demand from economic forecasts is to assume that demand for the transport of various commodity groups is directly related to variations in corresponding economic *indicator variables*. The most desirable indicator variables are those that measure goods output or demand in physical units (tons, cubic feet, etc.), but forecasts of such variables frequently are not available. More commonly available indicator variables are constant-dollar measures of output or demand; employment; or, for certain commodity groups, population or real personal income.

The indicator variables can be used either to derive *annual growth rates* or to derive *growth factors* representing the ratios of forecast-year values to base-year values. The procedure requires data on or estimates of transport activity or facility usage, by commodity group, for a reasonably "normal" base year, as well as forecasts of growth in the corresponding indicator variables. The basic version of this procedure is:

1. Divide base-year transport activity or facility usage by commodity group.

2. Associate each commodity group with an economic indicator variable that is related to the production of or demand for that commodity group and for which forecasts are available from some exogenous source. (For example, the transport of food products might be associated with production of food products.)

3. For each indicator variable, obtain either a *growth factor* by dividing its forecast-year value by its base-year value, or obtain a forecast *annual growth rate* (e.g., by determining the average annual growth rate implied by the variable's base-year value and its value in any forecast year).

4. For each commodity group, estimate forecast-year demand either by multiplying base-year activity by the corresponding growth factor or by applying the indicator variable's annual growth rate to base-year activity.

5. Aggregate the forecasts across commodity groups to produce forecasts of total transport demand and forecasts of transport demand for any set of commodity groups of interest.

3.3.1 Some Examples

The Vessel Traffic Services Study

One example of the use of economic indicator variables is a set of forecasts of waterway freight traffic and freight-vessel traffic developed for the Volpe National Transportation Systems Center (VNTSC) and for the U.S. Coast Guard.[7] Traffic forecasts were required for study zones surrounding 24 major ports in order to estimate the value of Vessel Traffic Service (VTS) systems being considered to enhance the safety of vessels traveling to and from these ports.

For the VTS study, base-year data on freight and vessel traffic were obtained, primarily from the U.S. Army Corps of Engineers (COE) commodity and vessel traffic files for 1987. For all but one of the study zones of interest, this file provided estimates of import, export, and domestic freight traffic, in tons, by commodity and direction, for several

[7] Herbert Weinblatt, *Commodity and Vessel Traffic Forecasts*, Task Report, prepared by Jack Faucett Associates for the Volpe National Transportation Systems Center, Cambridge, Massachusetts, March 1991.

waterway segments, for each of 159 commodity groups. Movements of four of these commodity groups were dropped from consideration because forecasts were not needed. On the other hand, a separate commodity code was created for liquefied natural gas (LNG), a commodity of particular concern for the VTS study. Information from the LNG import terminals was used to separate base-year LNG movements from other movements of "petroleum coal products, not elsewhere classified." For the Santa Barbara Channel, the one study zone for which COE data were not available, base-year estimates of freight traffic by commodity were derived from VNTSC estimates of vessel traffic through the channel and from commodity data for Los Angeles/Long Beach.

Forecasts of commodity traffic for four forecast years (1995, 2000, 2005, and 2010) were developed using annual forecasts for the 1986-2000 time period developed by the Bureau of Labor Statistics (BLS) in 1988.[8] The forecasts used were the moderate growth forecasts of real domestic output, exports and imports, by industrial sector. For these purposes, a correspondence was developed between 127 of the BLS's 226 sectors and the 155 commodity groups for which forecasts were required. (The BLS sectors used were the 126 goods-producing sectors plus the scrap sector.)

For each commodity group, the average annual growth rates in real output, real exports, and real imports of the corresponding BLS sector or sectors were determined. These growth rates then were applied to the base-year estimates for each commodity group of domestic movements, exports, and imports, respectively, to produce forecasts for each forecast year of interest.

For three commodity groups of special interest to the study, the above forecasts were modified on the basis of additional data; and for a fourth commodity group, a separate forecast was developed.

- Forecasts of coastwise shipments of petroleum products for several ports were modified to reflect BEA employment forecasts[9] for oil and gas extraction in Alaska and for petroleum refining in Texas and Louisiana.

- Forecasts of crude oil imports entering three Texas port areas were adjusted to reflect the effect of a planned offshore petroleum terminal, using information from persons involved in the planning effort.

- Relatively conjectural forecasts of LNG imports were developed from data on 1990 LNG imports at two terminals, and from information

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[8] U.S. Department of Labor, Bureau of Labor Statistics, *Projections 2000*, U.S. Government Printing Office, Washington, D.C., March 1988.

[9] U.S. Department of Commerce, Bureau of Economic Analysis, *BEA Regional Projections to 2040*, U.S. Government Printing Office, Washington, D.C., June 1990.

about capacity at these two terminals as well as a third that was expected to resume operation at the time of the study. The forecasts for imports of all other petroleum products were reduced to be consistent with the forecasts of LNG imports.

The California Freight Energy Demand Model

The California Freight Energy Demand (CALFED) Model was developed for the California Energy Commission in 1983.[10] This model is used by the Commission and by the California Air Resources Board for forecasting truck and rail freight activity and energy consumption. These agencies expect to update and expand the model within the next few years.

The CALFED Model develops forecasts of truck and rail freight traffic for 11 commodity groups for five regions of the state, as well as additional forecasts of overall truck (freight and non-freight) activity by vehicle type and region. Forecasts of truck and rail freight activity are developed by applying growth factors to base-year estimates of activity by commodity, region, and vehicle type or railroad-car type.

Exhibit 3.1 lists the 11 commodity groups distinguished by the model and the corresponding economic indicators used for deriving the growth factors. California forecasts of all indicators shown in the exhibit are produced regularly by the Center for the Continuing Study of the California Economy (CCSCE). The CALFED Model uses forecasts expressed in physical units, where available, and forecasts of value of output or employment in most other cases; population forecasts are used for deriving growth factors to be applied to household-goods transport.

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[10] Herbert Weinblatt, *California Freight Energy Demand Model,* prepared by Jack Faucett Associates for the California Energy Commission, Sacramento, California, June 1983.

Exhibit 3.1 Economic Indicators Used by the CALFED Model

Commodity Groups	Economic Indicators
1. Fruits and Vegetables	Food Products (tonnes)
2. Other Agricultural	Food Products (tonnes)
3. Construction and Mining	Employment in construction
4. Timber and Lumber	Lumber, plywood, etc. (board feet)
5. Food Products	Food products (tonnes)
6. Paper Products	Paper products (tonnes)
7. Chemicals	Chemicals (1972 dollars)
8. Primary Metals	Primary metals and transport equipment (1972 dollars)
9. Machinery	Machinery (1972 dollars)
10. Other Manufacturing	Cement and glass (tonnes); output of SIC codes 22, 23, 25, 27, 30, 31, 34, 38, and 39 (1972 dollars)
11. Household Goods	Population

The model uses exponential interpolation and extrapolation to derive forecasts for years in which CCSCE forecasts are not available.

For example, total production of food products in California in 1982 was 13.58 million metric tons (tonnes) and, at the time the model was developed, the CCSCE projected that production in 1987 would be 14.54 tonnes. These two figures imply an average annual growth rate of 1.38 percent in the production of food products over the period from 1982 to 1987. Accordingly, annual ton-miles of food products transported by rail and truck were forecast to grow by 1.38 percent in each year between 1982 and 1987. Using the CCSCE forecasts for 1992, 1997, and 2002, a somewhat higher annual growth rate (1.68 percent) was derived from the 1987-1992 period, and somewhat lower rates (1.33 percent and 1.08 percent) for the following 1992-1997 and 1997-2002 periods.

Separate CCSCE forecasts were available for each commodity group identified in Exhibit 3.1 except for Groups 1 and 2, fruits and vegetables, and other agricultural products. In the absence of forecasts for these two commodity groups, the growth rates obtained for food products (Group 5) were used for Groups 1 and 2.

The following is a somewhat simplified description of the development of base-year (1977) estimates of truck and rail traffic:

- Base-year estimates of truck transport of manufactured goods were developed using 1977 Commodity Transportation Survey data[11] on movements among eight BEA economic areas in California and between these areas and 165 economic areas in the rest of the country. Estimates of ton-miles in each of the model's five substate regions were derived using likely mileages within each of these regions for movements between each of the origin and destination areas. For interstate movements, separate mileages were assigned to each of several entry/exit routes (shown in Exhibit 3.2); every O/D pair was associated with one of these routes. Traffic moving through California originating and terminating in other states or other countries was assumed to be negligible.

  Base-year estimates of truck ton-miles of nonmanufactured commodities were derived from 1977 Truck Inventory and Use Survey data on the VMT of heavy vehicles serving the corresponding sectors, and estimates of effective average payload by commodity group. In

[11] U.S. Bureau of the Census, 1977 Commodity Transportation Survey, special computer tabulations prepared for the Transportation Systems Center, Cambridge, Massachusetts. (This Census survey was last conducted in 1977 and has since been replaced by the Commodity Flow Survey discussed in Section 3.1.2 and in Appendix C.)

Exhibit 3.2 Average Mileage in California for Interstate Truck Movements

BEA Economic Area	Entry/Exit Route	(1) San Francisco	(2) Los Angeles	(3) San Diego	(4) Sacramento	(5) Rest of State
		Mileage by Freight Model Region				
164. San Diego	I-5		138	60	71	520
	I-15		276	63		98
	I-8			70		
165. Los Angeles	I-5		68		71	581
	I-80		68		208	332
	I-40		244			5
	I-10		242			5
166. Fresno	I-5				71	403
	I-80				182	208
	I-15		150			159
	I-40		198			159
	I-10		256			151
167. Stockton	I-5				71	268
	I-80				198	73
	I-15		150			297
	I-40		198			297
	I-10		256			289
168. Sacramento	I-5				36	235
	I-80				146	55
	I-15		150		32	330
	I-40		198		32	330
	I-10		256		32	322
169. Redding	I-5					117
	I-80					196
	I-15		150		71	445
	I-40		198		71	445
	I-10		256		71	437
170. Eureka	I-5					164
	I-80					356
	I-15	129	150			450
	I-40	129	198			450
	I-10	129	256			442
171. San Francisco		80			28	235
		74			199	42
		55	150			313
		55	198			313
		55	255			296

the case of agricultural products, additional data from other sources supported the development of these estimates.[12]

- Base-year estimates of rail ton-miles by commodity group and California region were derived from 1977 railroad waybill data[13] using a variant of the procedure used for truck transport of manufactured goods.

3.3.2 Improving the Forecasts

The basic economic indicator procedure (as presented above) assumes that for any transport facility, the percentage change in demand for transport of each commodity group will be identical to the percentage change in the corresponding indicator variable. However, because of changes over time in the value of output per ton, output per employee, transportation requirements per ton, and competition from other facilities and modes, the percentage changes in the indicator variables and the commodity group transport demand are unlikely to be the same. To the extent that the likely effects of these changes are understood and can be estimated at reasonable cost, the basic procedure should be modified to reflect these effects.

Additional discussion of factors influencing these effects is contained in Appendix A.

Value Per Ton

For most commodity groups, the relationship between the value of output (measured in constant dollars) and volume shipped (measured in pounds, tons, cubic feet, etc.) may change over time. These changes may be due to a change in the mix of commodities being produced within a given commodity group (e.g., more aluminum and less steel) or a change in the average real value per ton of major products within the group. As a consequence of these changes, the value per ton may either increase or decrease. For example, computers represent a product category in which the value per ton, or per pound, has decreased appreciably due to the shift to personal computers from mainframes.

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[12]Jack Faucett Associates, *The Multiregional Input-Output Accounts, 1977: Interregional Commodity Flows*, Volume VI, prepared for the U.S. Department of Health and Human Services, August 1982; U.S. Department of Agriculture, *Agricultural Statistics, 1980*, U.S. Government Printing Office, 1980; and U.S. Department of Agriculture, *Fresh Fruit and Vegetable Shipments*, Calendar Year 1978, FVUS-7, Washington, D.C., July 1979.

[13] U.S. Department of Transportation, Federal Railroad Administration, 1977 Waybill File, Washington, D.C.

When forecasting transport demand for several different commodity groups, making adjustments for expected changes in value per ton for all commodity groups will be relatively expensive and may have little effect on the overall transport demand forecast. If there are one or two commodity groups of particular interest, some consideration should be given to determining how the real value per ton for these groups has been changing and how it is likely to change over the forecast period. Information about past trends and potential future changes usually can be obtained from industry associations or informed observers. Government publications (e.g., *Agricultural Statistics* or the *Census of Manufacturers*) are other potential sources of historic price data for specific products.

Output Per Employee

Real output is related more closely to transport demand than is employment, so employment is a less desirable indicator variable than real output. However, because long-term forecasts of employment are more available than forecasts of output, employment forecasts must be used for some purposes.

As a result of improvements in labor productivity, the real dollar value of output per employee increases over time, and physical output (in tons or cubic feet) tends to increase as well. Forecasts of the overall increase in real dollar-valued output per employee for goods producing industries (i.e., agriculture, mining, construction, and manufacturing) can be obtained from DRI/McGraw-Hill. To avoid a downward bias in the forecasts of transport demand, forecasts of the percentage change in employment should be converted to forecasts of the percentage change in (real dollar-valued) output. This is achieved by multiplying the estimated percentage change in employment by the estimated compound growth in labor productivity over the forecast period.

Transportation Requirements Per Ton of Output

Decreases in the real cost of transportation over time have resulted in a general tendency for industry to increase its consumption of transport services as a substitute for more expensive factors of production. Consequently, shipment sizes have been decreasing while both lengths of haul and standards of service have been increasing. This has generated a demand for premium quality services (e.g., just-in-time delivery) provided by traditional modes, as well as diversion to more expensive modes that offer faster, more reliable service.

Statistical analyses, using procedures such as those presented in Section 3.4, should provide useful data for forecasting the extent to which these trends are likely to increase the overall demand for freight transport. However, analyses of the secular shift toward higher quality modes are unlikely to produce reliable results because of the difficulty in controlling for temporal changes in modal service quality.

Competitive Factors

As appropriate, forecasts of demand for a facility or mode should be adjusted to reflect expected changes in the degree of competition from other facilities or modes. These changes may result from:

- Expected changes in relative costs;
- The elimination of base-year supply constraints at the facility in question or at competing facilities;
- The development of future supply constraints at the facility in question or at competing facilities;
- The development of new competing facilities; or
- Changes in the routing decisions of major carriers (e.g., intermodal container carriers).

The forecasting problems posed by base-year supply constraints often may be avoided by choosing a base year in which no significant supply constraints existed. When this is impractical, the effects of the supply constraints may be eliminated by using a combination of historic data and subjective judgment to adjust the estimates of facility use in the base year. Annual growth rates or growth factors then may be applied to the adjusted estimates of base-year demand to produce the forecast demand.

■ 3.4 Statistical Techniques

3.4.1 Regression Analysis

Regression analysis, an alternative to the use of economic indicator variables, has a strong theoretical underpinning. Regression analysis involves identifying one or more independent variables – the explanatory variables – which are believed to affect the value of the dependent variable (the variable to be explained), and then calculating an estimate of the relationship between the independent and dependent variables. For our purposes, the dependent variable usually would be some measure of freight activity (e.g., ton-miles) and the independent variables usually would include one or more measures of economic activity. Forecasts must be available for all independent variables. These forecasts may be obtained from exogenous sources or from other regression equations (provided that the system of equations is not circular); alternatively, they may be developed by the forecaster using other appropriate techniques.

For forecasting purposes, regressions normally use historic *time-series* data[14] obtained for both the dependent and independent variables. Regression techniques are applied to the historic data to estimate a relationship between the independent variables and the dependent variable; this relationship is applied to forecasts of the independent variables for future time periods to generate forecasts of the dependent variable for the corresponding time periods.

Software for estimating the coefficients of the independent variables is widely available; easy to use; and, once the data are assembled, very inexpensive to run. Software ranging from spreadsheets to advanced statistical packages such as SAS, SPSS, and TSP provide regression capabilities. The researcher enters data for the independent and dependent variables and invokes the proper command to produce the parameter estimates. The packages also present the researcher with some statistical measures, discussed below, which can be used to assess the appropriateness of the model.

Appendix E contains an introduction to regression analysis along with references to several textbooks. Some of the basic requirements for using regression techniques for forecasting transport demand are discussed below.

3.4.2 Some Basic Issues

The use of time-series regression analysis requires the availability of historic time-series data for the dependent variable, and for all independent variables (or proxies for these variables) that have a significant influence on the value of the dependent variable. A frequently used proxy variable is "time," which can be used to represent any influences (e.g., value per ton or output per employee) that tend to increase or decrease uniformly over the historic time period and are expected to have a similar effect over the forecast period. However, when using time as a proxy, steps must be taken to ensure that it does not capture historic trends (e.g., modal diversion) that may not be expected to persist into the future.

A related issue is the use of transport activity as the dependent variable. As observed in Section 3.1, transport activity actually represents transport demand under certain price and service conditions. If these conditions

[14] An alternative to time-series regression is cross-sectional regression, which uses observations of the dependent and independent variables across a set of similar entities (e.g., states, industries or firms).

remained reasonably constant over the historic period and are expected to remain constant over the forecast period, they need not be represented explicitly in the regression. However, any price and service conditions that have varied significantly (or are expected to vary) should be represented by the independent variables or otherwise be given special treatment.

Of particular concern when using transport activity as the dependent variable is the effect of any supply constraints at the facility of interest or at a competing facility. Although, such constraints have no effect on transport demand, they may have a significant (albeit temporary) effect on transport activity. If such constraints only affect transport activity in a single historic time period (e.g., a single year), it is appropriate to exclude data for that period from the regression. If activity is affected in several time periods, it may be preferable to represent the effect of the constraint in the regression, possibly by using a *dummy* variable (i.e., a variable that has a value of one in time periods when the effect is present and is zero in other time periods).

3.4.3 Univariate Time-Series Techniques

Unlike regression analysis, which is based on a presumed theoretical relationship between dependent and independent variables, univariate time-series methods[15] are not based on economic theory or interaction. The basic time-series methods are sophisticated extrapolation tools which allow the past behavior of a variable to be characterized and projected into the future. Because time-series models do not explain behavior, they do not provide a basis for estimating the impact of changing policy variables.

Time-series models require less data than regression models. Historic data are required only for the variable being forecast. The models implicitly presume the following:

- The effects of all of the variable's significant influences (e.g., growth and cyclical variation in economic activity, changes in competition from competing facilities/modes) can be adequately captured by an analysis of the historic changes in the variable itself; and

- During the forecast period, these influences will not change in character (e.g., the character of the business cycle will not change and overall economic growth will not significantly accelerate or decelerate).

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[15] The seminal work on time series methods is G.E.P. Box and G.M. Jenkins, *Time Series Analysis: Forecasting and Control*, Holden Day, San Francisco, 1970 (revised edition, 1976).

The requirement that the influences on the variable to be forecast not change makes these techniques more appropriate for short-term forecasting than for developing the long-term forecasts usually required for facility planning. Also, it should be noted that, like all other techniques presented in this chapter, the use of historic data on transport *activity* to represent transport *demand* presumes that the activity data do not reflect the effects of any significant supply constraints.

Time-series analysis assumes that the data series to be forecast has been generated by a random process with a structure that can be defined and modeled.[16] Indeed, time-series models describe the random nature of the process that generates the data series under investigation in a way that will be useful to planners for forecasting purposes. Furthermore, time-series models generate confidence intervals for predictions; this confidence band widens as the length of the prediction period increases. Planners find the range estimates to be more realistic than the simple point estimates provided by extrapolation techniques.

Time-series models require that the variable to be forecast be "stationary," a situation in which its random or stochastic properties do not vary with respect to time. In other words, the forecast variable's mean value, its variance, and its covariance with other observations of the variable must be independent of time. This is a major limitation of time-series models, since it means that they cannot be used to forecast variables that exhibit any type of trend. However, they can be used to develop such forecasts indirectly by substituting a "detrended" variable for the variable of interest.

A common procedure for developing a detrended variable is through differencing – i.e., by creating a time series consisting of the difference between each data point and its predecessor. If the resulting time series is stationary, time-series forecasting techniques can be applied to it, and forecasts of the variable of interest can be derived from its base-year value and from forecasts of the change in its value during each subsequent time period.

Brief discussions of three univariate time-series techniques are presented below. Additional discussion of time-series methods is presented in Appendix E.

ARIMA

The most common nonregression time-series model is the Auto-Regressive Integrated Moving Average model, known as ARIMA.

[16] This discussion is drawn from Robert S. Pindyck and Daniel L. Rubinfeld, *Econometric Models and Economic Forecasts*, McGraw-Hill, Inc. 1981, pp. 493-500.

ARIMA tools are widely available in statistical software packages and spreadsheets.

An ARIMA model requires the analyst to specify three parameters, *p*, *d*, and *q*:

> *p* is the order of the autoregressive dimension of the model, i.e., the number of lagged values of the dependent variable;
>
> *d* is the number of times the dependent variable, Y, is differenced to achieve the stationary form Y*;
>
> *q* is the number of lagged values of the error term which represents the moving average component of the model.

To develop and use an ARIMA model, an analyst follows three steps:

- Model identification, in which the values of *p*, *d*, and *q* are determined;
- Estimation of other model parameters; and
- Verification that the model is satisfactory.

Of these steps, model identification is most critical and most challenging. The analyst must interpret several statistics, including a *correlogram*,[17] to determine which model specification is best for the data series in question. ARIMA models often are considered to be a "partial art form" because they leave much room for interpretation.

Exponential Smoothing

Exponential smoothing involves removing the random fluctuations in a data series to establish its underlying pattern, and then using that pattern to develop forecasts. Forecasts developed through smoothing are most appropriate for a short time horizon in which the underlying trends of the past are expected to continue to be the primary determinant of the variable's value.

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[17] A *correlogram* is a plot of the autocorrelation coefficient, r_k. Its pattern can often reveal the particular form of the ARIMA model to an experienced analyst. For a good discussion of correlogram patterns and the specifications they suggest, see Peter Kennedy, *A Guide to Econometrics*, Third Edition, MIT Press, Cambridge, Massachusetts, 1984, pp. 260-261.

Curve Fitting

Curve fitting estimates how well a time series "fits" or can be described by a standard mathematical function ("curve"). Some of these functional forms, such as a straight line, are very simple, while others are more complex, such as a logistic curve. Most software packages provide a variety of functional forms to use for evaluating the data series and allow the analyst to project the curve beyond the estimation period. Forecasts developed in this way also are most appropriate for short-term use.

3.4.4 The Structural Econometric Time-Series Approach

One limitation of the ARIMA model and other time-series methods is that their analyses lack any explanatory power. There is no underlying theoretical relationship specified between the dependent variable and those factors which might affect its value, as there is in a regression model. The dependent variable itself contains all information needed to estimate its own future values. That specification is unsatisfying to analysts who are interested in estimating how changes in other variables affect the dependent variable.

It may be difficult or impossible to explain the movement of a time series by relating it to an economic variable. First, the researcher may be unsuccessful in finding an explanatory variable that is related to the time series in a systematic way. Alternatively, no data may be available for the explanatory variables that the researcher believes has an effect on the time series. Furthermore, a structural model relating economic explanatory variables to the time series may have standard errors so large that the model's coefficients are statistically insignificant, and the standard forecast errors produced by the model may be too large for the results to be useful. In cases where the structural model approach proves unsatisfactory, the time-series model represents a useful alternative.[18]

Econometricians who were dissatisfied with the lack of a theoretical basis for time-series methods eventually developed a synthesis which combines the structural and time-series models. An approach known as the structural econometric time-series approach (SEMTSA) was one of the results of this effort. As Peter Kennedy explains:

> SEMTSA is based on the observation that dynamic structural equation econometric models are special cases of multivariate time-series (Box-Jenkins) processes in which *a priori* restrictions suggested by economic theory have been imposed on the parameters. Furthermore, if the exogenous variables in the

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[18] Pindyck and Rubinfeld, op. cit., pp. 470-471.

econometric model can be viewed as being generated by a multiple time-series (ARIMA) process, then each of the individual endogenous variables in the econometric model can be expressed as a univariate Box-Jenkins ARIMA process.[19]

SEMTSA develops a traditional, theoretically grounded, structural model; derives the properties of corresponding ARIMA equations; and uses time-series methods to estimate the ARIMA equations. The results are checked for consistency with the structural model. If inconsistencies are noted, the proposed structural model is re-examined to identify its probable flaws. This approach makes it possible to model the underlying relationships between the dependent variable and the factors influencing it. At the same time, SEMTSA takes advantage of the ability of the time-series approach to identify and model the random processes at work in the dependent variable through a process that accounts for patterns in the past movements of the variable and that uses that information to predict future movements of the variable.[20]

■ 3.5 Alternative Futures

The two preceding sections have presented procedures for producing a single forecast of freight demand. The goal of these procedures is to produce as good a forecast as is practical with available resources. However, planners are cautioned that the forecast is likely not to be completely accurate – either because some of the assumptions (e.g., those relating to economic growth) prove to be inaccurate, or because of deficiencies in the procedure itself.

Because it is impossible to guarantee that any forecast is perfectly accurate, effective planning requires that planning decisions account for possible inaccuracies in the forecast. The consequences of these possible inaccuracies will influence how the planners may wish to use the forecast. For example, for some capacity expansion projects, the cost of not being able to accommodate demand may be much greater than the cost of over expansion. In such cases, planners may wish to develop a "high likely" forecast of demand to use as the basis of expansion plans. On the other hand, for bond-financed projects, the greater concern might be whether capacity utilization will be high enough to generate sufficient revenue for paying off the bonds. For these projects, the focus may be on identifying the lowest level of future demand that is likely to occur.

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[19]Kennedy, *op cit.*, p. 249.

[20] Pindyck and Rubinfeld, op. cit., pp. 470-471.

The conventional approach to analyzing the effects of alternative futures is to subject a forecast to some form of *sensitivity analysis*. This approach is discussed in the first subsection below, but with an emphasis on forecasting those alternative futures that are of greatest concern.

A different approach to sensitivity analysis involves *starting* by identifying the alternative futures of concern and *then* identifying the conditions under which these futures could occur. This alternative, which we shall call *futures analysis*, is discussed in the second subsection.

3.5.1 Sensitivity Analysis

The development of any forecast requires that a number of explicit or implicit assumptions be made. Some of the assumptions that may be incorporated into forecasts of demand for a transportation facility relate to the following:

- Economic growth – both nationally and locally;
- Growth in the economic sectors that generate significant volumes of freight handled by the facility;
- Transport requirements of these sectors (which may be affected by increased imports or exports, or by changes in production processes);
- Modal choice (which may be affected by changing transport requirements or changes in the cost and service characteristics of competing modes);
- Facility use per unit of freight volume (which may be affected by changes in shipment size or container size);
- The availability and competitiveness of alternative facilities;
- Value per ton of output; and
- Output per employee (if employment is used as an indicator variable).

Sensitivity analysis consists of varying one or more of these assumptions so that alternative forecasts may be produced. The most common alternative assumptions to be considered are those related to economic growth. Indeed, economic forecasters (including BLS) frequently provide high and low forecasts of growth in addition to a medium (or most likely) forecast. These alternative forecasts of economic growth can be used to generate alternative forecasts of transport demand, and additional alternative forecasts of exogenous variables (e.g., trade) can be used to produce an even larger set of forecasts of transport demand (e.g., high growth, high trade; high growth, low trade; etc.). However, simply varying these exogenous forecasts generally will not produce a set of transport-demand forecasts that represents the full range of demand that might exist in future years. For a better understanding of this range of demand, a more thorough sensitivity analysis should be conducted.

One approach to conducting a thorough sensitivity analysis is to generate two reasonable alternatives for each explicit and implicit assumption in the analysis: one that would increase the forecast of demand, and one that would decrease it. A high forecast of demand can then be generated by using the alternative assumptions that would tend to increase the forecast (or at least all those that are logically compatible with each other); and a low forecast can be generated by using the alternatives that would tend to decrease the forecast. These high and low forecasts should provide planners with appropriate information about the possible future range of transport demand. Planning decisions then can incorporate any changes in transport demand within this forecast range.

A somewhat more systematic type of sensitivity analysis consists of making small changes in the analytic assumptions, one at a time, and determining the effect of each change on forecast demand. The resulting sensitivity estimates help to identify the assumptions to which the forecast is most sensitive. These assumptions can then be reviewed and, if appropriate, improved. Also, a subjective determination can be made about the degree of confidence one has in the accuracy of the assumptions. Assumptions that are not deemed to be highly accurate can be varied and the implications of such variation can be determined – either by repeating the forecasting process using appropriate sets of alternative assumptions; or by making the simplifying (and not necessarily accurate) assumption that the effect of changing each of the analytic assumptions is linear and deriving alternative forecasts from the original forecast and the previously estimated sensitivities.

The second type of sensitivity analysis can provide more insight into the relationships between the various analytic assumptions and the forecasts produced, but this approach requires a greater expenditure of resources. Furthermore, the most important sensitivity results – high and low forecasts of demand – can be generated using either approach, although these forecasts will be affected by the alternative analytic assumptions used to generate them and the care with which the high and low forecasts are then generated.

3.5.2 Futures Analysis

The preceding subsection discussed the use of alternative assumptions about the future and possibly about economic relationships as the basis for generating alternative forecasts of transport demand. In futures analysis, this process is essentially reversed. More specifically, futures analysis may be viewed as consisting of two steps. First, identify those alternative futures (e.g., levels of future demand) that would warrant a different planning decision than the one indicated by the original forecasts. Then, for each such alternative future, identify the circumstances under which it might occur.

For some capacity expansion projects, there may be concern about the potential inability to meet future demand without further capacity expansion that could be accomplished most efficiently as part of the current project. For such projects, the second step of the futures analysis would include a determination of the conditions under which future demand might exceed planned capacity. Some of the possible contributing causes to be considered would include:

- Higher-than-expected economic growth;
- Higher-than-expected growth in the mode(s) served (due to changes in transport requirements of shippers or in cost and service characteristics of competing modes);
- Higher-than-expected growth in transport demand in the region served by the facility (due to unusual growth in production and/or consumption in the region); and
- A temporary or permanent loss of capacity at a competing facility.

If there appears to be a significant probability that future demand would indeed exceed planned capacity, further analysis then would be performed to obtain a better understanding of this probability and the expected costs and benefits of expanding the planned expansion.

For bond-financed projects, in particular, an alternative future of concern would be one in which demand for the facility would not generate sufficient revenue for operating the facility and paying off the bonds. We assume that the total cost of financing the facility is reasonably well known and that the cost of operating the facility (as a function of usage) is understood. Then, for a given user-fee schedule, the minimum level of usage that will pay the financing and operating costs of the facility can be estimated.

The second step of a futures analysis for this type of project would include a determination of the conditions under which future use would fall short of the required minimum level. Possible contributing causes would include lower-than-expected growth in the overall economy, in the mode(s) served, or in the region served, as well as an unanticipated increase in competition from other facilities (including potential new facilities). If it is determined that use may not be adequate under the assumed user-fee schedule, other user-fee schedules should be considered, incorporating appropriate adjustments in usage forecasts to reflect the effects of the alternative fees.

4.0 Demand Forecasting for New Facilities

Transportation planners frequently must estimate how much a proposed new transportation facility or project will be used. The estimated future use of a new facility is a critical consideration in deciding whether or not to go ahead with the project.

Overestimates or underestimates may be equally costly. Overestimates result in the construction of projects or facilities that will be underutilized and that may not generate enough revenue to cover project costs. Underestimates result in the failure to build needed facilities, thereby causing congestion and delays at existing inadequate or outmoded facilities, increasing transport costs, and placing the area served by the facility at a competitive disadvantage.

This chapter addresses the issue of forecasting demand when the contemplated facility or project is new – i.e., situations in which planners do not have the benefit of a past record of facility use upon which to base a projection of future use. While the previous chapter focused on the issue of projecting future use of existing facilities, this chapter deals with the projected use of new facilities. Included in this discussion are such projects as: a new freight airport; a new highway (e.g., an intercounty connector highway, a bypass route, an outer beltway, etc.); a new intermodal facility; or development of a new doublestack rail line.

Planners projecting the demand for new facilities must define the available universe of freight flows from which the new facility could draw business, and must decide how this universe of freight is likely to grow in the future. The first section of this chapter discusses the identification of the universe of freight flows that might use a new facility, and the second section discusses forecasting changes in these flows.

Once the universe of relevant freight flows is established and projections for that universe are developed, the focus shifts to assessing how much of the current and future freight traffic would use the new facility. For most new facilities, most or all of the freight using the new facility will be shifted to the facility as a result of *route diversion,* i.e., the freight will continue to be transported via the same combination of modes used prior to the opening of the new facility, but the route used will change to make use of the new facility. In some cases, a modest portion of the freight using the facility will be diverted from another mode; and in some relatively unusual cases, such as a new waterway or a new rail line through an area without rail service, modal diversion will be the most significant source of freight using the facility. Also, a small amount of freight using the new facility may represent new freight movements stimulated by the establishment of the facility. The third section of this chapter discusses these sources of demand for a new facility in some detail, and the fourth section presents four procedures for estimating this demand.

The fifth section of this chapter provides a brief discussion of the analysis of alternative futures (which is discussed in more detail in Section 3.5.). Additional information on data sources, cost estimation, and mode diversion is contained in Appendices C, F, G and H, and a case study describing the analysis of the demand for a new freight airport in North Carolina is presented in Appendix I.

The four steps described above are summarized in Exhibit 4.1.

Exhibit 4.1 Demand Forecasting for New Facilities

1.	Identify the potential freight market
2.	Forecast changes in the market
3.	Estimate the new facility's market share
4.	Evaluate the effects of alternative futures

■ 4.1 The Potential Freight Market

Most of the use of most new facilities would be drawn from a reasonably identifiable set of existing facilities with which the new facility would compete. In the case of a new road, the competing facilities consist of existing roads to which the new road would provide a reasonable alternative. These alternatives may be nearby (e.g., alternatives to a new route through a metropolitan area generally consist of the existing routes traversing the area in the same general direction), or they may be more distant (as in the case of a possible new Interstate-quality highway designed to serve traffic currently using I-40 or I-70).

In the case of a new intermodal facility, the competing facilities consist of most or all of the facilities that have service areas that overlap the natural hinterland of the new facility. In the case of some facility types (e.g., container ports), the hinterlands can be quite extensive, and the set of competing facilities might be relatively dispersed geographically.

The first step in estimating the use of a new facility is to identify those competing facilities from which most of the facility's traffic is expected to be drawn and identifying the types of traffic of interest (e.g., selected commodity groups, containerized or bulk traffic, etc.). For each of the competing facilities, data on the current volume of these types of traffic should be obtained. (Published sources of such data are discussed in Section 3.1 and in Appendix C.)

In making these identifications, consideration should be given to the question of how broadly the sets of competing facilities and types of traffic of interest should be defined. An overly broad definition will result in an unnecessary increase in the amount of data required and, more importantly, in the amount of subsequent analysis required to determine the portion of total identified traffic that is likely to be diverted. In general, for analytical purposes, omitting facilities and traffic types that are expected to be only minor contributors to the new facility is desirable. It must be recognized, however, that this will result in a slight downward bias in estimated diversion.

■ 4.2 Forecasting Changes in the Market

The second step in estimating usage of a new facility consists of estimating expected changes in the volume of traffic identified in Step 1 that are likely to occur over the forecast period. These forecasts are obtained using either economic indicator variables (as described in Section 3.3) or statistical procedures (such as those discussed in Section 3.4 and Appendix E). Once an initial forecast is obtained, it should be improved using sensitivity analysis and/or futures analysis, as discussed in Sections 3.5.

■ 4.3 Sources of Demand for a New Facility

The usage of a new transportation facility may come from several sources:

- Diversion of traffic from a competing facility without any change in modes used (i.e., route diversion);
- Diversion of traffic from another mode (i.e., modal diversion);
- Increased production by existing shippers in the area served by the facility; and
- Establishment of new shippers in the area.

Of these four sources, *route diversion* normally will be the principal source of demand for the new facility. *Modal diversion* may be a significant source of demand when a facility introduces a new mode into an area, but most new facilities will result in very little true modal diversion (although there may be some reduction in access hauls to intermodal terminals).

The last two sources, which represent *induced demand,* also are likely to be quite minor sources of demand for a new transportation facility. However, because they are sources of particular importance to the area's economy, they frequently are viewed as an important reason for building the facility.

The first subsection below contains an extended discussion of route diversion, and the second contains briefer discussions of the two forms of induced demand. Procedures for estimating all four sources of demand for a new facility follow in Section 4.4.

4.3.1 Route Diversion

An individual freight movement is packaged and loaded on transportation equipment at the point of origin and discharged at the final destination, often with one or more intermediate transfers between modes, equipment types, or carriers. Routing may be narrowly defined as an itinerary made up of modal linkages (highways, rail lines, ocean and air routes) and origin, destination and intermediate transshipment points (ports, airports, truck terminals, rail yards, intermodal hubs). A more general definition could incorporate the type of carrier, equipment and level of service (e.g., overnight large package routing via an integrated air carrier).

The factors which determine cargo routing patterns include:

- Transportation infrastructure;
- Cost, quality and reliability of service;
- Specialized facility and service requirements;
- Decision-making process and control; and
- Competitive environment.

Route diversion analysis requires the identification of competing routings for various markets and submarkets. The routing of a freight shipment between points A and B will be determined primarily by the available modal linkages, with the range of options varying with type of shipment and number of compatible modes. A truck shipper may be able to choose among many different carriers and highway routings between two points, while a rail shipper may be captive to a single line with track to the shipment's origin and/or destination. Similarly, an air cargo shipper may be restricted to certain international airports due to limited air service to particular markets.

The capacity and quality of the transportation infrastructure are major factors driving the cost and service characteristics of competing routes. For similar service options, transit time and transport cost often are the determining factors in routing decisions, with transit time affecting both the quality of service and operating costs for the carrier. The trade-off between cost and service often is differentiated in the routing options, such as the choice between a local terminal with limited services versus a regional hub with comprehensive but congested services. Again, the analysis of route diversion in most cases, must consider the relative cost and time factors for the entire routing, not just the portion involving a comparison with a similar facility.

Routing decisions may be constrained by special requirements for handling, storage or processing. For example, certain agricultural imports must be quarantined at U.S. government-authorized facilities which are available only at certain ports and airports. Similarly, an overweight intermodal container may be restricted to routings that avoid roads on which overweight truck operation is not permitted. Market projections for new facilities should include only those commodities and markets which are compatible with available facilities and services.

Given the underlying economics and technical constraints, routing decisions ultimately determine the potential for route diversion. The routing of an individual shipment may be determined by the shipper, the consignee, the carriers involved, or third-party operators (e.g., freight forwarders), with multiple decision-makers often involved. A small package shipper which tenders freight to an integrated carrier may neither know nor care about the true routing. On the other hand, a large barge shipper may operate private truck and barge fleets and have full control of door-to-door routing, including the ability to build new facilities. In estimating route diversion, it is critical to understand who makes the routing decisions, and how the decisions are made.

Route-choice criteria can vary by shipment or type of shipment. Factors influencing route choice may include cost, transit time, service frequency, reliability, cargo security, and cargo-tracking capabilities. The selection of a particular facility may be direct or indirect. For example, an air exporter might choose an international carrier based on its authorized gateway airports, or might instruct its forwarder to use a particular airport based on cargo security. On the other hand, the shipper may select a "generic" service without regard to the particular routing. The rise of mini-bridge container routings in the ocean liner industry (e.g., Japan to U.S. East Coast via transcontinental rail service) was partially the result of shippers' general indifference to port selection for intermodal routings.

Routing patterns also may depend on who controls the transportation, the shipper or the receiver. Typically, this is determined in the terms of sale. In international transactions, routing patterns often are dictated by relationships between shippers and receivers with national transportation companies. For example, Japanese importers and exporters traditionally have controlled the transportation to the U.S. inland in both directions, resulting in a market advantage to affiliated Japanese ocean carriers.

Shippers often leave routing decisions to carriers, or to forwarders, brokers, or other third-parties which select the carrier or carriers. Transportation providers will seek to optimize their own internal systems rather than individual movements, typically leading to patterns different from those based on individual shippers' decisions. In particular, carriers may have large fixed investments in certain routings which restrict the ability to shift service patterns. A new facility seeking to attract traffic can either entice a carrier to serve the facility, or encourage shippers either to select a carrier using the facility or to direct their carrier to serve the facility.

A multimodal example may illustrate route diversion to new facilities. Assume that a parts manufacturer currently is exporting containerized products to a buyer in central England using the following routing:

- Truck from factory to rail yard in Chicago;
- Rail to East Coast port;
- Loaded on outbound container vessel in North Atlantic port rotation;
- Discharged at U.K. container port; and
- Truck to final destination.

The routes involved in this shipment include:

- Roads between origin and rail yard;
- Rail line to East Coast port for selected railroad;
- Load and discharge port plus intermediate calls for liner service; and
- Roads and highways between U.K. port and final destination.

The potential "diversions" for this shipment include:

- Alternative truck route to rail yard;
- Alternative truck route direct to U.S. port;
- Alternative rail routing to same U.S. port;

- Alternative rail routing to different U.S. port;

- Alternative ocean routing to same U.K. port;

- Alternative ocean routing to different U.K. port; and

- Alternative truck route to final destination.

The "new facility" options include:

- **New Highway to Rail Yard (in the United States or in the United Kingdom) -** Route diversion would depend mostly on the comparative cost and time factors relative to existing routings. Unless the new highway directly parallels the existing route, the analysis would require comparing total costs and time, including access from origins and destinations.

- **New Rail Facility for Current Railroad -** Route diversion would be determined mostly by the railroad which could dictate the use of a new facility, assuming no difference in cost or service to the shipper or to other transportation providers with decision-making power.

- **New Rail Facility for Competing Railroad -** Route diversion would be based on improved costs or services over the existing facility. If the new railroad serves a competing U.S. port, the improved service also may shift port traffic.

- **New U.S. or Foreign Port Terminal -** A new port terminal can divert traffic from existing terminals in the same port or from competing ports. As previously observed, the new facility could entice a carrier to serve both facilities or to replace the existing call with a call at the new facility. A new carrier also could initiate competing services. New traffic would include traffic from a new carrier serving the facility captured from existing ports and carriers, and traffic from an existing carrier split or entirely diverted from the existing port.

The techniques required to estimate route diversion to new facilities include:

- A detailed estimate of carriers' or shippers' flows;

- Comparative analysis of cost and service for routings with the new facility compared to current routings; and

- Projection of the sensitivity of current flows to diversion using cost elasticities if available or, more likely, using comparable market situations.

Detailed cargo-flow data generally are not available, and flow projections must be based on single-point traffic statistics (e.g., port and airport statistics), which then can be associated with specific commodity, service or carrier markets. "Shippers" often must be defined in general geographical and commodity categories for which routing distributions are developed (e.g., a certain percentage of Midwest corn exporters ships via Port A). As previously noted, the required scope for the market definitions will depend on whether the competitive environment is localized or generalized. For example, the market for the fifth container terminal in a large ocean port may be based on projected patterns through that port alone, while projecting the market for a new type of facility might require a national analysis.

Having specified the baseline routing conditions, a comparison of relative costs and services can be used to "calibrate" the existing traffic patterns. Non-economic factors also should be considered. Unless the market is dominated by a few commodities or shipment types, this often requires developing prototype movements, which are used to represent the spectrum of flows. A useful simplifying assumption is to incorporate all service and time differences into a total cost which can be used to compare routings. For example, an estimated inventory cost often is used as a measure of the service benefits from improved transit times or as a measure of the cost penalty for congestion-related delay.

4.3.2 Induced Demand

As previously noted, induced demand may result from increased production by existing shippers in the area or the establishment of new shippers in the area. These two sources of induced demand are discussed briefly in the following sections.

Existing Shippers

In concept, any reduction in transport costs reduces the costs of existing firms in the area and increases their ability to compete with firms from other areas. In practice, except for producers of low-value commodities (e.g., grain), the transport cost savings obtained by any single shipper as a result of a new facility are likely to represent substantially less than one percent of the delivered price of the shipper's product. The effect on total production, and therefore on use of the new facility, is likely to be small, and may not be worth estimating separately.

If analytic estimates of this effect are desired, they can be developed for a particular product by estimating the annual volume of inbound and outbound movements associated with the product and estimating the transport-related cost savings expected for these movements (using procedures presented in Appendix F). Expressing these savings as a percentage of the value of the product delivered annually (and ignoring any economies of scale[1]) produces an estimate of the maximum percentage reduction in the product price that can result from the reduction in transport costs. For manufactured products, in the absence of specific information on the price elasticity of demand, unit elasticity can be assumed; i.e., a one percent reduction in price can be assumed to produce a one percent increase in shipments.

Demand for agricultural and mining products may be much more elastic, but the supply of these commodities usually is quite inelastic. Accordingly, a reduction in transport costs for these products is unlikely to have any significant effect on their shipment volume (although such a reduction may have a substantial positive effect on the profitability of local producers of these commodities).

New Shippers

A major reason for considering the development of a new transportation facility may be the hope that it would result in new shippers moving into the area. Although a new transportation facility may increase the attractiveness of the area to potential new shippers, actual location decisions will depend both on the resulting transport costs and quality of service, as well as on a variety of other locational factors.

A new road or intermodal facility may increase the attractiveness of the area served to new firms by improving accessibility to markets and decreasing transport costs. In theory, this effect could be greatest when the new facility makes it practical to use a form of transport that was not previously available. For example, a new airport in an area that has no airports could enable a firm that requires air service to consider locating in the area. On the other hand, if service at the airport is relatively limited, as is likely in the case of a new airport, such a firm might not find the air service adequate for its needs.

If information is available on the expected inbound and outbound transportation requirements of a particular firm that is considering moving into the area, the procedures of Appendix F could be used to estimate the value of a prospective new transportation facility to that firm. However, the firm's decision to locate in the area depends on several other factors, including overall accessibility to suppliers and markets; available industrial sites; labor costs; taxes; and, perhaps, financial inducements. The complexity of industrial location decisions makes it difficult for outside observers to make reliable predictions as to whether or

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[1] If economies of scale exist, an increase in production may result in some further reduction in costs. However, for manufactured goods, the small increases in production that are probable are unlikely to produce any significant economies of scale.

not a firm actually will locate in a particular area, and the relatively small impact of new transportation facilities on total costs limits the likely effect of such new facilities on these decisions. Accordingly, in the absence of solid commitments by new firms to locate in the area, transportation planners probably should assume that such firms are unlikely to generate significant use of a new transportation facility.

■ 4.4 Estimating Demand

Procedures for estimating the demand for a new transportation facility include:

- Surveying shippers and carriers to determine their likely use of the new facility;
- Developing estimates from forecasts of the overall market (discussed in Sections 4.1 and 4.2) and information about the degree of market penetration by similar facilities that have been developed in the past;
- Allocating the overall market among competing facilities on the basis of proximity and expected level of service; and
- Performing a detailed analysis and comparison of total logistics costs (TLC) for shipments when transported via their current routings and when transported via the new facility.

4.4.1 Surveying Shippers and Carriers

A survey is likely to be attractive to many planning agencies. A survey is capable of developing estimates of demand that are based primarily on information provided by the parties whose decisions will determine the extent to which a new facility actually will be used. Nonetheless, the survey approach may be somewhat more complex than it appears, and use of this approach to obtain reasonable estimates of actual demand requires a good deal of care.

The steps required in performing a survey are as follows:

1. Determine the universe of potential users of the new facility;
2. Select a sample of firms to survey;
3. Prepare the survey questions;

4. Conduct the survey; and

5. Expand the survey results to estimate total usage of the new facility.

1. Determine Universe of Potential Facility Users

The first step in conducting a survey involves determining the universe of firms whose decisions will determine usage of the new facility. For a new intermodal facility, the universe includes any air, water, or rail carriers that may decide to serve the facility; trucking companies usually should be excluded from the universe, since their use of the facility is likely to be determined entirely by the decisions of others. For a new road, the universe should include both private and for-hire truck operators that may use the road.

In addition, the universe of relevant firms includes all firms that ship into or out of the area served (or, more properly, the subset of these firms that actually control the routing decisions of these shipments). To control the size of this portion of the universe, it may be desirable to include only firms with facilities actually located in the area and to structure the questions so as to learn about both the shipments and receipts at these facilities.

2. Select Sample for Surveying

The second step consists of determining which firms in the universe to survey. If the universe is small (relative to study resources), it may be practical to survey all firms in the universe. More likely, it will be possible to survey only a sample of shippers and receivers (although it usually will be desirable to survey all carriers).

If a sample is to be selected, it generally is desirable to stratify the universe of shippers and receivers on the basis of industry, firm size, and/or location and to vary the sampling rates by stratum. For a new airport, high sampling rates may be desirable for shippers that are large, located relatively close to the airport, or ship and receive high-value goods that are relatively likely to go by air, with lower sampling rates used for other strata. Strata consisting solely of firms that are likely to make little or no use of the facility may be deleted from the survey, with usage by firms in these strata treated as being negligible.

For each stratum, a reasonably unbiased sample of firms should be selected; e.g., by enumerating all firms and selecting every *n*th firm. If the universe is large, it may not be practical to identify all small firms individually. However, for any individual stratum, some care should be taken to make sure that the percentage of firms sampled does not drop off as firm size (or shipment volume) declines or distance from the facility increases.

3. Prepare Survey Questions

The third step is to prepare the survey questions. These should include questions relating to: total volume of shipments originating and/or terminating in the area; the percentage likely to be shipped via the new facility; any effect the new facility is likely to have on shipment volume (induced demand); and identification of the decision-maker (shipper, receiver, or carrier) that would actually determine whether the facility is used. A question on the extent to which likely usage depends upon the level of carrier service should also be considered. Responses from those who are not decision-makers generally should be excluded from the analysis; however, responses from shippers and receivers that are not decision-makers should be used as proxies when the actual decision-maker is an out-of-area receiver or shipper.

The survey material should include appropriate information about the new facility, and shippers should be provided with a description of the level of carrier service expected at the facility.

Requested information may include:

- Company name and address;
- Type of facilities operated in study area (manufacturing, warehousing, etc.);
- Major commodities shipped and received;
- Total volume of shipments and receipts;
- Expected use of the new facility (volume by commodity);
- Effect of the new facility on routings of these shipments (e.g., Commodity A will be moved by truck from Plant B to the new facility instead of to Intermodal Facility C);
- Expected effect of the new facility on operations in the area; and
- Name and telephone number of the survey respondent.

The survey should be designed for clarity and to minimize the time and effort required by the respondents. Any major survey should be pretested on a small sample of respondents to identify wording that can be improved and areas where respondent burden can be reduced. An interview survey form used in a recent study of demand for a possible rail/truck intermodal facility is reproduced in Appendix D.

4. Conduct the Survey

The fourth step consists of the actual conduct of the survey. Although several options exist, a telephone/mail/telephone follow-up procedure usually produces a high response rate with a relatively moderate expenditure of resources. This procedure starts with an initial set of telephone calls to determine that each firm actually is a potential user of the new facility, to identify the most appropriate respondent within the firm, and to enlist that person's cooperation in responding to the survey. In the case of large firms, routing decisions may be handled at a headquarters office rather than at individual facilities in the study area. If a firm is not a potential user of the facility, no further questions need be asked, but the firm should be retained in the survey sample as representative of a number of firms in the same stratum that are not expected to use the facility.

The survey forms then are mailed to the participating firms and the firms are given two or three weeks to respond by mail. Additional telephone calls should be made to each firm that does not respond to encourage a response and possibly to obtain an oral response. The appropriateness of telephone responses will depend upon the specific questions asked and whether or not respondents are expected to review their records or perform any analysis before responding.

If telephone responses are allowed, firms that do not respond can be presumed to be relatively uninterested in the new facility and so can be presumed to make little or no use of it. Even if written responses are required, nonrespondents are likely to make less use of the new facility than respondents.

5. Estimate New Facility Use

The final step in the process is expanding the survey results to produce an estimate of total usage of the new facility by all potential users. A substantial amount of care is required in this step to avoid double-counting the responses.

For each stratum, total estimated usage by surveyed firms can be divided by the number of firms sampled (including non-respondents and firms that indicated that they would not use the facility) to obtain an estimate of usage per firm. If only written responses are used, some upward adjustment of this ratio is appropriate to allow for usage by non-respondents. The result is multiplied by the number of firms in the stratum to produce an estimate of total usage in the stratum. The use of this estimate presumes that the total number of firms in the stratum is known or has been reliably estimated and that the sample selected for the stratum was not biased toward higher volume shippers (e.g., by picking the most visible members of the stratum). Finally, the estimates of total usage by stratum are added across strata to produce an overall estimate of usage of the new facility.

In adding the estimates, some care will be required to determine that the shipper and carrier surveys produce complementary estimates of facility usage; i.e., that the former survey provides an estimate of usage for shipments whose routings are determined by the shipper while the latter survey provides a corresponding estimate for shipments routed by the carrier. A careful review of survey responses will be necessary to avoid such double-counting.

Another, but usually less important, source of potential double-counting occurs in the case of shipments that both originate and terminate in the study area. If both shippers and receivers of such shipments claim responsibility for routing decisions, double-counting will result.

The resulting estimate of new facility use will represent usage due to route diversion, mode diversion, and increased shipments to or from firms currently in the area. Shipments to or from firms that may be induced to move into the area by the new facility will not be explicitly represented in this estimate, but this effect is likely to be small.

A more significant issue is the extent to which use is overestimated as a result of exaggerated usage forecasts by respondents expecting to benefit from the new facility. Such exaggeration may take the form of carriers stating an unwarranted expectation of moving operations to the new facility and shippers overestimating expected increases in traffic volume (a natural occurrence even when there is no incentive to exaggerate). Satisfactory procedures do not exist for identifying such exaggeration and minimizing its effects on estimated usage of the new facility. The lack of such procedures limits the reliability of estimates produced by the survey approach.

4.4.2 Comparisons with Previous New Facilities

The comparison approach is a relatively attractive option, particularly in the early stages of the planning process. This procedure consists of:

1. Identifying similar facilities that have been developed recently;
2. Obtaining market share data for these facilities;
3. Adjusting these market shares so that they are applicable to the proposed new facility; and
4. Applying the adjusted market shares to forecast demand in the study area to produce a range of estimates of forecast usage of the new facility.

The comparison approach presumes that at least some new transportation facilities of the type under consideration have been developed in the recent past. If not, this approach cannot be used and, perhaps more importantly, careful consideration should be given to identifying and understanding the reasons why no such facilities have been developed.

1. Identify Recently Developed Facilities

The first step in the comparison process involves identifying other new transportation facilities of the types being considered that have been developed in the recent past (probably over the past 10 to 20 years), and selecting those facilities that are most similar to the facility being considered. Factors to be considered in evaluating the similarity of facilities include facility capacity, geographic size of the relevant market area, geographic density of freight generated in the area (measured in weight or volume units per square mile), types of freight originating and terminating in the area, and characteristics of the existing facilities with which the new facilities must compete. Since it is unlikely that there will be good matches for all these factors, a fairly generous standard of "similarity" should be used and, if possible, several similar "comparison" facilities should be identified.

2. Obtain Market Share Data

The second step in this process involves obtaining information about the shares of the relevant markets captured by the comparison facilities and the number of years required to attain that market share. This step entails the collection and interpretation of data and information from the operators of the comparison facilities. A useful adjunct to this activity would be to conduct more extensive discussions with the facility operators in order to gain additional insight into the facility planning and development processes.

At the conclusion of the second step, a very preliminary range of estimates of demand for the new facility should be developed by applying the market shares captured by each of the comparison facilities to the projected overall market in the area served by the new facility (see Section 4.2). These preliminary estimates may be useful in determining the level of effort to be expended on the remainder of the analysis and even whether any additional analysis is warranted.

3. Adjust Market Share Data

The third step involves a careful review of the differences between the market shares obtained by each of the comparison facilities and the market share likely to be obtained by the new facility. For each comparison facility, differences to be considered in this step include the following:

- **The Market Areas Served by the Two Facilities** – Do both market areas extend into the natural hinterlands of competing facilities to an equal extent; or is one market area limited to areas close to the new facility or to the comparison facility, while the other includes a substantial amount of area in which shipments generated are relatively unlikely to use the new facility or the comparison facility?

- **Commodity Mix** – Are the mixes of commodities shipped into and out of the two areas reasonably similar, or does one area have a commodity mix weighted more heavily toward commodities that are likely to be shipped via the facility in question than does the other area?

- **Service by Scheduled Carriers** – Are both facilities expected to receive the same level of service (quality and frequency) by scheduled air, water, or rail carriers, or is one likely to receive better service?

- **Competition from Existing Facilities.** – Are both the new facility and the comparison facility subject to the same degree of competition from other facilities with respect to proximity, facility capabilities and constraints (storage capacity, channel depth, runway lengths, etc.), level of service of scheduled carriers, etc.?

For each comparison facility, each of the differences relative to the proposed new facility should be analyzed. This analysis should be used as the basis for adjusting the comparison facility's market share to produce a market share that better represents the likely market share of the proposed new facility.

4. Produce Range of Usage Estimates for the New Facility

The result of the third step is a set of adjusted market shares, with one value derived from the original market share of each of the comparison facilities. The extensiveness of the adjustments that were made and the degree of judgment required for these adjustments will affect the relative reliability of each of the adjusted market shares. Any outliers that are considered to be relatively unreliable should be dropped, and the remaining values should be used to define a range of likely market shares for the proposed new facility. Applying this range of market shares to the projected overall market produces a revised range of estimates of demand for the new facility.

As described above, the analysis explicitly reflects the effects of route diversion and any mode diversion. It does not produce separate estimates of induced demand, nor is the projected overall market adjusted for any increase resulting from induced demand. However, because induced demand *is* included in data on usage of the comparison facilities, it is implicitly included in the market shares developed in Steps 2 and 3. Because induced demand is likely to be quite small in comparison to the overall market (which includes freight that continues to be shipped via competing facilities), the exclusion of induced demand from the projected overall market is likely to have only a small effect on the resulting estimates of demand for the new facility; a correction for this omission probably is not warranted.

Some operators of comparison facilities may have data that purports to represent the extent of induced demand attributable to the development of their facilities (which, presumably, could be used to infer induced demand at a similar new facility). However, substantial care should be exercised in accepting such data at face value - such data frequently attribute all traffic growth to the advent of the facility in question without attempting to exclude the effects of normal growth in the area's economy that would have occurred even if the facility were not developed.

4.4.3 Evaluating Proximity and Level of Service

Another relatively attractive option for estimating the demand for a new intermodal facility is to allocate the market between the new facility and competing local facilities based on the relative proximity and the relative levels of service expected to be provided at the various facilities. This procedure may be viewed as a variant of a gravity-model approach. One variant of this procedure is used in a case study presented in Section 1 of Appendix I. This procedure consists of the following:

1. Dividing the study area into subareas and forecasting the annual freight volume of interest originating or terminating in each subarea;
2. For each subarea, assigning a proximity score for each of the facilities;
3. Developing a set of level-of-service (LOS) scores for the new facility and for all competing facilities that serve the study area;
4. Combining the LOS and proximity scores;
5. For each subarea, allocating the Step 1 freight volumes across facilities; and
6. Adding the estimates of freight volume allocated to the new facility across all subareas to produce an overall estimate of usage.

1. Divide Study Area into Subareas

The first step in this procedure involves dividing the market area to be served by the new facility into subareas (e.g., counties or county aggregates) and forecasting the annual volume of the freight of interest originating or terminating in each of the subareas. Potential sources of base-year estimates include data from the Colography Group and Reebie

Associates (see Appendix C). (An example presented below describes the use of Colography Group data for analyzing demand for a new airport.) The base-year volume estimates may be used to distribute forecasts of the total volume of freight of interest across subareas; or, alternatively, forecasts of freight by subarea may be developed directly from the base-year estimates.

2. Assign Proximity Scores

In the second step of this proximity/LOS procedure, proximity scores are assigned to each subarea/facility pair. Each score should be based on the road distance from the facility to the approximate centroid of economic activity in the subarea (e.g., using highway mileage tables for household goods carriers). As an option, the distances may be adjusted to reflect transport costs, transit times, and transit-time reliability. A proximity score of 10.0 should be assigned whenever road distance or the adjusted road-distance-value is less than 50 miles; longer distances should produce lower scores.

Two suggested functions for converting distances to proximity scores are shown in Exhibit 4.2. The stepwise function[2] presumes a sharp break in the attractiveness function at 300 miles, while the continuous function assumes a more gradual decline in attractiveness with distance. (The continuous function is obtained by using a score of 10 for distances less than 100 miles, and by dividing 1,000 by the distance in miles for longer distances.)

3. Develop LOS Scores

The third step involves the development of forecasts of the relative levels of service expected at the new facility and at each of the existing facilities servicing the study area. A level of service (LOS) score of 10.0 should be assigned to the facility with the highest level of service. Each of the other facilities should be compared to this facility in terms of:

- Number of destinations or markets accessible via scheduled air, water or rail service from the facility (preferably weighted by the size of the destination market);

- Frequency of service to markets accessible via both facilities; and

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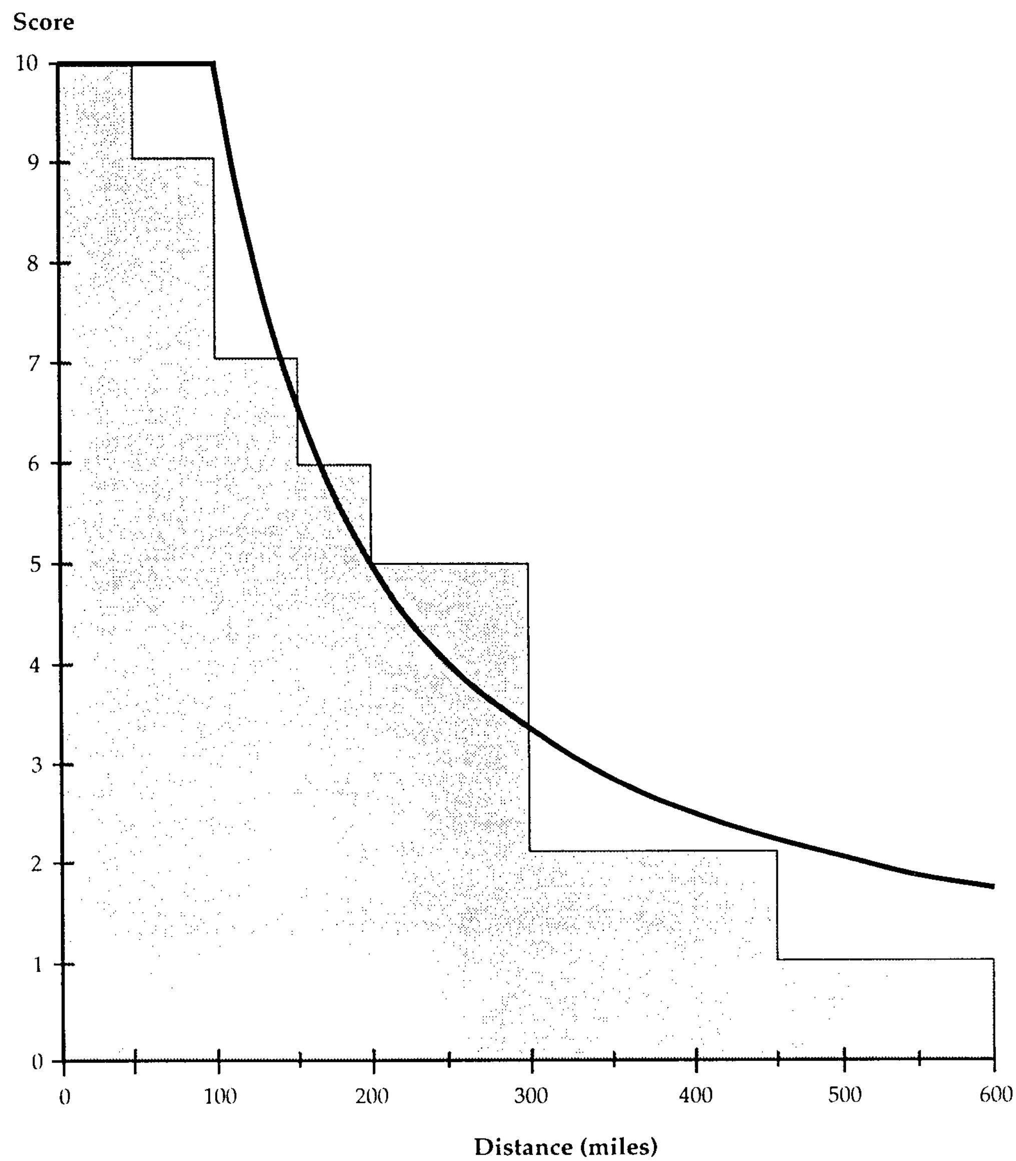
[2]The stepwise function was used in a study described in Section 1 of Appendix I. (Transportation Management Group, Inc., Leeper, Cambridge and Campbell, Inc., and COMSIS Corporation, *North Carolina Air Cargo System Plan and a Global Air Cargo Industrial Complex*, February 1992.) In the North Carolina study, the proximity and LOS scores were added (instead of being multiplied, as suggested in Step 4).

Exhibit 4.2 Suggested Proximity-Score Functions



- Any differences in carrier costs per unit of cargo for serving the two facilities (e.g., due to the higher cost per unit of cargo for using smaller vessels to serve low-volume markets or to access ports with limited channel depth).

These comparisons then should be used to assign LOS scores to each of the other facilities, with a LOS of 5.0 being assigned to a facility whose LOS, based on the above criteria, is half as good as that of the facility with the highest LOS. In many analyses, it may be desirable to assign separate sets of LOS scores for different types of traffic (e.g., domestic vs. international or short haul vs. long haul) and, in Step 1, to develop freight forecasts that are similarly disaggregated.

For the existing facilities, the LOS scores should be derived using information about current service available at the facility and any expected changes during the forecast period. For the new facility, it will be necessary to develop reasonable forecasts of the level of service that would be provided. It is important that these forecasts be reasonable because overestimating the level of service to be provided by the carriers will result in overestimating freight demand.

4. Combine LOS and Proximity Scores

The fourth step involves computing an overall score for each of the facilities being considered. One option is to obtain this score as the product of the LOS and proximity scores.

5. Allocate Freight Volumes Across Facilities

The fifth step involves allocating freight originating or terminating in each subarea among the competing facilities. For each subarea, this allocation should be proportional to the Step 4 scores (perhaps after eliminating facilities with very low scores).

6. Produce Overall Usage Estimate

The results of the fifth step then can be aggregated across all subareas of the study area to produce forecasts of the share of freight originating or terminating in the study area that would use each of the facilities serving this area. The resulting forecast of new facility usage represents usage due to route diversion, the primary source of usage. In some cases, a modest upward adjustment to this forecast may be made, on the basis of factors discussed previously, to reflect additional usage resulting from modal diversion and induced demand.

As described above, the study area will be a reasonable approximation to the entire area served by the new facility. However, it may exclude significant portions of the areas served by the competing facilities. Accordingly, the usage forecasts produced for those facilities will represent only a portion of their actual usage.

The LOS/Proximity Procedure: An Example

Consider a region consisting of five of the airport market areas (A, B, C, D and E) distinguished in Colography's *U.S. Air Freight Origin Statistics,*[3] and assume that the region is served by two airports. Further assume that the development of a third airport is being considered. Such an example is shown schematically in Exhibit 4.3.

The first step in the procedure is to forecast air cargo traffic originating and terminating in each market area for an appropriate forecast year. Colography data is used to obtain base-year air cargo traffic originating in each of the market areas for 73 manufacturing industries and for a 74th "all other" industry. Base-year air cargo terminating in the region is obtained from data on cargo received at the two existing airports and distributed across market areas in the same way as the originating traffic is distributed.

Forecasts are developed using one of the procedures presented in Chapter 3.0 (e.g., using economic indicator variables). The first column of Exhibit 4.4 shows an assumed forecast of total air cargo traffic originating and terminating in each market area. Total forecast-year traffic for all five regions is assumed to be 380,000 units. To simplify the example, we have chosen not to distinguish between originating and terminating traffic, although such a distinction usually would be made when developing an actual freight demand forecast. Also, any current or future usage of the three airports by traffic that does not originate or terminate in the study region has been ignored.

The second step of the procedure involves assigning a proximity score to each market area/airport pair. For each market area, the approximate centroid of air cargo generation (or, more simply, of manufacturing activity) is located, and the road distances to each of the three airports is obtained. These distances are shown in the last three columns of Exhibit 4.4.

The second part of Step 2 converts the Exhibit 4.3 distances to proximity scores. The scoring system used in this example is the stepwise function shown in Exhibit 4.2. The resulting proximity scores are shown in Exhibit 4.5.

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[3] The Colography Group, *U.S. Air Freight Origin Statistics,* Marietta, Georgia., annual. A one-page description of this data source is contained in Appendix C.

Exhibit 4.3 Study Region for Proximity/LOS Example

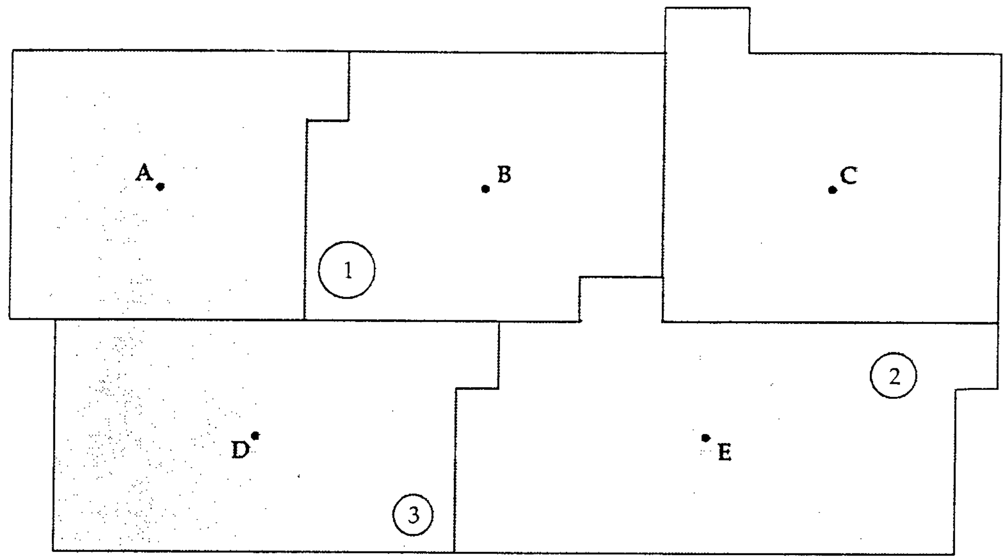

Exhibit 4.4 Distances and Traffic Volumes for Proximity/LOS Example

		Distance to Airport (Miles)		
Market Area	Annual Traffic	1	2	3
A	70,000	140	465	240
B	100,000	100	265	225
C	90,000	315	115	365
D	70,000	125	390	70
E	50,000	265	110	230
	380,000			

Exhibit 4.5 Overall Scores for Proximity/LOS Example

	Airport			
Market Area	1	2	3	Total
A	70	6	25	101
B	90	30	25	145
C	20	42	10	72
D	70	12	45	127
E	50	42	25	117

The third step consists of assigning LOS scores to each facility. A score of 10 is assigned to the facility that is expected to have the best service in the forecast year, assumed to be Airport 1, and proportionately lower scores are assigned to the other facilities. This scoring is necessarily subjective, combining easily quantified measures (number of flights per week, number of destinations served, etc.) with more qualitative ones (relative importance of the destinations served, schedule characteristics, etc.). The scores should reflect attractiveness to the "typical" shipper, recognizing that different shippers are likely to be interested in different destinations and may have other unique service requirements. In the example, Airport 2 is assumed to warrant a LOS score of 6.0; and forecast service at the new airport, Airport 3, is assumed to warrant a score of 5.0.

In Step 4, overall scores are computed for each market area/airport pair by multiplying the proximity scores by the LOS scores. The resulting overall scores are shown in Exhibit 4.5. Also, for each market area, the last column of this exhibit shows the sum of the three separate market area/airport scores.

In the fifth step, the Step 1 forecast freight volumes for each market area are allocated across airports on the basis of the overall market area/airport scores. The fraction of Area A air cargo shipped via Airport 1 is obtained by dividing 70 (from Exhibit 4.5, Column 1) by 101; and the forecast volume of such freight is obtained by multiplying this fraction by 70,000 units. The results of this step are shown in Exhibit 4.6.

The final step consists of obtaining forecasts of the total volume of air cargo shipped via each of the three airports by adding the volumes originating and terminating in each of the five market areas. These forecasts are shown at the bottom of Exhibit 4.6.

Exhibit 4.6 Proximity/LOS Sample – Forecasts of Annual Traffic

	Airport		
Market Area	1	2	3
A	48,515	4,158	17,327
B	62,069	20,690	17,241
C	25,000	52,500	12,500
D	38,583	6,614	24,803
E	21,368	17,949	10,684
Total	195,534	101,911	82,555

Additional Discussion

The proximity/LOS procedure can be modified to consider a more extended study area that includes most or all of the area served by all the facilities under consideration. If this is done, then, with one additional step, usage forecasts can be produced for all the facilities studied. The extra step involves adjustments for a small amount of freight "leaking" into or out of the study area; i.e., out-of-area freight that is shipped via one of the facilities studied, and study area freight shipped via a competing facility that is not studied. In the case study presented in Appendix I, this modified procedure was used – the study area was taken to be the entire state of North Carolina plus selected counties in adjoining states, and freight forecasts were developed for each of the state's three major airports both with and without the addition of a proposed new all-cargo airport.

Another advantage of an extended study area, as suggested in the preceding paragraph, is that it permits the allocation system to be calibrated using data from a recent year. The calibration process involves performing Steps 1 through 5 using data for the base year and comparing the resulting allocation of freight among the existing facilities to the known freight volumes in that year. The judgmentally derived scoring system used in Steps 2 through 4 then is reviewed and modified to improve the match between the allocations produced by the procedure and actual freight volumes. This optional calibration step (used in the Appendix I case study) reduces the role of judgment and should improve the quality of the forecasts produced. However, judgment will still play a critical role in forecasting the level of service to be provided at the new facility.

Once the analysis has been completed, a review should be conducted to determine whether the Step 6 forecast of usage of the new facility justifies the level of service assumed in Step 3. This review may make use of information about service provided at existing facilities with similar levels of usage. If the assumed level of service is higher than justified, it is unlikely to materialize, and actual usage would be lower than the forecast indicates. In this situation, two analytic alternatives exist.

The first alternative involves repeating Steps 3 through 6 using a lower LOS for the new facility. Because a lower LOS will produce a lower usage forecast, some experimentation may be necessary to determine the extent to which the LOS must be reduced to obtain an assumed LOS that is justified by the forecast usage of the facility.

The second alternative is simply to accept, without further experimentation, the provisional conclusion that demand for the new facility is likely to be insufficient to attract the kind of service that would be necessary to make the facility viable.

4.4.4 Analyzing Total Logistics Costs of Individual Shipments

The fourth procedure is the most disaggregate and the most difficult to implement. This procedure consists of the following:

1. Selecting a representative sample of shipments originating or terminating in the study area;

2. Estimating the total logistics costs for each of these shipments if shipped via its current route and if shipped via the new facility;

3. Determining the likelihood that the shipment would be diverted to go via the new facility; and

4. Expanding the Step 3 results obtained for the sample of shipments to represent the universe of shipments originating or terminating in the study area.

1. Select a Sample of Shipments

The first step consists of selecting a sample of shipments originating or terminating in the study area. This sample usually is stratified by commodity, and may be stratified by other variables as well (e.g., by current modes used, by whether the shipment originates or terminates in the area, by subarea of origin or destination, etc.). An important consideration in constructing the sample is that it include a reasonable number of shipments representing each of the strata that are likely to contribute any significant amount of usage to the new facility.

2. Estimate Total Logistics Costs

The second, and most difficult, step involves estimating the total logistics costs (TLC) for each shipment if transported via the new facility and if transported via its current route. A slightly simpler alternative is to focus on estimating the differences between these two TLC values. When only route diversion is involved, the principal potential contributors to this difference are:

a. Transport cost differences resulting from differences in the length of haul required by any one mode;

b. Transport cost differences resulting from differences in the efficiency with which the two facilities can be served (e.g., as a result of differences in vessel sizes); and

c. Differences in transit times and transit time reliability resulting from differences in scheduled service at the two facilities.

Estimates of transport cost differences resulting from differences in the length of haul or service efficiency can be developed using estimates of length of haul along with transport cost information presented and referenced in Appendix F. Estimates of differences related to scheduled service at the two facilities require forecasts of differences in the level of service offered by carriers serving the two facilities as well as commodity-specific information about inventory costs and stock-out costs. For many shipments, the relative values of the two estimates of TLC will be significantly affected by the quality of service forecast for the new facility. The difficulty of developing a reliable forecast of quality of service, combined with the effort required to perform the rest of the Step 2 analysis, generally makes this procedure less attractive than the others.

3. Estimate Potential Diversion to New Facility

The third step consists of estimating the likelihood that the shipment would be diverted to make use of the new facility. The simplest alternative for this step is to assume that the alternative with the lower estimated TLC will be selected. A more complex and somewhat more reliable alternative is to use a logit formulation[4] to assign shipment shares to the two alternatives, allowing for the effects of random errors in the TLC estimates and in the shippers' perception of TLC, and allowing for the effects of random imperfections in carrier pricing.

4. Develop Total Usage Forecast

The final step consists of expanding the estimates of usage of the new facility by shipments in the sample to represent a total usage forecast for the facility. This step simply entails dividing the results for each stratum by the sampling rate (expressed as a fraction) and summing across all strata. The result represents usage of the facility as a result of route diversion and (if considered in Step 2) modal diversion.

As in the case of the preceding procedure, it is recommended that the Step 4 estimates of facility usage be evaluated to determine whether they are consistent with the level-of-service assumptions made for the new facility. If estimated facility usage appears to be inadequate to justify the assumed level of service, the analysis should be repeated, assuming a lower level of service at the new facility.

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[4] E.g., see Thomas A. Domencich and Daniel McFadden, *Urban Travel Demand: A Behavioral Analysis*, American Elsevier Publishing Company, New York, NY, 1975.

■ 4.5 Alternative Futures

As the preceding discussion indicates, the private sector decisions that determine demand for a transportation facility are more difficult to forecast in the case of new facilities than in the case of existing or replacement facilities. Consequently, a careful evaluation of the effect of alternative futures on the need for and likely success of a facility is even more important in the case of new facilities than in the case of existing facilities.

Procedures for performing such an evaluation are presented in Section 3.5. These procedures apply to new facilities as well as to existing facilities. However, in the case of a new facility, there are certain alternatives that must be given careful attention. The most important of these alternatives is the possibility that one or more carriers or other expected major users of the facility will make substantially less use of the facility than anticipated. The circumstances under which such reduced use may occur should be carefully evaluated, and the sponsors of a new facility should determine in advance how they would deal with such a possibility.

If a survey procedure is used, the best method of performing the alternative futures analysis requires some careful consideration. Ideally, this analysis would be incorporated directly into the survey (e.g., by adding questions relating to the effect of alternative levels of service on usage), but any such additional questions must be handled with care to avoid overburdening respondents and reducing their level of cooperation.

A-2: Freight Demand Forecasting Studies

Appendix A-2: Review of Freight Demand Forecasting Studies

(from NCHRP 8-30 Interim Report)

Guidebook for Comprehensive Freight Planning: Four Step Urban Planning Approach Applied to Freight Planning

Frederick Memmott, Roger Creighton Associates, *Application of Freight Demand Forecasting Techniques*, National Cooperative Highway Research Program, Report No. 260, 1983.

This NCHRP Report presents a methodology for states to use in conducting freight studies to be used to meet a wide range of needs including: facility, service, or regulatory problems; state policies toward infrastructure investment, energy use, life cycle costs; and freight components of statewide master plans. It appears to be the most recent and comprehensive effort to assist states with freight demand forecasting. As such, it is very relevant for our current study. It would be useful to have more information on how this report has been used by states. The report, itself, includes several prototypes of how the procedures suggested can be implemented to solve practical transportation questions. It would be relevant to determine how many additional applications resulted from the suggested procedures. It would also to know if the outlined procedures have been updated or whether such an updating is a desired output of the current NCHRP effort.

This report provides a user manual of the three steps involved in freight forecasting. These steps are borrowed from the urban transportation passenger travel forecasting model. They include: freight generation and distribution; mode choice; and traffic/route assignment. Each of these components is described in detail in a separate chapter of the study. There is a complete reporting of the state-of-the-art developments in each component. Specific references are provided for each of the individual model components. There is a description of how to accomplish each component of the model regardless of the type of data that are available for the state. The first step in the freight planning process is freight traffic generation and distribution. This involves estimating current volumes of traffic and flows of different types of traffic between specific origins and destinations.

Accordingly, a base case commodity flow matrix is developed. This is used as the basis for making projections and future year commodity flow matrices. A variety of options are available to move from the base year to the future year matrix. One is to project future traffic flow directly from the base year matrix. A second is to project commodity production and consumption on an individual commodity basis and adjust the commodity flow matrix accordingly. A third is to forecast macro-economic indicators and adjust the base year commodity flow matrices.

The next step is modal division, i.e., splitting commodity movements among competing modes. Again, a variety of options are available to accomplish a modal division. Modal cost and rate comparisons can be developed and employed as the basis for splitting the traffic. The comparisons of modes can also be made from the perspective of shipper logistics. The author provides some detail regarding the available methods for costing of the services of different modes.

While claiming to be a user's manual, the study appears more like a catalog of state-of-the-art developments in freight forecasting. It seems clear that any state wanting to initiate a specific freight study using this report would still need the services of an outside consultant to link the individual components in a comprehensive fashion. There are a lot of individual pieces and good advice about the relevant ones depending on the specific circumstances, but insufficient guidance on the linkage across components or the development of an integrated package.

This is not a user-friendly, how-to integrated freight package.

Guidebook for Comprehensive Freight Planning: Four Step Urban Planning Approach Applied to Freight Planning

Frederick W. Memmott and Russell H. Boekenkroeger, "Practical Methodology for Freight Forecasting," *Transportation Research Record*, No. 889, 1982, pp. 1-7.

The authors present a straightforward procedure for freight forecasting. This is a more condensed format of the methodology and approach outlined in NCHRP Report No. 260.

It is driven by a base case commodity flow matrix. Added onto this are cost and rate data for the individual transportation modes. The heart of the model lies in a series of basic cost and revenue relations or estimating equations – one applicable for each commodity-flow/routing possibility.

In summary, this provides a fairly simple, yet practical method for freight forecasting. The authors note that current techniques for modal choice forecasting remain very elementary and are not yet suited for inclusion in freight forecasting models.

Application of Four Step Urban Planning Model Approach to Freight Planning

John Kim and Jere J. Hinkle, "Model for Statewide Freight Transportation Planning," *Transportation Research Record*, No. 889, 1982, pp. 15-19.

The authors employ the standard urban transportation modeling process to the freight area. That process involves essentially four steps: trip generation (total volumes), trip distribution (origin-destination commodity flows), modal split, and route assignment.

The authors don't provide details beyond a general sketch of how the elements of the urban transportation modeling process can be adapted to the freight modeling situation.

Kurth, *et al.*, *A Research Process for Developing a Statewide Multimodal Transportation Forecasting Model*, prepared by Barton-Aschman Associates, for the New Mexico State Highway and Transportation Department, Santa Fe, August 1991.

This report presents the results of a two-day, April 1991, workshop intended as the first phase of an effort to produce a statewide multimodal forecasting model. The workshop produced a proposal for an effort that would focus on producing an intercity passenger model and a goods movement model. The latter was envisioned as a three-stage model consisting of: commodity generation; commodity distribution and mode choice (combined); and assignment. New Mexico subsequently provided Barton-Aschman with funds to begin development of this model; however, this effort has since been placed on hold, and no further reports have been issued.

Trip Generation and Trip Distribution: Forecasts of O-D Freight Flows Using Various Macro-Growth and Micro-Production Models.

David P. Middendorf, Mark Jelavich, and Raymond H. Ellis, "Development and Application of Statewide, Multimodal Freight Forecasting Procedures for Florida," *Transportation Research Record*, No. 889, 1982, pp. 7-14.

Beginning with base year freight origin-destination volumes by type of commodity, information from input-output models, forecasted personal income, forecasted industry earnings, in combination, are used to give commodity consumption growth and production growth. These growth projections are combined with the base year tables to give projected origin-destination volumes by type of commodity.

The authors also indicate that efforts to develop a modal split model through a logit formulation were unsuccessful. The difficulties associated with development of a modern discrete choice modal split model seems to be a common observation across a number of these studies.

Jack Faucett Associates, Inc., *California Freight Energy Demand Model*, California Energy Commission, 1983.

Weinblatt, "The California Freight Energy Demand Model," *Transportation Research Record*, No. 935, 1983, pp. 26-32.

The California Freight Energy Demand (CALFED) Model uses estimates of base-year truck stock and rail freight and truck activity in five regions of California and forecasts of changes in California production and employment by sector to produce forecasts of changes in truck stock and rail freight and truck activity. Truck activity is estimated by vehicle size class and trailer/body type for freight and non-freight purposes (combined). Rail freight activity is estimated for trailer-on-flatcar service and seven types of carload freight. Diversion of nonlocal freight between truck and rail is estimated using forecast changes in relative costs and pseudo-elasticities for ten commodity groups using aggregate data from the 1977 Commodity Transportation Survey and from other sources. The disaggregate forecasts of truck and rail activity and truck stock are combined with exogenous forecasts of fuel efficiency and fuel prices by fuel type to produce forecasts of truck and rail freight energy demand.

Forecasts of O-D Flows Based on Input-Output Models

Treyz, B. Stevens, and D. Ehrlich, *A State Core Forecasting and Policy Simulation Model*, NCHRP Project 8-15A, Handbook 2, Regional Science Research Institute, July 1982.

This is the second of two handbooks produced to facilitate use of input-output models by state transportation planners. In this part of the study, more attention is placed on using IO as a forecasting and policy simulation model (FPSM). In addition to its potential usefulness in assessing the economic impacts of transportation investment, these techniques could also be used to assess the effects of transportation policies such as an additional tax on motor fuel. Computer programs were also supplied with the handbook. In this regard, the results could fit with a comprehensive structural approach to forecasting impacts of policy changes. However, it appears that these input-output models have been little used for actual state planning activities.

Jack Faucett Associates, *The Department of Transportation Long-Range Forecast Model*, U.S. Department of Transportation, Office of the Secretary, January 1980.

The Department of Transportation Long-Range Forecast Model consists of an input-output model (the INFORUM model of the University of Maryland) and a transportation submodel, with detail for 31 commercial and private transportation modes. The submodel calculates output levels for the transportation modes consistent with the economic projects and industrial detail from the main model.

The transportation submodel distinguishes six major modes for transporting domestic intercity freight (rail, commercial and private trucking, inland and coastal water, and petroleum pipelines). A modal split model incorporating own and cross-price elasticities is used to estimate modal diversion among the first four of these modes (rail, inland water, and the two truck modes) resulting from changes in modal costs. Other modes distinguished include air freight, international water freight, commercial and private local trucking (separately), non-freight trucking, government trucking, and transportation services and warehousing. Total freight traffic is estimated separately for 48 commodity groups using INFORUM forecasts, with additional analyses performed for grain, coal, crude oil, and petroleum products.

Passenger transportation forecasts are exogenous and are specified as inputs to the transportation submodel. The transportation submodel also calculates input requirements for each transportation mode, including detailed inputs of fuels.

Forecasts of O-D Flows Based on Reebie and Rail Waybill Data

Eusebio and S. Rindom, *Interstate Movements of Manufactured Goods in Kansas*, Kansas Department of Transportation, May 1991.

This study was done for the purpose of determining the flow of manufactured goods between Kansas and various origins/destinations, and also to determine the flows of goods moving by rail and truck. The Reebie Associates Transearch data base was used for truck data, while the ICC Waybill tape was used to obtain rail data. The bulk of the report is a series of 57 tables noting various commodity flows. This type of state study points to the value of providing better access to the states for rail and truck flows data.

Trip Generation and Trip Distribution Forecasts Based on Linear Programming Models

Mary Marchant, "Analysis of the Effects of Rising Transportation Costs on California's Fresh Fruit and Vegetable Markets," *Journal of the Transportation Research Forum*, Vol. XXXII, No. 1, 1991, pp. 17-32.

This article looks at a linear programming model to allocate freight (i.e., competitive agricultural crops) among several producing regions and various markets in order to minimize total costs (the sum of production and transportation costs) subject to various production and consumption constraints. In particular, the model analyzes the impact of rising transportation costs (from increased fuel prices) on California's produce market share. The analysis suggests the complexity of analyzing impacts of factors such as changing fuel costs on freight traffic flows.

The implication of this type of study is that freight allocation models could go beyond taking a base set of freight flows adjusting for prospective changes in the economy and changes in modal split to utilizing an input-output framework and incorporating changes in shipping patterns as this study has done for produce.

Trip Generation/Trip Distribution: Linear Programming and Network Approach

Michael Florian and Teodor Crainic, editors, *Strategic Planning of Freight Transportation in Brazil: Methodology and Applications*, University of Montreal, July 1989.

This study lays out a comprehensive network modeling approach toward strategic planning for freight transport services. Network model methods are used to simulate flows, service levels, and costs for alternative modes. The models used are multi-product, multi-commodity network flow problems. The transportation system is specified in terms of links and nodes with given capacities among them. Added to this are data on service and cost characteristics of each mode as well as origin to destination demands for products.

The output of the model are flows on a particular mode between a particular origin and destination on the network. The study provides detailed analytical procedures and applications in the Brazilian context. This type of methodology is quite complex and may be extremely difficult to transport to other regions/nations. It was designed specifically to use available data from Brazil.

Trip Generation/Trip Distribution: Linear Programming and Network Approach

Jacques Guelat, Michael Florian and Teodor Crainic, "A Multimode Multiproduct Network Assignment Model for Strategic Planning of Freight Flows," *Transportation Science*, Vol. 24, No. 1, February 1990, pp. 25-39.

This provides a journal-length description of the full study discussed above. The authors point out that previous uses of network models have been confined mainly to urban transportation studies for prediction of passenger transportation flows within an urban area. Less attention has been given to the freight flow problem as a result of the inherent complexities of freight transportation.

Spatial price equilibrium models have been previously used for predicting inter-regional freight flows. This study uses network models. One aspect of this network model which differs from previous work is that individual shippers and carriers are not identified explicitly. This type of approach is more appropriate for strategic planning at a national level.

This article provides a good review of network models and their use in freight planning applications. From a network modeling standpoint, there are a number of technical innovations associated with the Brazilian project.

Trip Generation/Trip Distribution: Combination of Approaches –Manufacturing Data, Network Modeling

Black and J. Palmer, *Transport Flows in the State of Indiana: Commodity Database Development and Traffic Assignment Phase I*, Transportation Research Center, Indiana University, February 1993.

This study is one of the most sophisticated modeling exercises done by or for state transportation departments. The purpose is to produce an extensive analysis of key rail and highway flows in the state of Indiana. Network models are used, drawing from the FHWA highway network model and the Census TIGER files. Data was drawn from the ICC Waybill tapes, energy data bases, grain flow data and the now somewhat dated 1987 Census of Manufacturing tapes. One use of the study is to designate key highway corridors for upgrading and maintenance. Indiana is continuing with follow-up studies for more accurate determination of traffic flows. This study suggests that national freight data, made more readily available to the states, would be of use in such studies. In particular, truck flow data is very critical for planning purposes and difficult to obtain. It also points to the potential usefulness of updated and more readily available rail and highway network models. It should be noted that this study did not involve forecasts of future flows, but only determination of current flows.

Trip Generation and Trip Distribution: A Survey of Methods Used to Predict Future Trends

David V. Grier and L. Leigh Skaggs, *A Review of 16 Planning and Forecast Methodologies Used in U.S. Army Corps of Engineers Inland Navigation Studies,* U.S. Army Corps of Engineers, Water Resources Support Center, Institute for Water Resources, Fort Belvoir, Virginia, June 1992.

The projection methodologies of the 16 studies reviewed as part of this effort fall into four broad groups: (1) the application of independently derived commodity-specific annual growth rates to base year traffic levels; (2) shipper surveys of existing and potential waterway users to determine future plans to ship by barge; (3) statistical analysis using regression and correlation to predict future waterborne traffic based on independent economic variables; and (4) a detailed long-range commodity supply-demand and modal split analysis incorporating the production and consumption patterns of individual economic regions within the waterway hinterland.

The basic focus of these studies is the prediction of traffic on all, or a portion, of the inland waterway system. As such the studies lack the comprehensiveness of the integrated structured approach outlined in the Statewide Demand Forecasting study.

The authors ask the question: "What is the best kind of method" for forecasting inland waterway traffic. The authors set some assessment criteria: the most practical methodology appears to be one that uses a consistent set of macroeconomic assumptions in generating international, national, and regional level projections. Methodology should be easily updatable based on latest historic and forecast data, be relatively low-cost for the project manager to implement, and be PC-based.

The authors find that "the methodology incorporating commodity-specific growth rates applied to one or more base year traffic levels appears to best meet the established criteria." In contrast, methods which rely on shipper surveys tend to build in an optimistic bias and do not sufficiently address long-term forecast issues. Statistically based regression and correlation methods inherently assume a continuation of past trends. Finally, a long-term evaluation of regional market demands, resource bases, production levels and transportation modes, while detailed, extensive and methodologically defensible – is unfortunately the type of massive forecasting effort that is not easily updated and may be impractical for smaller planning staffs.

Unfortunately, these commodity-specific top-down growth rate projections are often too general to be disaggregated to the local level without a serious loss of reliability. However, the authors believe that this forecast method can be used to provide a consistent national framework that can be refined in a project level analysis by planners equipped with knowledge of local industry, markets and transportation patterns.

Sources of Truck Data for Determining Trip Generation/Trip Distribution

Hu, T. Wright, S. Miaou, D. Beal, and S. Davis, *Estimating Commercial Truck VMT of Interstate Motor Carriers: Data Evaluation,* Oak Ridge National Laboratory Report, November 1989.

Data availability is a key issue for freight forecasters, and this report provides information about a number of data sources for commercial trucks:

- Truck Inventory and Use Survey from the Bureau of the Census

- Nationwide Truck Activity and Commodity Survey from the Bureau of the Census

- National Truck Trip Information survey from the University of Michigan Transportation Research Institute

- Highway Performance Monitoring System form the FHWA

- State fuel tax reports from each individual state and the International Fuel Tax Agreement

- International Registration Plan of the American Association of Motor Vehicle Administrators.

This report evaluates each of these data sources in subsequent chapters, with particular attention to the ability of each source to estimate vehicle miles of travel by carrier type and by state. This type of data is useful for determining accident rates, highway investment needs, and economic impacts of FHWA policies. The report would also be useful for anyone seeking further details on truck data sources.

Aggregate Approach Mode-Split/Mode Choice Model: Aggregate Approach

Michael W. Babcock and H. Wade German, "Changing Determinants of Truck-Rail Market Shares, *Logistics and Transportation Review*, Vol 25, No. 3 (1989), pp. 251-270.

This analysis provides an equation to estimate rail market share as a function of rail/truck rate and service comparisons, macro-economic interest rates, and a time trend variable. The equation is estimated separately for a pre- and post-1980 time period.

There is an equation to estimate rail market share in each two-digit STCC classification aggregate annually for the entire United States. While data are available on rail tonnage by commodity, truck tonnage, and, therefore, gains or losses in traffic, is imputed by comparing rail tonnage with total industrial production.

The authors rely on time dummy variables to estimate the effects of such factors as a shift to just-in-time production, changing oil prices, and changes in size and weight regulations on market share changes between rail and truck. The single time dummy variables does not allow the researcher to untangle or to measure explicitly the impact of each of these factors individually in the model.

This technique provides a rough, aggregate measure of changes in market share between rail and truck. It deals only with some broad, overall measures and provides little insight into the incremental contribution of specific factors. Furthermore, the broad product categories employed make mask many differences that exist in each of the disaggregated product categories.

Freight Demand/Mode Split Estimation Based on Aggregate Commodity Data

Ann F. Friedlaender and Richard H. Spady, "A Derived Demand Function for Freight Transportation," *Review of Economic and Statistics*, Vol. 16 (1980), pp. 432-441.

This article develops improved estimations of freight demand. One improvement is explicitly treating transportation as an input in the production process and using Sheppard's Lemma, deriving transportation demand functions from initial cost equations. The empirical work also takes into account the interdependence of rates and service characteristics. Freight demand equations are estimated using a cross-section of 96 three-digit Standard Transportation Commodity Code industries. This methodology can be used to derive estimates of modal spilt and effects of policy changes on the demand for rail and truck services.

Aggregate Mode Shift Models: Explanation of Traffic Shifts Among Modes Due to Productivity Changes

Martha B. Lawrence and Richard G. Sharp, "Freight Transportation Productivity in the 1980s: A Retrospective," *Journal of the Transportation Research Forum*, Vol. XXXII, No. 1, 1991, pp. 158-171.

Authors assess general issues relating to productivity growth in the transportation sector during the 1980s. Authors advocate use of the total factor productivity (TFP) techniques in order to improve comprehensiveness and eliminate biases from single factor productivity measures. Authors generally criticize a number of productivity studies because of an undue reliance on financial indicators as a substitute for physical productivity measures and inadequate controls for changes in output mix.

Perhaps the most relevant section for our purposes is one on productivity and traffic shifts between modes. The authors cite data on the continued loss of market share to motor carriers in the 1980s and its effects on overall productivity changes.

The authors also highlight the importance of service advantages of trucks arguing that trucks provide a fundamentally different type of service from rail. Trucks offer service ubiquity, freedom from sunk cost facility commitments, and adaptability to smaller units of shipment. Accordingly, mode choice studies must go beyond the traditional service characteristics of transit time and variation and rates in modeling shipper choice.

Aggregate and Disaggregate Freight Demand Models: Survey of Previous Efforts and Prospect of Combining Approaches

Clifford Winston, "The Demand for Freight Transportation: Models and Applications," *Transportation Research*, Vol. 17A, No. 6, (1983) pp. 419-427.

This review article classifies freight demand models as being aggregate (where the unit of observation is the aggregate share of a particular mode in a broad product and geographic market) or disaggregate (where the unit of observation is an individual shipper or shipment). While Winston argues that disaggregate models are more attractive from a theoretical viewpoint since they can be derived from cost-minimizing behavior by firms, he also notes that some of the more recent aggregate models have also been derived from firm cost-minimizing behavior and, therefore, have a stronger theoretical basis.

The Oum and Freidlaender and Spady models, estimated from aggregate data, might be more useful in the analysis of freight flows for policy analysis or practical prediction in the context of large, scale regional or national studies.

Two types of disaggregate freight demand models have been developed: behavioral and inventory. The behavioral models take the perspective of the physical distribution manager in making mode choice decisions to maximize utility with respect to expense and service. Typically, a random utility model is used with discrete choice estimation tools. Inventory-based models analyze freight demand from the perspective of an inventory manager in an attempt to integrate the mode choice and production decisions.

The article discusses a number of applications of freight demand models, including intermodal competition, regulatory analysis, and forecasting of freight flows. Most relevant for this project is the latter application. Previous attempts to forecast freight flows have used techniques such as input-output and regional flow models, but have not combined these techniques with a realistic freight demand model. It is Winston's opinion that the combination of a forecasting system with a realistic freight demand model imbedded into it could contribute significantly to the accuracy of freight flow forecasts.

Thomas L. Zlatoper and Ziona Austrian, "Freight Transportation Demand: A Survey of Recent Econometric Studies," *Transportation*, Vol. 16 (1989), pp. 27-46.

This paper surveys econometric studies of freight transportation demand published between the mid-1970s and the mid-1980s. It describes the variables, data sources, and estimation procedures utilized by the studies. In addition, it summarizes their statistical results. The studies included in this survey typically accounted for freight rates and service characteristics (e.g., transit time and reliability). Data sources often varied across the studies.

Based on the data they utilized, the surveyed studies are classified as either aggregate or disaggregate.The data in the aggregate studies consist of informatin on total flows by modes at the regional or national level, while the data in the disaggregate studies pertain to individual shipments. The earlier aggregate studies estimated linear logit models. It has been pointed out that when they are estimated on aggregate data, these models are subject to certain shortcomings. To avoid these shortcomings, more recent aggregate studies have estimated flexible forms such as translog functions. The disaggregate studies surveyed in this paper used either logit or probit models.

Statistical results often varied with the commodities analyzed, making it somewhat difficult to generalize the findings of the different studies. One finding common to several studies reviewed is that freight rates have a significant impact on shipment decisions. Certain theoretical and empirical limitations of the surveyed studies are discussed; and suggestions for future research in freight transport demand are offered.

Mode-Split/Mode Choice Models: Discrete Individual Shipper Choice

R. Wilson, B. G. Bisson, and K. B. Kobia, "Factors That Determine Mode Choice in the Transportation of General Freight," *Transportation Research Record 1061*, 1986, pp. 25-31.

This study relies on data collected from a survey of manufacturers regarding their modal selection and shipment characteristics. It uses the survey data in a linear logit model to determine the variables that influence the selection of the various modes and the relationship between each mode and the explanatory variables. Shippers are asked to state their preferred shipping mode for their main product over their primary origin-destination link.

The modal choice explanatory variables are divided into the following categories: characteristics of the transportation system; characteristics of the shipment; characteristics of the carriers; and characteristics of the shipper. The model has quite a comprehensive set of considerations as explanatory models.

The model has most relevance for predicting how an individual shipper might select a particular model based on shipment characteristics as well as firm characteristics (such as firm size, volume of business). The model would not be appropriate if the researcher were attempting to look at overall shipment levels and model uses. However, the model does suggest that a number of quite detailed individual firm characteristics do influence the selection of mode.

Mode-Split/Mode Choice Model: Discrete Individual Shipper Choice

Narasimha Murthy and B. Ashtakala, "Modal Split Analysis Using Logit Models," *Journal of Transportation Engineering*, Vol. 113, No. 5, September 1987.

Extensive survey of over 7,000 shippers in Alberta, Canada used to develop a cross-classification table looking at modal split as a function of the following variables: shipment size; full load vs. less-than-full load; private or for-hire transportation; control over mode choice; and type of commodity.

This cross-classification table provides the input for a multi-way contingency analysis (logit analysis) specifying the relationship between each of the variables, by itself and interacting with the other variables, and mode split.

The coefficients developed in the model can be employed to predict modal shares under a variety of scenarios regarding each of the analysis variables. However, it should be noted that the model gives no consideration to modal rate or service comparisons. Thus, the model could not be used to analyze how modal shares would change based on relative rate and service changes in the various modes. This would be a serious drawback for many of the uses of the model contemplated by policy makers.

Saleh Ali and Yorgos J. Stephanedes, "Policy-Sensitive Disaggregate Techniques for Estimating Freight Highway and Rail Use," *Journal of the Transportation Research Forum*, Vol. XXV, No. 1, 1984, pp. 155-164.

The authors develop a mode split model based on data from Midwest grain elevators. One of the main variables included in the model was rate information. Truck rates were considered as a function of distance, while rail rates were considered as a function of shipment size and distance. The authors also included transit times for rail and truck and service time availability (i.e., the time between the equipment is ordered by the shipper and the time it is received at the grain elevator). Further, the authors include a measure of transit time variability in their model.

Results indicate that the freight rate and service availability time were the most significant determinants of modal decisions.

Vivien P. Jeffs and Peter J. Hills, "Determinants of Modal Choice in Freight Transport: A Case Study," *Transportation*, Vol. 17, 1990, pp. 29-47.

Authors surveyed a number of organizations with regard to the following variables which influence the modal choice at the firm level: customer-requirements; product characteristics; company structure/organization; government interventions; available transport facilities; and perceptions of the decision maker in the firm. The authors argue that it is the interactions and inter-relationships among these variables that influence the modal split. Thus, the relevant focus of modal split analysis should be on the firm and its characteristics.

The authors support their viewpoint with a survey of firms in England in the paper, printing, and publishing sector. They rely on factor analysis to show that many of the individual items discussed above interact to influence mode choice.

The main contribution of the paper is the viewpoint that modal choice is influenced by a large variety of characteristics of the firm, including ones that are individual firm-specific. For example, the urgency of delivery as well as the timing of delivery are factors that could be relevant in developing some inferences on the just-in-time trends that are becoming so important in our economy.

While showing that many of these firm-specific factors are important, this paper provides no explicit framework for entering these considerations into a modal choice model.

However, this methodology (i.e., survey shippers about their modal choices and influencing factors) could be employed to analyze the impact of future policy decisions and freight trends. For example, the impact of restricting truck access during peak hours could be analyzed through such an approach.

Pike, *Major Factors Influencing Modal Choice in the UK Freight Market*, Transport Operations Research Group, University of Newcastle upon Tyne, Department of Civil Engineering, December 1982, National Technical Information System.

The basic source of information for this study was information from ten companies who provided detailed data regarding their modal choice decision processes. In their study, the authors have uncovered a variety of modal rate and service characteristics that affected shipper choice. The authors conclude that the wide range of non-rate factors influencing modal choice decisions suggests that modal split models must be conducted at a disaggregate level.

The authors don't develop their own model, but discuss the importance of modal service characteristics in the decision process of the individual firm.

Mode Choice/Mode Split Considerations: Need to Include Shipment Size and Inventories in Discrete Shipper Selection Models

Chiang, Paul O. Roberts, Jr. and M. Ben-Akiva, "Short-Run Freight-Demand Model: Joint Choice of Mode and Shipment Size," *Transportation Research Record*, No. 838, 1981, pp. 9-12.

This paper estimates a freight demand model that involves the choice of mode as well as the choice of shipment size. A disaggregated approach is used. The basic data employed in the model comes from the 1972 Commodity Transportation Survey. One innovation of the model is to include from an inventory theory elements of logistics costs, including capital carrying costs in storage and in transit, order costs, loss of value during transit and storage, and direct transportation charges. One result of the model is that shippers put a very high value on improved travel times.

Mode Choice Models: Discrete Individual Choice with Elimination of Choices Based on Attributes

Young, A.J. Richardson, K.W. Ogden, and A.L. Rattray, "Road and Rail Freight Mode Choice: Application of an Elimination-by-Aspects Model," *Transportation Research Record*, No. 838, 1981, pp. 38-44.

These authors challenge the notion of most mode choice models that each individual considers all alternatives, and each attribute that describes those alternatives, before making a choice. Rather, the authors argue, shippers may attempt to simplify the choice process by eliminating many alternatives and/or attributes from active consideration. Models that allow for the elimination of attributes, such as the Elimination-by-Aspects approach, are viewed as preferable.

One feature of the model is that it assumes that individuals search modal attributes in a sequential fashion, proceeding from those attributes considered most important through to those that are considered least important. As each attribute is considered, each alternative is compared to that attribute. If the alternative fails this test, (i.e., less that minimally acceptable), it is no longer considered. This process continues until only one alternative is left.

The Elimination-by-Aspects model considers nine modal attributes: transit time, reliability, equipment availability, frequency of service, freight rates, loss and damage, convenience of service times, and communication with the carrier. The model is calibrated for different shipper classes. Depending on the type of shipper, different sets of attributes are shown to have a significant impact on mode choice.

The model's most significant contribution is to show that different factors influence the mode choice of shippers of manufactured and non-manufactured goods. Models assuming that all attributes affect the choice of all shippers are inconsistent with this finding.

Network Assignment Models for Freight Planning

Michael C. Bronzini, *Freight Transportation Energy Use*, prepared by CACI, Inc. – Federal for U.S. Department of Transportation, Transportation Systems Center, four volumes, July 1979.

This is one of a series of multimodal network models developed by CACI in the late 1970s. The models consist of node and link representations of rail, highway, waterway, and pipeline systems plus a set of intermodal links. Time and cost functions are associated with each node and each link. Mode and route choice for individual shipments or commodity flows are determined to minimize a commodity-specific function of time and cost. The commodity-specific values of time used in this function were adjusted to calibrate the model to base-year (1972) data. A comparison of the resulting values of time used to initial estimates based on commodity values indicates that significant difficulties were encountered in this calibration process.

Robert C. Bushnell, and Edward S. Pearsall, "Applications of a Freight Network Model to the Analysis of Competitive Situations," Proceedings, Transportation Research Forum, Vol. 22, 1981, pp. 379-393.

The Integrated Transportation Network Model contains representations of the highway, rail, and waterway networks, as well as costs and time delays resulting from mode transfers, operations through railroad yards, and transfers between rail carriers. This model was developed in the late 1970s under contracts with the U.S. Departments of Transportation and Energy and the State of Michigan. However, it was never developed as fully as the CACI model described above. An updated version of the rail component of this model with 1989 routings of doublestack trains and the location of container loading facilities was used as the first stage of a two-stage model of container import and export traffic recently developed by Jack Faucett Associates *(The U.S. Export/Import Containerized Freight Model,* 1990).

Teodor Crainic, "Operations Research Models of Intercity Freight Transportation: The Current State and Future Research Issues," *Logistics and Transportation Review,* Vol 23, No. 2 (1987), pp. 189-206.

The author argues that it is now possible to build comprehensive interactive graphic-planning systems that run on micro-computers and thus put impressively powerful computational and planning means within easy financial reach of practically every size of organization (carrier, shipper, etc) involved in the transportation system.

The author provides a classification of how network models can be used according to three alternative planning horizons: strategic or long-term planning, which may include decisions such as facility location and physical network design and upgrading; tactical or medium-range planning, which would involve service and routing decisions; and operational or short-term planning, including scheduling and routing of vehicles.

The main focus of this article is on tactical level issues. However, the decisions faced by state transportation departments would most often include the strategic planning variety.

Network Assignment Models for Freight Planning: Rail Models

Teodor Crainic, Michael Florian, and Jose-Eugenio Leal, "A Model for the Strategic Planning of National Freight Transportation by Rail," *Transportation Science,* Vol. 24, No. 1, February 1990, pp. 1-24.

This article describes in more detail the rail portion of the multimodal, multiproduct network model done for Brazil. It provides a review of network models for rail transportation, updating earlier reviews by Assad (1980), Crainic (1987), and Freisz (1983).

It provides an illustration of how the model can be used to assess the impact of a new rail construction project on current and projected freight flows in a Brazilian rail corridor.

Jerome M. Lutin and Alain L. Kornhauser, "Development of a Differential Route Share Model for Railroad Freight Traffic," 1980.

This article describes the railroad network model developed by Kornhauser and used over a number of years through ALK & Associates. The model provides a comprehensive replication of the US railroad network. Traffic data were obtained from the ICC's waybill sample. Regression models were used to predict how traffic would flow across alternative rail routings. The main variables which predict traffic flow are: impedance, which includes track condition, total distance, and originating carrier length of haul; total route length; and junction frequency. This model has been used in a number of policy applications, including traffic diversion effects from railroad mergers.

Network Assignment Models: Review and Ability to Incorporate Behavioral Intentions of Individual Shippers

Terry L. Friesz, Roger Tobin, and Patrick Harker, "Predictive Intercity Freight Network Models: The State of the Art," *Transportation Research,* Series A, Vol. 17A, pp. 409-417 (1983).

This is a review article of network models. Table 1 reviews six major network models (Harvard-Brookings, CACI, Peterson, Lansdowne, Princeton, Penn/ANL) on sixteen criteria (multiple modes; multiple commodities; sequential loading of commodities; simultaneous loading of commodities; congestion; elastic transportation demand; explicit shippers; explicit carriers; sequential shipper and carrier submodels; simultaneous shipper and carrier submodels; sequential macroeconomic and network models; simultaneous macroeconomic and network models; nonmonotonic functions; explicit backhauling; blocking strategy; and fleet constraints). The article includes a section on recent advances and suggestions for future research, including more attention to behavior intentions for shippers and carriers.

Use of Input-Output Models to Assess Economic Impact of Investments

Stevens, *Basic Regional Input-Output for Transportation Impact Analysis,* NCHRP Project 8-15A, Regional Science Research Institute, July 1982.

This ambitious project is an effort to provide state highway and transportation planners with hands-on input-output analysis tools. Input-output (IO) models can be used in a number of planning activities. In a structural approach to freight forecasting, such models can be used to determine flows of goods from various origins to destinations. The emphasis in this report is on the use of IO models for analyzing economic impacts of state highway investment and other similar investment. Such investment generates employment from construction activity, and can also result in more travel, new businesses locating in the area and the like. Estimating the cumulative economic impact, including these multiplier effects, is the subject of this report. Although not specifically in the purview of freight demand forecasting, this was an area cited by transportation planners in Iowa as an important tool in analyzing proposed transportation investment, to be used in conjunction with forecasting tools in determining where investment dollars might best be spent.

Use of Simple Time-Series Forecasts to Predict Trends in Freight Flows of Particular Industry Sectors

Eusebio and S. Rindom, *Grain Transportation Service Demand Projections for Kansas: 1995 and Beyond,* Kansas Department of Transportation, July 1990.

This study provides an example of state use of direct forecasting techniques. The first stage of the study projects grain production and livestock and poultry populations for the state. Then time series methods, specifically exponential smoothing and an autoregressive component from the SAS statistical package, are used to produce forecasts. Finally, with production data forecast, transportation is assumed at 95% of production. This study suggests that simple, time series forecasting techniques, now available through standard statistical packages, can be well utilized by state planners without the aid of outside consultants. Also, it points to the state-specific type of data sometimes used in forecasting studies, suggesting limitations to our ability to provide all-encompassing forecasting data.

A-3: Freight Energy and Emissions Studies

A-3: Freight Energy and Emissions Studies

Although there have been many studies of fuel use by various freight modes, there has been little study of emissions from freight. As noted above, the emissions from trucks and rail operations depend on some knowledge of the amount of travel, engine energy or fuel use. In considering emissions associated with freight transport, it would be useful to have some factors which relate emissions to freight moved. Freight movement could be measured in terms of tons or ton-miles. For intercity freight, in one nonattainment area, the total number of tons moved should be a useful number. This is based on the assumption that the average ton of intercity freight, by one particular mode, will travel some average number of miles in the nonattainment area. For larger areas, the number of ton-miles will be the more important variable. Just as the energy required to transport a given amount of freight increases with distance, the emissions would be expected to increase as well.

Studies of freight energy use could be used to estimate emissions by applying fuel-based emission factors, assuming that sufficient data on fuel use are available to apply the factors. Existing studies which have examined emissions from freight transport are described below. In addition, energy-use studies which can be used to estimate emissions are considered.

Many studies of fuel and emissions attributed to freight use have compared different freight modes. To the extent that these studies show an advantage to a particular mode, they have often been criticized by the freight modes that were not determined to be the best. Perhaps the most significant criticism of some studies is that for many freight shipments there are other considerations besides fuel efficiency and emissions which determine shipper preferences. The discussion below is not intended to determine if one particular freight mode or another is better, but to focus on the methodology used to determine the fuel use and emissions that can be attributed to freight shipments. The goal of this discussion is to describe existing approaches and point out their strengths and weaknesses. The approaches described below will be modified as necessary to develop the appropriate tools to be used in later tasks in this study.

Great Lakes Study: The Great Lakes Commission conducted a study which compared energy use, emissions and predicted accident rates for truck, rail and marine freight in the Great Lakes and St. Lawrence River areas.[1] The report considers 11 scenarios which are examples of products and routes shipped in this region. The scenarios "represent more than 10 percent of the average annual tonnage" for this region. All 11 scenarios

[1] Steve Thorp, "Great Lakes and St. Lawrence River Commerce: Safety, Energy and Environmental Implications of Modal Shifts," Great Lakes Commission, Ann Arbor, MI, June 1993.

considered both marine and rail shipments. For 3 of the 11, truck shipments were considered. The main commodities shipped in this region are low-value bulk commodities such as coal, potash, ore, limestone and grain.

Truck energy requirements were evaluated by assuming a fuel economy of 5.3 miles/gallon. Round trips with empty backhauls were assumed to have the same fuel economy with no freight carried as for a fully loaded truck. Fuel use for marine vessels was obtained from actual one-way movements. Data were provided by various shippers for different cargos. Rail freight movements also used various fuel efficiencies depending on the cargo carried. These ranged from 467 ton-miles/gallon for petroleum product shipments to 877 ton-miles per gallon for taconite pellets. Round-trip fuel efficiencies were reduced to account for empty backhauls.

The truck emission factors were obtained from the EPA MOBILE4 model. The emission factors for 1988 model year trucks operating in 1993 were used. The actual emission rates for trucks are shown in Table 3.7.

Marine emission factors in pounds per gallon of fuel were taken from AP-42. Rail emission factors were taken from the Booz·Allen study[2]. These factors are shown in Table 3.8., along with the fuel-based factors used for trucks.

Table 3.7.
Truck Emission Factors used in Great Lakes Study

HC	1.7 grams/mile	0.0198 pounds/gallon
CO	8.9 grams/mile	0.1039 pounds/gallon
NOx	19.4 grams/mile	0.2266 pounds/gallon

Table 3.8.
Emission Factors from Great Lakes Study
Units of pounds per gallon of fuel for each mode

Species	Steamships	Diesel Motorships	Rail	Truck
CO	0.00727	0.061	0.05905	0.1039
HC	0.00172	0.024	0.0179	0.0189
NOx	0.0636	0.550	0.499	0.2266

[2] "Locomotive Emission Study," prepared by Booz·Allen & Hamilton, Inc., for California Air Resources Board January 1991.

All modes were assumed to have empty backhauls with essentially the same fuel usage as a loaded haul. Marine return trips used slightly less fuel than the fully loaded trips. The study did not account for loading (drayage) operations. Only the destination to destination emissions for the individual mode were considered. Marine shipments in this region were found to be the safest, most fuel efficient and least polluting mode of transport. In the three comparisons of truck versus rail, rail usually had an advantage in fuel efficiency, safety, and emissions. The only case where trucks had an advantage over rail was for a short-distance shipment where the truck distance was only 194 miles while the rail distance was 360 miles. For this scenario, the truck NOx emissions were 113.1 tons/year as compared to 114.97 tons/year for rail. These NOx emissions were the only case where trucks had an advantage over rail.

Abacus Technology Corporation: This study, which was done for the Federal Railroad Administration (FRA), examined the relative fuel efficiency of truck freight and rail freight[3]. This study was designed to compare fuel use for a variety of route/commodity combinations in which trucks and rail are competitive. The fuel-use results were obtained by simulation programs for both truck and rail.

The simulations showed that the ratio of truck fuel use to rail fuel use, for the comparable commodity and route combinations, ranged from 1.40 to 5.61 for routes greater than 100 miles. For routes less than 100 miles, trucks used from 4.03 to 9.00 times as much fuel as rail. The fuel use figures presented in the report could be used to calculate emissions, provided the appropriate fuel-based emission factors were used. For the truck scenarios, data on percent of maximum power are given. These data could be used (in addition to the cumulative time data and the maximum engine power of 350 hp) to derive total engine energy use in bhp-hr, which would allow use of g/bhp-hr emission factors for estimating emissions.

The commodities examined in the Abacus study were selected from those that represent at least one percent of rail freight and at least one percent of long-distance truck freight. The railroad routes, selected in consultation with the FRA and participating railroads, were truck-competitive for the particular commodity. Truck routes were selected to be the most direct links between each origin and destination for the comparable rail route. The report compared truck and rail fuel economy for 27 long-distance and 11 short-distance routes.

The Abacus study was not designed to make an overall comparison of rail and truck fuel economy. In the introduction to the study, the authors state:

> *In previous studies, researchers have noted the futility of developing a single number to depict rail energy intensiveness and have pointed out that the individual circumstances for each run must be considered. This report, by looking at specific routes, equipment and loads, attempts to satisfy the need for route-specific analysis.*

The final results of the study were presented as a series of fuel-economy comparisons.

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[3] Stacy C. Davis, "Transportation Energy Data Book: Edition 14," Oak Ridge National Laboratory, Report ORNL-6798, May 1994.

The Abacus study accounted for fuel used in rail terminal operations and truck drayage. The simulations considered one-way trips only. No accounting was made for repositioning of empty trucks or railcars. However, some of the rail simulations did have empty cars on the train. The total fuel used in the truck simulations was used in computing the ton miles per gallon for truck freight. For rail, the following equation was used to compute the share of the train fuel assigned to the freight:

$$\begin{bmatrix} \textit{Fuel used} \\ \textit{by freight} \end{bmatrix} = \frac{\begin{bmatrix} \textit{Total weight (tare plus} \\ \textit{lading) of rail car} \end{bmatrix}}{[\text{Gross weight of train}]} \begin{bmatrix} \textit{Total fuel used} \\ \textit{by train} \end{bmatrix}$$

The rail simulations with empty cars would have additional fuel (as compared to a train with no empty cars) that would be included in the total fuel used by the train. However, the use of the gross weight of the train, rather than the trailing weight, in the equation above would not distribute any of the fuel used by the locomotive to the freight. The locomotive weight accounted for 4% to 22% of the total weight of the train with an average of 10%, depending on the scenario. If the increase in freight fuel were 10%, the truck-to-rail fuel ratios cited above would change to a range of 1.27 to 5.10 for routes greater than 100 miles, and to a range of 3.67 to 8.18 for routes less than 100 miles.

The rail simulations were performed using a train performance simulation initially developed by the Missouri Pacific Railroad. It was later adapted by the U.S. Department of Transportation for fuel efficiency studies and is now a public domain program[4]. The rail scenarios covered a range of currently used locomotives and freight car types (mixed freight, trailer on flatcar, doublestack, auto unit, and mixed freight with autos). The horsepower per trailing ton ranged from 0.9 to 3.8 except for one train with 5.7 HP/trailing ton.

The truck simulations were done by Cummins using its proprietary Vehicle Mission Simulator (VMS). The simulations used a variety of truck types (van trailer, flatbed with and without sides, container trailer, dump trailer and auto hauler). The trailer type was assumed to have aerodynamic aids appropriate to that type to improve fuel economy. Low-profile radial tires with a smaller coefficient of rolling friction were assumed in the simulations. The truck engine used in the simulation was a Cummins F-350 engine. This is a very efficient engine with a minimum BSFC of 0.316 lb/bhp-hr and a maximum power output of 350 HP.

The Abacus report presents detailed results for all rail and truck scenarios. The results for the truck scenarios provide the distance traveled, the fuel used, the travel time, and the average engine load (as a percent of maximum power). The report authors did not present average results because they did not want the averages to be misinterpreted as some sort of national average result. However, it is useful to examine some "average" quantities for the overall simulations considered. If the distance, time, fuel use, and

[4] "Heavy-Duty Vehicle Cycle Development," prepared by Systems Control, Inc. [Formerly Olson Laboratories], for the U.S. Environmental Protection Agency, July 1978.

engine power are summed for each scenario, the following average quantities can be derived for the truck scenarios:

Average speed:	57.9 miles per hour
Average fuel economy:	6.39 miles per gallon
Average BSFC:	0.348 pounds per bhp-hr

The fuel economy result is somewhat higher than the expected fuel economy for Class 8B trucks and the average BSFC is only slightly higher than the minimum value for this engine. Both of these factors are indications of a very efficient engine.

The detailed results of the truck simulations also provide an indication of the difference between truck operations in the transient test procedure and truck operations in line-haul freight transport. The average load factor on a Diesel engine in the transient test procedure is 28%[5]. In contrast, the average load factor for the truck simulations in the Abacus study ranged from 46% to 58%.

As part of the rulemaking on the California Federal Implementation Plan, EPA used the results of the Abacus study to evaluate the expected NOx emissions from truck and rail freight[6]. EPA concluded that truck freight produced about three times the NOx emissions, per ton mile, of rail freight. A Task Force of the American Society of Mechanical Engineers (ASME)[7] also used the Abacus study to estimate emissions from freight operations; this evaluation concluded that switching 10% of intercity freight from truck to rail would decrease NOx emissions (from intercity truck freight) by 6.2% and PM emissions by 4.4%. The reductions in HC and CO from this 10% switch were 1.6% and 2.9%, respectively. The ASME task force averaged the results of the Abacus study to obtain these numbers. This assumes that the Abacus results are representative of overall freight transport rather than comparisons of various route scenarios.

Transport Canada Study - This study examined the fuel use and emission rates for freight transport by truck, rail, marine vessel, air freight, and pipelines in Canada[8]. Two analysis approaches were used: the first examined the aggregate statistics for energy use and total freight transported; the second approach, similar to the Abacus study, compared truck and rail fuel economy and emissions for selected routes. The author also used a freight demand model to predict (1) the generation and/or attraction of freight on an origin-destination basis, (2) modal splits, and (3) interzonal freight flow.

[5] C. France, "Transient Cycle Arrangement for Heavy-Duty Engine and Chassis Emission Testing," U.S. Environmental Protection Agency, August 1978.

[6] T. Wysor, and C. France, "Selection of Transient Cycles for Heavy-Duty Vehicles," U.S. Environmental Protection Agency, June 1978

[7] C. France, "Transient Cycle Arrangement for Heavy-Duty Engine and Chassis Emission Testing," U.S. Environmental Protection Agency, August 1978.

[8] Op. Cit.

The aggregate statistics for energy use per ton-mile of freight* are shown in Table 3.9. For comparison with U.S. data, the aggregate intercity freight energy use from reference 1 is also shown.

Table 3.9.
Aggregate Energy Use (Btu/ton-mile)
for Freight Modes

Mode	Transport Canada	U.S. DOE ORNL
Rail	433	399
Marine	507	328
Oil Pipeline		274
Oil & Gas Pipeline	874	
Truck	3,303	2,410
Air	26,821	

The second part of the study, with route-specific comparisons, used the fuel-based emission factors, shown in Table 3.10., to compute emission rates. These emission factors were changed to correspond with changes in emission standards. No attempt was made to account for the gradual phase-in of trucks meeting the new emission standards are gradually introduced into the fleet. This will tend to underestimate the truck emissions in years immediately after standards are changed. Fuel consumption data for rail were obtained from Canadian railroads; data for trucks were taken from average fuel consumption rates.

*All data from the Transport Canada study reported here have been converted from the metric units in the original study to provide a common set of units.

Table 3.10 Emission Factors in Transport Canada Study					
Freight Mode	Year	Emission Factors (pounds per gallon of fuel)			
		HC	CO	NOx	PM
Truck	1985	0.0531	0.0633	0.4369	0.0245
Rail	1985	0.0225	0.0876	0.4590	0.0142
Truck	1990	0.0531	0.0633	0.2442	0.0245
Rail	1990	0.0225	0.0876	0.4590	0.0142
Marine	1990	0.0346	0.1450	0.4590	0.0209
Truck	1995	0.0531	0.0633	0.2038	0.0040
Rail	1995	0.0175	0.0442	0.4423	0.0110
Marine	1995	0.0303	0.1450	0.2038	0.0040

Unlike the Abacus study, the simulations performed in the Transport Canada study assigned all the fuel used by the train to the freight. The Transport Canada study examined only a limited number of routes, and the power to weight ratios used in those simulations (1.0 to 2.1 HP per trailing ton) were lower than the ones used in the Abacus study (0.8 to 5.7 HP per trailing ton). The Canadian study would be expected to have a higher figure for the ton-miles per gallon than the Abacus study because it assigns all the train fuel to the freight. However, the lower HP per trailing ton ratios in that study should result in lower train fuel consumption overall. This decrease in overall train fuel consumption apparently offsets the increase due to the alternative calculation procedure.

This study initiated a debate among Canadian trucking and rail groups regarding the relative merits of rail and truck freight. A review of the critique of the study by Nix[9] and the response by Canadian National (CN) Railways[10] provides the following points.

- The Transport Canada study did not account for the drayage energy associated with rail. (The CN response notes that there may be similar drayage from a shipper to a truck terminal.) These comments point out the need to fully analyze the origin to destination effects of any freight shipment.
- The Transport Canada study does not account for different shipment lengths by rail and by truck. (The CN response notes that truck and rail distances are the same in Canada.) An appropriate analysis of freight energy and emissions must consider the actual routes.

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[9] Fred P. Nix, "Trucks and Energy Use. A Review of the Literature and the Data in Canada," prepared for Ontario Trucking Association, Quebec Trucking Association, and Canadian Trucking Association, August 23, 1991.

[10] "Response by Canadian National Railways to the Paper by Fred P. Nix 'Trucks and Energy Use'," November 1, 1991.

- The Transport Canada study uses low values for freight fuel efficiency. For example, the 1990 fuel economy for trucks is 4.6 miles/gallon. This compares with the figure of 5.98 miles/gallon for 1990 trucks used in MOBILE5a. (This number can be derived from the conversion factor and BSFC data in Table 2.)
- Nix states that overall comparisons between all truck freight and all rail freight do not account for commodities that are shipped exclusively or almost exclusively by one freight mode or another for other reasons that are important to the shipper and company receiving the shipment. The Transport Canada study looked at both overall comparisons and specific route/commodity comparisons, this criticism does not apply to the latter comparisons.
- Nix questions the use of ton-miles per gallon as a measure of freight efficiency and suggests an alternative measure: energy use per dollar of revenue or energy use per dollar of gross domestic product. However, he does not consider any other measure for emissions.

The debate over the results of the Transport Canada study highlights the need to ensure that freight emission and fuel economy studies fully account for all emissions and energy use between the origin and the final destination. Comparisons of specific routes and commodities, which can provide a direct comparison, do not allow any statement about overall energy use and emissions from a freight system.

Other Studies: Envirotrans[11] did a recent study for Canadian freight transport which considered truck, marine, rail and air freight. This study did consider emissions as well as energy use. It also considered emission of CO_2 as a greenhouse gas in addition to the traditional criteria pollutants. This study provides a direct contrast to the route-specific study by Abacus; it relied on overall energy use for the various transportation modes to arrive at an overall emissions impact. This overall approach has the net effect of lumping together urban areas and rural areas where air emissions may not be a significant problem.

The emission factors used in this study are shown in Table 3.11. These data show a higher NOx emission factor for trucks in 1990 than for rail. This does not agree with the data presented previously on the standard EPA emission factors.

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[11] Chris Holloway, "The State of Canada's Railway Industry and Resulting Environmental Implications. A Review," submitted to Environment Canada, Transportation Systems Division, by Envirotrans, Ottawa, Canada, May 1994

Table 3.11 Emission Factors From Envirotrans Study (lb/gallon in 1990)				
Mode	VOC	CO	NOx	PM
Rail	0.0228	0.0877	0.4552	0.0144
Trucks	0.0531	0.6333	0.4754	0.0245
Marine	0.0346	0.1450	0.4590	0.0217
Air	0.1419	0.7344	0.6676	0.0053

Newstrand[12] analyzed the impacts of modal shift from marine freight routes in the Great Lakes to truck and, where possible, to rail. Details of the analysis are not presented and individual species are not considered in the emission calculations. Instead a single factor for the emissions of all species is used. The results for the routes and commodities selected show an advantage to marine freight.

Migliorino[13] presents a proposal for shifting freight transport in Italy to sea routes. His paper does not account for emissions, but does present European data on energy use of various freight modes.

Conclusions on Freight Studies: Studies of emissions and energy consumption from freight transport can be categorized as comparisons of individual shipments or as comparisons of overall freight systems. The former group of studies is useful in considering relative modal efficiencies for specific routes and commodities, but does not give any information on overall efficiency or emissions from an entire modal freight system. However, studies that compare entire freight systems are subject to the criticism that they do not compare equivalent types of shipments.

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[12] M. William Newstrand, "Environmental Impacts of a Modal Shift", in *Transportation Research Record 1333*, Transportation Research Board, National Research Council, 1992, pages 9-12

[13] Gianni Migliorino, "Italy's Intermodal Alternative: The Sea Road," in *ISTEA and Intermodal Planning*, Special Report 240, Transportation Research Board, National Research Council, 1993, pages 99-112

A-4: Freight Emissions Estimating Procedures

(authored by Sierra Research)

A-4: Freight Emissions Estimating Procedures

■ Overview of Methods for Truck Emissions

Emissions from any pollutant source are generally calculated from the product of an emission factor (e.g., lbs of NOx per ton of material combusted) and a measure of activity (e.g., tons of material combusted per year). For on-road motor vehicles, emission factors are estimated in units of grams per mile (g/mi), and vehicle activity is compiled as vehicle miles traveled (VMT).* Motor vehicle emission factors are calculated with the MOBILE, PART5, and EMFAC models, while VMT estimates are obtained from transportation models that have been designed for specific communities. The emission factor estimates prepared with available models vary according to parameters such as calendar year of evaluation, average vehicle speed, vehicle type, etc., all of which can be affected by control strategies aimed at freight movements. Thus, the discussion that follows provides an overview of how MOBILE, PART5, and EMFAC calculate emission factors for on-road motor vehicles, with particular emphasis on their treatment of heavy-duty trucks.

General Methodology: Since the mid-1960s, both EPA and CARB have implemented increasingly stringent regulations to control emissions from on-road motor vehicles. For that reason, and because emission control systems tend to become less effective as they age, the emissions from each vehicle on the road are not the same. For example, in 1995, emissions from a 1969 model-year passenger car will be higher than emissions from a 1979 model-year passenger car, which will be higher than emissions from a 1989 model-year passenger car. In addition, not all cars on the road are driven the same number of miles every day. As vehicles become older, there are fewer of them in the fleet and they are generally used less. Thus, although older vehicles have higher emissions (on a g/mi basis), their impact on emissions from the entire fleet is mitigated to some extent by the fact that fewer miles are attributed to those vehicles. EPA and CARB models account for this by assuming that the vehicle fleet is made up of 25 model years,* and assigning a "travel fraction" to each model year. For each vehicle class considered by the models (e.g., passenger cars, light-duty trucks, heavy-duty trucks, etc.) the following calculation is performed:

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*VMT is estimated on the same time basis as desired for the overall emissions inventory, e.g., daily VMT would be used to obtain emissions in tons/day, annual VMT for tons/year.

* In EMFAC7F, 35 model years are assumed to make up the passenger car fleet. In addition, all of the emission factor models considered in this report assume that the motorcycle fleet is made up of 12 model years.

$$EF_{i,j,k} = \sum_{m=1}^{n} TF_m * \left(BER_{j,k,m} * CF_{j,k,m...} \right)$$

where:

$EF_{i,j,k}$ = fleet-average emission factor for calendar year i, pollutant j, and process k (e.g., exhaust or evaporative emissions);

TF_m = fractional VMT (i.e., travel fraction) attributed to model year m (the sum of TF_m over all model years n is unity);

$BER_{j,k,m}$ = base emission rate for pollutant j, process k, and model year m;

$CF_{j,k,m}$ = correction factor(s) (e.g., temperature, speed) for pollutant j, process k, model year m, etc;

and the sum is carried out over the n model years making up the vehicle class.

As indicated in the equation above, a variety of corrections are applied to the base emission rates to account for conditions that are not included in the standard test cycles used to develop the base emission rates (e.g., exhaust emission rates may be corrected for non-standard speeds, evaporative emissions may be corrected for non-standard temperatures, etc.).

Travel Fraction Calculation: The methodology to calculate the travel fraction is based on applying an estimated annual mileage accumulation rate by vehicle age to an estimated registration distribution for the number of model years assumed to comprise the fleet. The travel fraction for each model year (TF_m) is calculated from:

$$TF_m = \frac{REG_m * MILES_m}{\sum_{m=1}^{n} (REG_m * MILES_m)}$$

where $MILES_m$ represents the annual mileage accumulation for model year m, REG_m represents the registration fraction for model year m, and n is the total number of model years in the fleet. Typically, the registration fractions are a user-input to the emission factors models, since most communities can obtain data on the local fleet make-up through the state's Department of Motor Vehicles.

Heavy-Duty Engine Test Procedure: For the purposes of emission inventory preparation, vehicles that have a gross vehicle weight rating (GVWR) above 8,500 lbs are considered heavy-duty vehicles. Because of the large number of applications for which heavy-duty engines are utilized, emissions testing is normally engine-specific and is performed on an engine dynamometer. Additionally, the heavier GVWR of heavy-duty vehicles (which can range from 8,500 to over 80,000 lbs.) precludes testing on most chassis dynamometers. Therefore, transient engine dynamometer test cycles have been developed that simulate average urban driving for gasoline and Diesel heavy-duty engines. These test cycles specify RPM and torque by second and are roughly 20 minutes long. Emission rates are determined on the basis of mass per unit of work required for the engine to complete the test cycle, i.e., grams per brake horsepower-hour (g/bhp-hr). The engine speed and torque specifications for the transient dynamometer cycle are specified in terms of the maximum engine speed and torque for the particular engine. Thus high-power engines are tested under greater loads than lower-power engines.

The transient test cycles developed for heavy-duty gasoline and Diesel engines are the result of a significant effort by EPA and industry to simulate heavy-duty vehicle operation in urban areas. The data used to develop the cycles were collected from instrumented heavy-duty trucks that operated in New York City and the Los Angeles Basin in the mid-1970s.[2] The complete 20-minute cycles were formulated from four separate 5-minute cycles that represented freeway driving in New York City, non-freeway driving in New York City, freeway driving in Los Angeles, and non-freeway driving in Los Angeles.[3,4] An optional chassis dynamometer test cycle was also developed in this program which covers 5.73 miles at an average speed of 19.45 mph.[4]

Heavy-Duty Engine Basic Emission Rates: The basic emission rates (i.e., g/bhp-hr) developed for the EPA and CARB emission factor models are based on engine dynamometer test results collected during a cooperative test program with engine manufacturers. For heavy-duty Diesel vehicles, a total of 30 engines were tested that were representative of the 1979 to 1984 model years. For heavy-duty gasoline emission rates, 18 engines were tested by EPA. These were from the 1979 to 1982 model years. Unfortunately, heavy-duty engine testing is very expensive, so data are generally sparse. No new data since the mid-1980s have been developed with which to update heavy-duty emission factors.*

The impact of new emission standards has been incorporated into model predictions by simply applying the ratio of the standards to the basic emission rate equations described above. In addition, EPA's models assume that deterioration in emissions performance is negligible for heavy-duty Diesel vehicles (e.g., a 1990 model year heavy-duty Diesel vehicle will have the same emission rate in 1990 as it does in 2010). This is an important consideration from the perspective that heavy-duty Diesel vehicles are assumed to operate below their certification standards for their entire life, which generally does not occur for motor vehicles, especially those subject to relatively stringent controls. Thus, estimates prepared with EPA's models may underestimate the emissions impact of freight movements with heavy-duty Diesel vehicles, which could bias comparisons being made to freight movements by rail.

On the other hand, CARB's EMFAC model utilizes basic emission rates that incorporate deterioration of emissions performance over time. Those rates were generated with the above test data, but the results were modified with a fairly elaborate procedure to account for the impacts that specific component defects, malmaintenance, and tampering have on emissions from heavy-duty Diesel vehicles. A comparison of 1994 model year heavy-duty

* The one exception to this is the exhaust particulate emission factors used in the PART5 model for 1988 and later model year heavy-duty Diesel vehicles. Those are based on manufacturer certification data submitted for the 1988 model year.

Diesel vehicle emissions (at 200,000 miles) indicates that EMFAC predicts NOx emissions to be nearly 40% higher than MOBILE. Roughly half of that difference is related to differences in how the models account for emission control system defects, while the other half is related to differences in the way the "conversion factors" were calculated. This latter topic is discussed below.

Heavy-Duty Vehicle Conversion Factors Because the heavy-duty engine exhaust emission test procedure results in emissions reported in units of g/bhp-hr, it is necessary to convert the results into g/mi units to be consistent with available travel activity data. Therefore, EPA has developed conversion factors (in bhp-hr/mi) to represent the emission results obtained from engine dynamometer testing in units appropriate for inventory purposes. The derivation of heavy-duty conversion factors is described in a 1984 EPA technical report[5] which was updated in 1988.[6] Only a summary of the methodology is presented here.

Because it is difficult to measure bhp-hr/mi directly, a methodology was developed to calculate this parameter with available data. The conversion factor is represented by:

$$CnvF = \frac{\rho}{BSFC \ x \ FE}$$

where :

CnvF = conversion factor (bhp-hr/mi),

ρ = fuel density (lb/gal),

BSFC = brake-specific fuel consumption (lb/bhp-hr), and

FE=fuel economy (mi/gal).

Thus, by obtaining estimates of fuel density, brake-specific fuel consumption, and fuel economy, it is possible to estimate CnvF. Once the values of CnvF are obtained for each GVWR class, a fleet composite CnvF is established by weighting the class-specific values by an estimated VMT fraction for each GVWR class. These calculations are carried out separately for gasoline and Diesel vehicles.

The GVWR classes considered by EPA in generating heavy-duty Diesel vehicle conversion factors generally follow the FHWA class definitions. However, there is some consolidation across the FHWA classes when data are collected on heavy-duty vehicles. Thus, EPA has also defined the following classes based on GVWR range:

EPA Vehicle Class	FHWA Class	GVWR (lbs.)
Class 2B	2B	8,501-10,000
Light heavy-duty Diesel	3,4,5	10,001-19,500
Medium heavy-duty Diesel	6,7,8A	19,501-60,000
Heavy heavy-duty Diesel	8B	60,000+

The value of CnvF generally increases with increasing GVWR. That is because both the fuel economy and the brake-specific fuel consumption (which is a measure of engine efficiency, i.e., lower values represent more efficient engines) decrease with increasing GVWR. Thus, the <u>fleet-average</u> heavy-duty Diesel conversion factor will be lower (and, therefore, emission rates will be lower) than those applicable only to line-haul trucks (i.e., Class 8B vehicles). It is important that this be accounted for in any analysis of emissions associated with freight movements by line-haul trucks. If a standard MOBILE heavy-duty Diesel vehicle emission rate is used (which represents the <u>average</u> emission rate from <u>all</u> heavy-duty Diesel vehicles), the analysis will underestimate emissions from freight transported by Class 8B vehicles.

Although neither MOBILE nor EMFAC calculate emissions for each heavy-duty Diesel vehicle class separately, it is possible to do that calculation outside of the models so that emissions from Class 8B trucks can be determined.* Such an approach is needed if freight transport is to be fairly compared between truck and rail. The recommended methodology for that calculation is the topic of a later section of this report.

Other Heavy-Duty Diesel Vehicle Correction Factors: MOBILE and EMFAC contain factors that correct emissions for operating conditions that are not observed in the standard emission test cycles. These corrections include temperature, operating mode (i.e., cold start versus hot stabilized operation), and speed. However, only speed is assumed to significantly impact emissions from heavy-duty Diesel vehicles. To perform this correction, the basic emission rate is multiplied by the appropriate speed correction factor, which is calculated from the speed correction coefficients according to the following formula:

$$SCF = \exp(a + bs + cs^2)$$

where

a,b,c = speed correction factor coefficients,

s = average vehicle speed, and

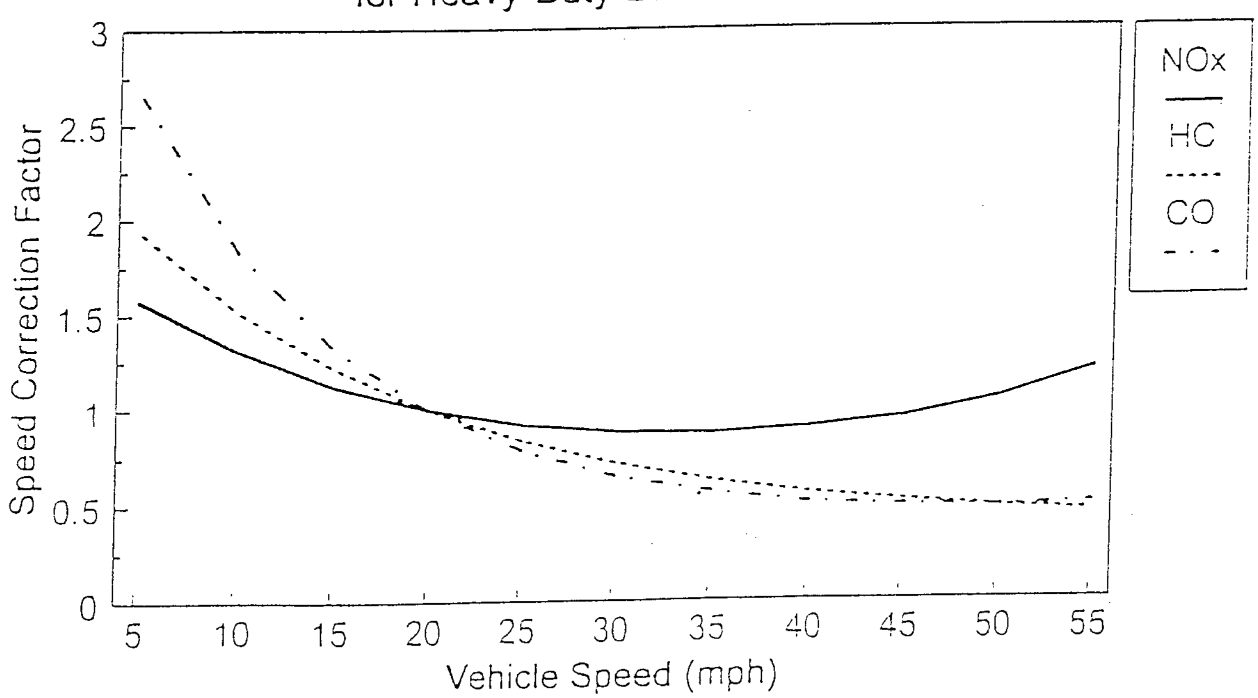
exp = exponential function.

* Note that the PART5 model calculates particulate emission rates independently for each of the four EPA-defined heavy-duty Diesel vehicle weight classes.

Figure 2-1 shows a graphical representation of the heavy-duty Diesel vehicle speed correction factors for HC, CO, and NOx.* (The same speed correction factors apply to all model year vehicles.) It is interesting to note that these speed correction factors have been used since the MOBILE2 version of the model, and the same factors are used in EMFAC7F. These were developed 15 years ago, and formal documentation of how they were developed was not identified. However, it appears that the heavy-duty Diesel vehicle speed correction factors were developed from data collected in limited chassis dynamometer testing performed by Southwest Research Institute in the early 1980s. That test program collected emissions data separately for each segment of the heavy-duty transient test procedure, and data from 3 of the 4 segments were used to develop speed correction factors (at speeds of 7.3 mph, 16.8 mph, and 46.9 mph). The first segment of the test cycle was not used to eliminate the effect that cold start might have on emissions (which is generally considered negligible for Diesel vehicles). Although chassis dynamometer testing of heavy-duty Diesel vehicles has become more common in recent years as more facilities have become available to test heavy-duty Diesel vehicles, incorporation of more recent chassis-based data into emission factor models appears to be several years away.

Figure 2.1

MOBILE5a and EMFAC7F Speed Correction Factors for Heavy-Duty Diesel Vehicles



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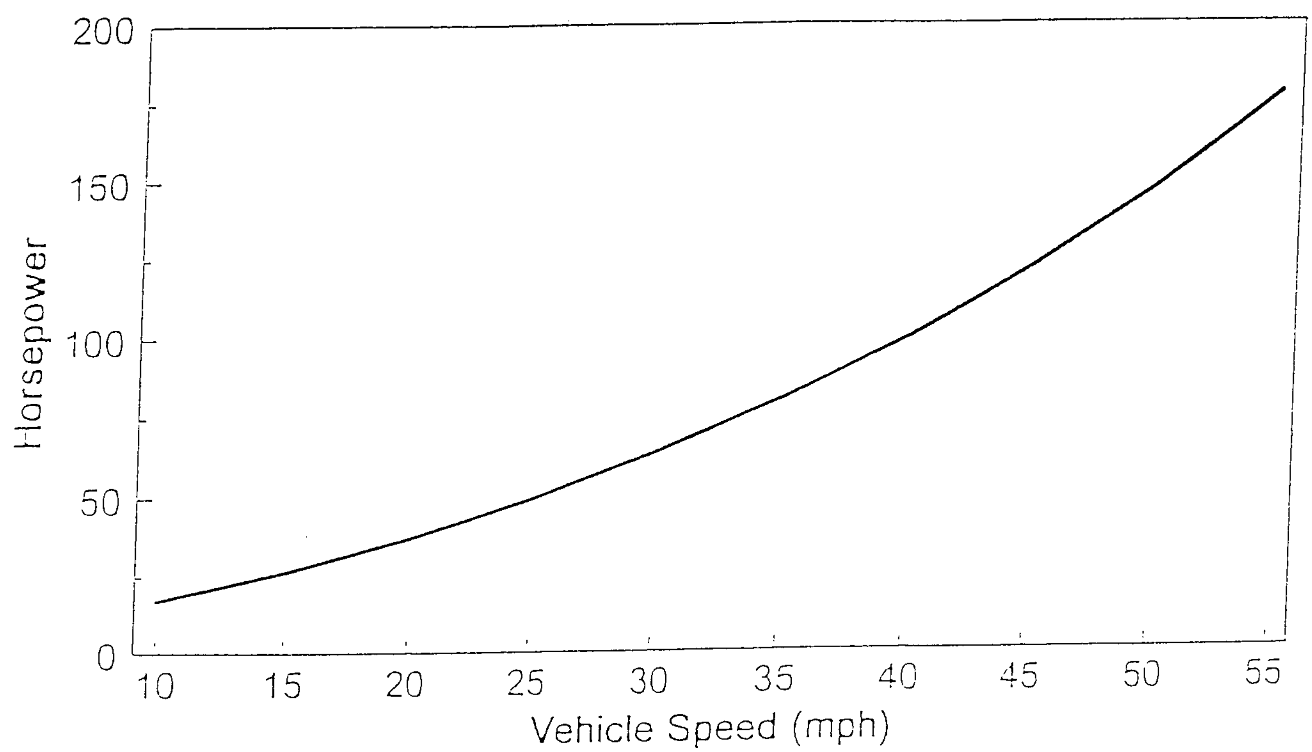
* Particulate and SO_2 emissions are not corrected for speed in EPA and CARB models.

As a point of comparison, the power required for a loaded, Class 8B truck to maintain a steady speed is shown in Figure 2-2. That figure shows a nearly five-fold increase in the power required at 55 mph relative to 20 mph (which is the speed to which heavy-duty vehicle speed correction factors are normalized). However, the power requirements at a steady speed cannot be directly translated into a speed correction factor because speed correction factors are developed from the average speed of specific driving cycles which contain a variety of accelerations, decelerations, and steady-state operation. In fact, low-speed cycles generally contain a large proportion of accelerations, which account for the majority of emissions collected over a particular test cycle.

Figure 2.2

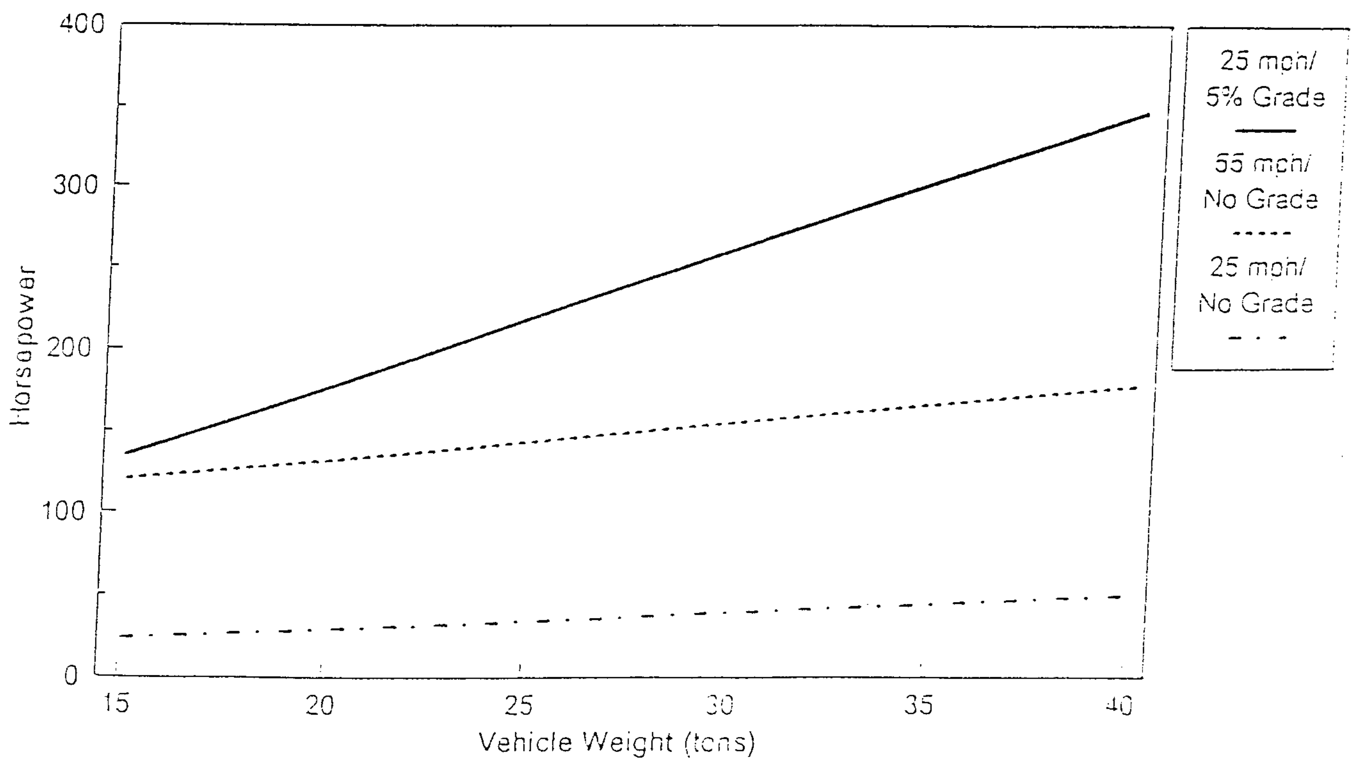
Power Requirements for an 80,000-lb Class 8B Truck to Maintain a Steady Speed



In addition to speed, a number of other parameters influence the power requirements and therefore the emissions of heavy-duty Diesel vehicles. This includes how heavily the vehicle is loaded (e.g., empty or carrying a full load) and road grade. Obviously, a fully loaded Class 8B truck traveling up a 5% grade will use more energy than an empty truck traveling at the same speed on a level road. The effects of vehicle weight and road grade on power requirements are illustrated in Figure 2-3, which shows three conditions: (1) 25 mph with a 5% grade, (2) 55 mph with no grade, and (3) 25 mph with no grade. The figure shows that as vehicle weight is increased from 15 tons (which approximates the empty weight of most Class 8B trucks) to 40 tons (which approximates a fully loaded Class 8B truck), power requirements to maintain a constant speed increase by nearly 50% for a vehicle at 55 mph with no grade. At 25 mph with a 5% grade, the power requirements increase by two and one-half times for a fully loaded truck compared to an empty truck. Although the effects of vehicle weight and road grade are not included in emission factor models, it is useful to keep these issues in mind when evaluating model output and making comparisons between truck and rail freight movements.

Figure 2.3

Effect of Truck Weight and Road Grade on Power Requirements



SOx and Non-Exhaust Particulate Emission Estimates: Sulfur oxides (SOx) and non-exhaust particulate emission rates are calculated in the EMFAC7F and PART5 models in a slightly different fashion than as described above for VOC, CO, NOx, and exhaust PM emission factors. For SOx, emission rates are estimated based on the sulfur content of the fuel (Diesel and gasoline), coupled with the fuel economy of the vehicle class being evaluated. For example, consider a 1990 model year Class 8B Diesel truck in 1995. The fuel sulfur content is assumed to be 0.05% (by weight) and the vehicle fuel economy is assumed to be 5.93 miles per gallon. In addition, the PART5 model assumes that 98% of the fuel sulfur is exhausted as gaseous SO_2,* and the density of Diesel fuel is 7.11 lbs per gallon. This results in the following g/mi SOx estimate (calculated as SO_2)::

$$SO_2 = \frac{\rho_{fuel}}{FE} \frac{M_{SO_2}}{M_S} w_s \, f_{SO_2}$$

where

ρ_{fuel} = the fuel density (7.11 lbs/gal);

FE = the fuel economy (5.93 miles/gal);*

M_{SO2} = the molecular weight of SO_2 (64.0588);

M_S = the atomic weight of sulfur (32.06);

w_S = the weight fraction of sulfur in the fuel (0.0005); and

f_{SO2} = the fraction of fuel sulfur converted to SO_2 (.98).

Using these data gives the following:

$$SO_2 = \frac{\dfrac{7.11\ lbfuel}{gal}}{\dfrac{5.93\ miles}{gal}} \frac{453.59\ g\,fuel}{lb\,fuel} \frac{\dfrac{64.0588\ g\ SO_2}{mole\ SO_2}}{\dfrac{32.06\ g\ S}{mole\ S}} \frac{0.0005\ g\ S}{g\,fuel} \frac{0.98\ mole\ SO_2}{mole\ S}$$

SO_2 = 0.533 g/mi

The same calculation is performed for the remaining model years, and the results are weighted by the travel fraction for each model year to arrive at a fleet-average SO_2 emission rate. The PART5 model assumes that 2% of the fuel sulfur is exhausted as direct particulate. The calculation is similar to that described above, except that the particulate sulfur is assumed to be in the form of sulfuric acid with seven associated water molecules, i.e., $H_2SO_4 \cdot 7(H_2O)$. Because of the similarities of the calculations, the gram/mile

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* The remaining 2% of the Diesel fuel sulfur is assumed to be exhausted as direct sulfate in PART5. On the other hand, EMFAC7F assumes all of the fuel sulfur is exhausted as gaseous SO_2.

*Taken from the MOBILE5a model for 1990 Class 8B trucks.

emissions of particulate sulfate, PS, are given in terms of the gram/mile SO_2 emissions by the equation:

$$PS = \frac{M_{PS}}{M_{SO_2}} \frac{f_{PS}}{f_{SO_2}} SO_2$$

The new symbols defined in this equation are:

M_{PS} = the molecular weight of $H_2SO_4 \cdot 7(H_2O)$ (224.18), and

f_{PS} = the conversion of fuel sulfur to particulate sulfate (0.02).

Replacing the variables in the equation with the appropriate data gives

PS = 0.07142 SO_2 = 0.038 g/mi.

Sources of non-exhaust particulate calculated by PART5 (and, in some cases, by EMFAC7F) include the following:

- tire wear (PART5 and EMFAC7F),
- brake wear (PART5),
- fugitive dust - paved roads (PART5), and
- fugitive dust - unpaved roads (PART5).

The tire wear emission factors are calculated in PART5 by using a tire wear emission rate for light-duty vehicles (0.008 g/mi) and scaling that value to other vehicle classes based on the average number of wheels for each vehicle class. For example, the tire wear emission rate from Class 8B vehicles (which are assumed to have 18 wheels) is simply:

$TIRE_{8B}$ = 0.008 * (18/4) = 0.036 g/mi.

In contrast, CARB's EMFAC7F model assumes a tire wear emission rate of 0.20 g/mi for light-duty vehicles and 0.66 g/mi for heavy-heavy-duty Diesel vehicles. It is unclear why such a large difference exists between the two models. Brake wear emissions (which are not calculated by EMFAC7F) are estimated by PART5, which assumes that all vehicle classes have a constant brake wear emission rate of 0.013 g/mi.

Finally, fugitive dust emissions from paved and unpaved roads are also calculated by PART5 (but not EMFAC7F). Those calculations are based on empirical formula from EPA's AP-42 document. The paved road emission rates are a function of road surface silt loading (in grams per square meter) and the fleet-average vehicle weight. The unpaved road fugitive dust emission rates are a function of the silt content of the road surface material (%), vehicle speed, fleet-average vehicle weight, fleet-average number of wheels, and the annual average number of precipitation days per year.

■ Emissions Factors for "Intercity" Truck Freight

As noted above, the MOBILE5a and EMFAC7F models provide emission factors on a g/mi basis for the entire heavy-duty Diesel fleet. These factors, used in general inventory development, are obtained from the basic engine standards (in g/bhp-hr) by conversion factors (in bhp-hr/mile) that represent a fleet-weighted measure of the engine energy required to travel one mile. The conversion factors are constructed from factors for individual subclasses based on the relative population of each subclass in the fleet. However, by knowing the fleet-weighted conversion factor and the subclass-specific conversion factors for each model year, it is possible to determine the emission rate of individual heavy-duty Diesel subclasses (e.g., Class 8B). The calculation is performed by: (1) dividing the MOBILE5a model-year-specific g/mi values by the fleet-weighted conversion factors to generate model-year-specific g/bhp-hr emission rates, (2) multiplying the resulting g/bhp-hr emission rates by the subclass-specific conversion factors to obtain g/mi emission rates, and (3) multiplying the g/mi emission rates by the travel fraction attributable to each model year making up the subclass being evaluated. The procedure is best illustrated with an example, which is summarized below.

The following process can be used to obtain emission factors for Class 8B trucks from MOBILE5a model-year specific output.

1. One or more calendar years are selected for study. Steps 2 through 8 are performed for each of the selected calendar years.
2. For each calendar year, MOBILE5a calculations consider a number of vehicle model years to be in use (e.g., the 2000 calendar year calculation is based on data for model years 1976 through 2000). MOBILE5a also outputs data on the fraction of vehicle travel that is contributed by each model year. The starting point of these calculations is the determination of the MOBILE5a emission factors in g/mi, and associated travel fractions, for each model year used in the calculation. These factors apply to the entire heavy-duty Diesel fleet.
3. The fleet-average gram/mile result for each model year is translated to a g/bhp-hr result for that model year using the fleet-average conversion factor for that model year.
4. The distribution of truck use by model year is used to weight the g/bhp-hr factors for each model year to obtain an average emission factor, in g/bhp-hr, for the given calendar year. This provides one possible set of emission factors. This is perhaps the most accurate set of factors, but it is usually the hardest to use, as data on bhp-hr are generally not available. These g/bhp-hr factors are independent of the truck size.

Emission factors can also be generated on a g/mi and a pound per gallon (lb/gal) of fuel basis. These factors are often easier to use because mileage and fuel use data are usually available, whereas bhp-hr data are not. In addition, these factors are different for different truck classes.

5. The conversion factors for Class 8B trucks are used to convert the g/bhp-hr factors for each model year (which were derived in step 3 above) into g/mi factors for Class 8B trucks in that model year.

6. The distribution of truck use by model year (i.e., the travel fraction) is used to weight the g/mi figure for Class 8B trucks to obtain an average emission factor, in g/mi, for the particular calendar year. This provides a second set of factors which requires data only on miles traveled. Because this cannot account for the amount of freight carried, it is perhaps the least accurate approach.

7. The model year specific brake-specific fuel consumption (BSFC) data used for determining the conversion factors are used with a Diesel fuel density of 7.11 lb/gal to convert the g/bhp-hr data for each model year into lb/gal emission factors for the model year.*

8. The distribution of truck use by model year is used to obtain an average emission factor, in lb/gal, for the calendar year.

The above calculations are summarized in Table 2 for NOx emissions in the year 2000. Several items are worth noting with respect to that table. First, no travel is associated with model year 2000 in a calendar year 2000 analysis. That is because MOBILE5a assumes a January 1 analysis date when calculating emissions.** Since the model year begins on January 1 for heavy-duty vehicles, there are no 2000 model-year heavy-duty trucks in the fleet on January 1, 2000. Second, the fleet-average NOx emission rate for the entire heavy-duty Diesel vehicle class is 10.60 g/mi, whereas the fleet-average NOx emission rate for Class 8B trucks is 15.59 g/mi, representing nearly a 50% increase. Clearly, if the MOBILE5a output for heavy-duty Diesel vehicles is used directly to make comparisons of freight transport between truck and rail, truck-based emissions will be significantly underestimated. Finally, although average vehicle mileage was not used in the above calculations, it is shown in Table 2 to give an indication of the much higher annual mileage accumulation rates of Class 8B trucks relative to the heavy-duty Diesel class as a whole.

The g/mi NOx emission rates given in Table 2 assume an average speed of 20 mph (which is the average speed of the test cycle used for emissions testing of heavy-duty vehicles). At 55 mph, the NOx speed correction factor for heavy-duty Diesel vehicles is 1.20. Thus, the NOx emission rate for the entire heavy-duty Diesel vehicle class would be 12.72 g/mi, and the NOx emission rate for Class 8B trucks would be 18.71 g/mi at 55 mph. (MOBILE5a assumes that speed correction factors for heavy-duty Diesel vehicles are independent of truck size.)

The data in Table 2-2 show the importance of calendar year in emission estimates. The truck emission factors, in grams/mile, become lower as newer, cleaner trucks replace older trucks. The overall emission factor is appropriate for trucks in calendar year 2000. If a specific project were replacing older trucks (or replacing the engines in older trucks

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* Reference 6 contains data on BSFC up to the 1987 model year. Data for future years were extrapolated by assuming a decrease (improvement) in BSFC of 0.01 lb/Bhp-hr every three years. This is slightly less than the observed trend of a 0.01 lb/Bhp-hr decrease every two or three years.

** It is possible to specify a July 1 analysis date in MOBILE5a, but the model performs that calculation by running the model for two succeeding years and taking the average of the two. For example, emission factors for July 1, 2000, are calculated from the mean of January 2000 and January 2001 model runs.

Table 2-2 Heavy-Duty Diesel Vehicle (HDDV) Emissions for Calendar Year 2000											
Heavy-duty Diesel Fleet Weighted Parameters						Class 8B Parameters					
Model Year	Travel Fraction	Average Mileage[a]	Conversion Factor	NOx Emissions (g/mi)	NOx Emissions (g/bhp-hr)	Travel Fraction	Average Mileage[a]	Conversion Factor	BSFC (lb/bhp-hr)	NOx Emissions (g/mi)	NOx Emissions (lb/gal)
2000	0	0	2.036	0	0.000	0	0	3.129	0.350	0.000	0.000
1999	0.1078	17,565	2.036	6.49	3.188	0.1044	31,088	3.129	0.350	9.974	0.143
1998	0.1008	51,552	2.036	6.49	3.188	0.0985	91,508	3.129	0.360	9.974	0.139
1997	0.0944	83,344	2.037	8.13	3.991	0.0930	148,513	3.129	0.360	12.488	0.174
1996	0.0884	113,109	2.039	8.13	3.987	0.0877	202,297	3.129	0.360	12.476	0.174
1995	0.0903	141,001	2.039	8.13	3.987	0.0902	253,042	3.129	0.370	12.476	0.169
1994	0.0708	167,159	2.033	8.13	3.999	0.0711	300,919	3.129	0.370	12.513	0.169
1993	0.0436	191,712	2.033	8.13	3.999	0.0440	346,090	3.129	0.370	12.513	0.169
1992	0.0420	214,776	2.033	8.13	3.999	0.0425	388,709	3.129	0.380	12.513	0.165
1991	0.0491	236,459	2.050	8.13	3.966	0.0499	428,920	3.129	0.380	12.409	0.164
1990	0.0480	256,859	2.066	9.87	4.777	0.0489	466,859	3.129	0.380	14.948	0.197
1989	0.0563	276,064	2.099	16.77	7.990	0.0575	502,654	3.129	0.390	24.999	0.321
1988	0.0442	294,159	2.132	16.77	7.866	0.0452	536,426	3.129	0.390	24.612	0.316
1987	0.0432	311,218	2.167	17.18	7.928	0.0442	568,290	3.129	0.390	24.807	0.319
1986	0.0322	327,311	2.214	17.56	7.931	0.0329	598,353	3.129	0.400	24.817	0.311
1985	0.0128	342,502	2.211	17.53	7.929	0.0131	626,717	3.138	0.400	24.880	0.311
1984	0.0147	356,852	2.406	19.08	7.930	0.0150	653,479	3.141	0.410	24.909	0.303
1983	0.0169	370,413	2.277	18.06	7.931	0.0172	678,728	3.150	0.410	24.984	0.303
1982	0.0137	383,237	2.376	18.84	7.929	0.0139	702,550	3.152	0.420	24.993	0.296
1981	0.0086	395,370	2.698	21.47	7.958	0.0088	725,027	3.255	0.420	25.902	0.297
1980	0.0056	406,856	2.716	21.47	7.905	0.0057	746,233	3.332	0.420	26.339	0.295
1979	0.0044	417,735	2.999	23.78	7.929	0.0044	766,241	3.307	0.430	26.222	0.289
1978	0.0032	428,042	3.187	33.633	10.553	0.0032	785,118	3.361	0.430	35.469	0.385
1977	0.0022	437,814	3.246	34.288	10.563	0.0022	802,929	3.402	0.430	35.936	0.385
1976	0.0066	447,082	3.179	33.935	10.675	0.0065	819,733	3.353	0.440	35.792	0.380
Fleet-Weighted Results:				10.60	4.93					15.59	0.205

with cleaner engines), then the emission rates for the actual model years of the older trucks should be used to compute the emissions prior to the change.

One surprising aspect of the data in Table 2-2 is the constancy of the conversion factor for class 8B trucks for model years beyond 1986. This implies that there will be no improvements in fuel economy, outside of engine efficiency improvements, beyond the 1986 model year. This is not consistent with a projection prepared by Energy and Environmental Analysis,[7] made after the analysis of conversion factors for MOBILE,[6] which predicts an improvement of 6% in FTP fuel economy as a result of non-engine related improvements (e.g., drag reduction, drivetrain optimization) between 1987 and 2001.

The approach outlined above can be used to determine the class-specific emission rates for any truck class. However, the vast majority of trucks in intercity, line-haul operation are expected to be class 8B trucks. In order to check this assumption, data in reference 6, taken from the 1982 truck inventory and use survey (TIUS), were examined. These data give the number of vehicles and the average annual VMT for trucks used in long-distance operations. (The TIUS data classify truck operations as local, short-haul, and long-haul; long-haul data are taken to be equivalent to intercity freight in this discussion.) The data on the number of trucks in each truck class, for both Diesel fuel and gasoline, are shown in Table 2-3.

Table 2-3
Estimate of Intercity Freight by Truck Class and Fuel Type
(Based on 1982 TIUS)

Fuel	Class	Number of Trucks	Annual Truck VMT	Total VMT (millions)	% of Total VMT	Midpoint of GVWR	Freight (pounds)	Ton-miles (millions)	% of total ton-miles
Diesel	2	2,126	29,853	63	0.20%	8,000	500	16	0.00%
	3	379	53,414	20	0.06%	12,000	2,000	20	0.01%
	4	-	-	-	0.00%	15,000	4,000	-	0.00%
	5	307	30,582	9	0.03%	17,750	7,000	33	0.01%
	6	3,826	46,970	180	0.55%	22,750	10,000	899	0.24%
	7	11,493	52,420	602	1.86%	29,500	15,000	4,518	1.20%
	8A	44,179	79,133	3,496	10.77%	46,500	20,000	34,960	9.25%
	8B	253,282	87,750	22,225	68.44%	70,000	30,000	333,382	88.22%
Diesel	Subtotal			26,597	81.90%			373,829	98.92%
Gasoline	2	412,753	13,178	5,439	16.75%	8,000	500	1,360	0.36%
	3	543	6,472	4	0.01%	12,000	2,000	4	0.00%
	4	5,536	8,101	45	0.14%	15,000	4,000	90	0.02%
	5	3,356	12,803	43	0.13%	17,750	7,000	150	0.04%
	6	14,052	15,565	219	0.67%	22,750	10,000	1,094	0.29%
	7	2,599	23,129	60	0.19%	29,500	15,000	451	0.12%
	8A	1,700	11,093	19	0.06%	46,500	20,000	189	0.05%
	8B	521	95,892	50	0.15%	70,000	30,000	749	0.20%
Gasoline	Subtotal			5,878	18.10%			4,086	1.08%
	TOTALS:			32,475	100.0%			377,914	100.0%

These data show that 68.44% and 10.77% of the long-haul truck VMT are due to Diesel-fueled, Class 8B and 8A trucks, respectively. A surprisingly large fraction (16.75%) of the long-haul truck VMT is attributed to class 2 trucks. To account for the differing amounts of freight that is carried by each truck class, an estimate of ton-miles attributable to each class was made. These estimates, based on the GVWR of the truck class, are also shown in Table 2-3. The resulting distribution of ton-miles of freight shows that 88% and 9% of the ton-miles of long-haul freight are carried in Diesel-fueled, class 8B and 8A trucks, respectively. This confirms the assumption that the Diesel-fueled, Class 8B truck (with some consideration of class 8A) can be used to characterize intercity freight.

Alternative Fuels

A final topic of discussion related to on-highway truck emissions is the calculation of emissions from alternative fuel vehicles, which is not possible with available emission factor models (i.e., MOBILE5a, PART5, and EMFAC7F). That is unfortunate, since alternative fuel vehicles are often considered by air quality planners when evaluating control measure options. For that reason, and because repowering locomotives with alternative fuels has also been considered as a control option, the following provides a description of how to calculate emissions from heavy-duty Diesel vehicles that have been converted to alternative fuels.

To account for the impact of alternative fuels on heavy-duty Diesel vehicle emissions, two adjustments have to be made: (1) the g/bhp-hr emission factor (by model year) must reflect emissions from an alternative fuel engine, and (2) the conversion factor must be adjusted to account for the lower energy efficiency of an alternative fuel engine relative to Diesel fuel. For natural gas engines (which, at this time, appear to be the most likely choice for Class 8B trucks), emission rates can be estimated from available test data and from EPA and CARB certification data. For example, a report prepared to support a CARB proposal for more stringent NOx and particulate emission standards for heavy-duty engines[8] lists emission rates for Diesel and natural gas heavy-duty engines (as well as methanol and liquified petroleum gas). Data from that report include emission rates for a 240 horsepower, natural gas Cummins L-10 engine and a similar Diesel version of the same engine (280 horsepower). The natural gas engine (which has been certified by CARB) has a NOx emission rate of 2.0 g/bhp-hr, while the Diesel engine (certified by EPA to 1992 emission standards, i.e., 5.0 g/bhp-hr NOx) has a NOx emission rate of 4.3 g/bhp-hr.*

The above g/bhp-hr emission rates can be converted to g/mi emission rates by applying the Class 8B conversion factor. However, an adjustment must first be made to account for the relatively lower fuel economy of engines powered with natural gas compared to Diesel fuel. Reference 7 indicates that natural gas engines experience an approximate 25% reduction in Diesel-equivalent fuel economy when compared to Diesel engines. Thus, the conversion factor must be adjusted accordingly. This adjustment is performed by dividing the Class 8B conversion factor (which is 3.13 for 1987 and later model year vehicles) by 0.75, yielding a natural gas engine conversion factor of 4.17. Using these conversion factors in conjunction with the g/bhp-hr emission rates results in the following g/mi NOx emission estimates for the Diesel and natural gas versions of this engine:

$$NOx_{Diesel} = 4.3 \text{ g/bhp-hr} * 3.13 \text{ bhp-hr/mi} = 13.46 \text{ g/mi}$$

$$NOx_{Natural\ Gas} = 2.0 \text{ g/bhp-hr} * 4.17 \text{ bhp-hr/mi} = 8.34 \text{ g/mi}$$

*The Cummins L-10 engine was designed primarily for use in transit buses. However, the approach outlined here for this engine could be applied to an engine designed for use in a Class 8B truck.

Thus, using natural gas in this application would result in a 38% reduction in NOx emissions. However, it should be noted that this estimate is based on certification data, which are generally lower than in-use emission rates. However, there is no information available on in-use deterioration of natural gas engines (or Diesel, for that matter).

Estimating the Emissions Impacts of Congestion

Measures that shift the transport of freight can have secondary impacts which reduce the general congestion of traffic. An example of this is the installation of grade-separated crossings in urban areas, with a concomitant reduction in congestion. In order to determine the emission benefits of such measures it is first necessary to determine the improvements in traffic flow. The emission benefits can be estimated by using the speed correction factor defined above.

Traffic planners often measure congestion in terms of level of service (LOS) or volume-to-capacity ratio (v/c). The Highway Capacity Manual[9] defines six levels of service, from A to F, with A representing the best operating conditions and F representing the worst. The v/c ratio, which is the volume of vehicles on a given highway segment (in vehicles per hour) divided by the capacity of that segment(i.e., the maximum rate at which vehicles can reasonably be expected to traverse a roadway in a given time period), is also used as a measure of congestion. Unfortunately, neither of those measures of congestion lend themselves to emissions analysis with standard emission factor models.

Although some work on emission estimates as a function of LOS has been conducted in recent years,[*] the primary means of estimating emission impacts from changes in congestion levels remains the speed correction factors built into the MOBILE and EMFAC models. Models developed to estimate the impacts of transportation control measures (e.g., TCMTOOLS) generally make use of this approach. As described previously, the speed correction factors have certain limitations (particularly for heavy-duty Diesel trucks), but few other options exist to estimate the emission impact of changes in congestion levels.

An example of the existing approach follows: Consider a one-mile section of a six-lane freeway that carries an average of 2,200 vehicles per lane per hour during the three-hour morning commute period. Assume that the average speed during that period is 35 mph. If a congestion mitigation measure is implemented that changes the average speed from 35 to 40 mph (for one direction), the emissions impact of that measure can be calculated as follows.

[*] For example, CARB has developed driving cycles for different roadway types (e.g., freeways, arterials, etc.) based on LOS. Those driving cycles were developed from chase car data collected in Los Angeles. However, since LOS is difficult to measure at the time drive cycle data are being collected, the LOS assignment for a particular drive or highway segment is somewhat subjective. For that reason, CARB has not incorporated an LOS parameter into its emission modeling efforts.

- The VMT affected by this measure is simply:

  - 1 mi × 3 lanes × 3 hr × 2,200 veh/lane-hr = 19,800 mi.

- The CO emission rates (calculated by MOBILE5a for a fleet of vehicles subject to a basic I/M program) under winter temperature conditions and the two speeds considered above are:

  - $CO_{35\text{ mph}}$ = 18.47 g/mi, and

  - $CO_{40\text{ mph}}$ = 16.67 g/mi.

- The CO emission impact of this measure is then:

  - $\Delta CO = (CO_{35\text{ mph}} - CO_{40\text{ mph}}) \times VMT$

  - ΔCO = (18.47 g/mi - 16.67 g/mi) × 19,800 mi = 79 lbs. CO

Note that the calculation above resulted in a CO emission reduction as a result of improving traffic flow (and hence, average speed). The same would not be true of NOx emissions, which are predicted by MOBILE5a to *increase* as speed increases over the range of speeds considered above. Also note that the calculation above was performed for the entire fleet of vehicles, not just Class 8B trucks. Although a particular measure might be aimed at removing a certain vehicle type from the roadway network, it will impact the operating conditions of the remaining vehicles traveling on the network. Thus, that emission impact should be accounted for when making comparisons among control measures.

Calculation of Railroad Emissions

Background: The operation of Diesel engines on locomotives is different from the operation of Diesel engines on trucks. Not only are the basic engine designs different--locomotive engines have higher power output for a given engine size and operate at lower engine speeds--but the variation in the load demand on the engine is also different. Truck engines are directly coupled to the drive wheels and are subject to transient operation. In the Diesel-electric locomotive power plant, the Diesel engine drives a generator which produces electric power. The electric power in turn drives electric wheel motors which can produce the large torque at low train speeds required for rail operation. Locomotive engine controls are based on "notch settings" which typically use eight power notches between the lowest power setting and the maximum ("notch eight") power output. In addition to these power settings, there are engine settings for idle and dynamic brake. The latter refers to the condition used on downgrades, where the wheel motors are run as generators to provide extra braking. The power generated is dissipated in a bank of electrical resistors. Some engines have more than one setting for idle and dynamic brake.

Because of the steady-state operation of locomotive Diesel engines, the overall operation of locomotives can be characterized by a duty cycle which represents the time spent in each notch position. Once the power output, emissions and fuel use in each notch position are known it is a simple matter to compute the average fuel use and average emission factor from equations like the following:

$$\frac{g}{bhp\text{-}hr} = \frac{\sum_{i=1}^{N} t_i \; e_i}{\sum_{i=1}^{N} t_i \; p_i}$$

$$\frac{lb}{MMBTU} = \frac{\left(\frac{1\ lb}{453.59\ g}\right) \sum_{i=1}^{N} t_i \; e_i}{Q_c \sum_{i=1}^{N} t_i \; f_i}$$

In these equations,

t_i = the fraction of time spent in notch i;

e_i = the emission rate (grams/hour) in notch i;

p_i = the engine brake horsepower in notch i;

f_i = the fuel rate (pounds/hour) in notch i; and

Q_c = the heat of combustion of the fuel (MMBTU/pound).

Aggregate emission factors for rail depend on the locomotive fleet (which determines the values for the emission rates, fuel rates and power settings in each notch) and the duty cycle (which determines the relative amount of time in each notch setting). As discussed below, different kinds of rail operations can have different duty cycles which will lead to different average emissions from the same locomotive.

Rail energy use is determined by similar parameters to truck fuel use--rolling friction, aerodynamic drag, and acceleration and hill climbing energy that is eventually dissipated in braking. High-speed trains consume more energy per mile than lower speed trains. In the normal operation of Diesel-electric locomotives, a train in the maximum power setting (notch eight) will ultimately reach a maximum speed determined by the overall resistance. The maximum train speed increases as the available engine power--expressed as engine horsepower per trailing ton--increases.* This leads to the use of horsepower per trailing ton as a rough indicator of freight fuel efficiency for rail. Low values are less than 1 HP/ton and high values are greater than 3 HP/ton.

Freight fuel use is important in emission calculations because these calculations use fuel-based emission factors. These factors are taken from the standard EPA inventory handbook, AP-42.[10] The rail emission factors have been recently updated and will be included in the next revision of AP-42.[11]

General Methodology for Emission Computation: The recommended EPA method for computing rail emissions divides the railroad fleet in a local area into yard locomotives (used for switching) and line-haul locomotives. The latter includes both passenger and freight locomotives. The emission factors for line-haul locomotives are shown in Table 2-4. The use of these factors in any given nonattainment region requires a determination of the fuel used in that region. EPA recommends the following procedures for obtaining local fuel use data.

For Class I railroads,** national fuel use rates, in terms of gallons per ton-mile of freight, are contained in annual submittals to the Interstate Commerce Commission (ICC), and data on the ton-miles of freight carried on tracks in the local nonattainment are generally known by the individual railroad(s) operating in the area. However, these data are considered proprietary, and would not be readily obtainable. The ratio of total fuel used to total freight carried based on national data is multiplied by the amount of local freight carried to obtain the local fuel use. This local fuel use is then multiplied by the line-haul emission factors in Table 2-4 to obtain the overall emissions.

*There are three separate measures of railroad ton-miles. Gross ton-miles are based on the total weight of the train, including locomotives, full and empty railcars, and the total freight (lading). Trailing ton-miles exclude the weight of the locomotives when calculating the weight of the train. Revenue ton-ton miles consider only the freight (lading). The revenue ton-miles are about half the gross ton-miles.

** Railroads are classified as Class I, Class II or Class III depending on their revenues. The ICC filing requirements apply to Class I railroads only. These railroads, which had an annual revenue greater than $253.7 million in 1993, accounted for 91% of the freight revenues that year. (The annual revenue figure that defines Class 1 railroads is adjusted annually.)

Table 2-4 Line-Haul Locomotive Emission Factors (pounds per gallon of fuel burned)	
Species	Factor
Hydrocarbons (HC)	0.0211
Carbon Monoxide (CO)	0.0626
Oxides of Nitrogen (NOx)	0.4931
Particulate Matter (PM)	0.0116
Sulfur Dioxide (SO_2)	0.0360
Note: The SO_2 factor is based on a fuel sulfur content of 0.25% by weight.	

Data for Class II and Class III railroads must be obtained from individual railroads. In many cases these railroads operate in local areas only and their total fuel use may be used to obtain their emissions. Where these railroads operate in more than one inventory area it is necessary to obtain an estimate, from the railroad, of the fuel used in the specific inventory area of interest. Since the Class II and III railroads are not required to keep track of fuel consumption, there are questions as to the availability and reliability of these data.

The emissions from yard locomotives are based on a separate duty cycle for yard operations and a national locomotive roster for yard operations. These emission factors are shown in Table 2-5 on the following page. This table shows both the fuel-based emission factors and the annual emissions from a yard locomotive assuming operation 365 days a year. This figure should be adjusted downward if the yard operation is less frequent. In addition, this figure should be multiplied by the number of locomotives normally in service. (In actual operation, there will be some standby yard locomotives that are placed in service when locomotives in normal use are repaired or inspected.)

Table 2-5 Yard Locomotive Emissions		
Species	Emission Factor (pounds per gallon of fuel burned)	Annual Emissions (pounds per locomotive-year)
Hydrocarbons (HC)	0.0506	4,174
Carbon Monoxide (CO)	0.0894	7,375
Oxides of Nitrogen (NOx)	0.5044	41,608
Particulate Matter (PM)	0.0138	1,138
Sulfur Dioxide (SO_2)	0.0360	3,075
Note: The SO_2 factor is based on a fuel sulfur content of 0.25% by weight.		

Depending on the data available for actual inventory, the emission factors shown for yard and line-haul locomotives can be modified to obtain a more accurate inventory. This can be done in the way listed below.

1. Adjusting the SO_2 emission factor to account for the actual fuel sulfur content.
2. Accounting for the actual composition of the locomotive fleet in a local area. This requires the use of specific emission factors (in pounds per gallon) for each locomotive type used in the area. This can also be done in determining project emissions for permit applications.
3. Using the actual locomotive duty cycle(s) for an area or project. This is usually not feasible for an area inventory unless a study has already been done. However, for individual projects, the railroad involved can run a train performance simulator to determine the actual fuel use. This can be combined with locomotive-specific emission factors to obtain a fairly accurate emission estimate for the project.

Derivation of Emission Factors for Rail: The latest EPA emission factors were based on a study of locomotive emissions in California that was sponsored by the California Air Resources Board.[12] The inventory year for that study was 1987. That work evaluated the locomotive duty cycle, for both line-haul and yard operations, by reviewing data tapes from individual routes in California nonattainment areas. These data tapes were used to determine the amount of time that the locomotive engine spent in each throttle notch for specific routes in each area studied. Locomotive data on emission rates and fuel rates for each notch position were then used to compute average emissions and fuel use. In addition, data on the gross ton miles for these routes were obtained. California-specific locomotive rosters were used to obtain the emission estimates in that study. The EPA emission factors, shown in Tables 2-4 and 2-5, are based on a national locomotive roster.

Instead of just two train types (line-haul and yard) this study considered five types, each of which is described below.

1. Mixed freight (including bulk freight). Mixed freight trains carry all types of equipment and operate with a range of engine power to train weight ratios. Bulk trains are large unit trains which are characterized by lower speeds and small fuel use per unit of freight carried. Because bulk train use is a small amount of California rail operations, this train type was combined with mixed freight for the California inventory.
2. Intermodal. This service is classified as trailer-on-flat-car (TOFC) or container-on-flat-car (COFC). Trains that include a number of cars with containers stacked two-high are usually referred to as double stack trains. (There are usually 10 containers per car on a double-stack train.) Intermodal service is generally high-speed service with high locomotive horsepower for a given train weight. Such trains typically use more fuel per amount of freight carried than mixed freight.
3. Local service. This is used to deliver freight cars from a central yard to local facilities which have rail lines. It is characterized by low locomotive horsepower.
4. Yard service. This is the operation of switching freight cars from one train to another. This service typically uses older, low-power engines.
5. Passenger service. This includes both commuter rail and intercity passenger rail. Passenger rail usually uses high-power locomotives to provide high speed transportation.

The differences in emission factors for these different service types are shown in Table 2-6 on the following page. There are some cases (e.g., HC and CO emissions for passenger trains) where there is a significant difference in the emissions factor. However, the variation in emission factors for various train services is 13.1% for NOx and 15.3% for PM, the two most significant pollutants from Diesel engines.

Table 2-6
Differences in Emission Factors for California Operations in 1987[12]
Units of pounds per gallon of fuel burned

Train Type	HC	CO	NOx	SOx	PM
Mixed Freight	.022	.066	.500	.038	.011
Intermodal	.0203	.0661	.500	.0367	.0108
Local Trains	.0241	.0768	.535	.040	.0115
Yard Operations	.032	.0806	.550	.030	.0125
Passenger Trains	.015	.035	.483	.035	.0108
Weighted Average	.022	.0684	.512	.0371	.0111

The data in reference 12 were expressed not only in terms of the conventional emission factor (pounds per gallon), but also in terms of emissions per gross ton-mile of freight. Converting emissions per gallon of fuel used to emissions per ton-mile of freight requires some measure of the fuel use per ton-mile of freight. The values of this fuel use for California were much greater than the national average. Several reasons were proposed for this difference:

- a higher level of switching operations,
- more hilly terrain compared to the rest of the U.S.,
- a higher level of intermodal operations which are less fuel efficient than other freight types, and
- a lack of any significant "bulk train" component in freight operations.

A California rail inventory for 1990 was developed for EPA,[13] using the methods of reference 12 and the standard EPA method of AP-42. This comparison showed great discrepancies between the two approaches. The main factor in the discrepancy was the difference in the fuel used by the individual trains. There was little difference in the pound-per-gallon emission factors. This study shows the importance of using locally generated emission factors if the necessary data are available.

Future Locomotive Emissions: The AP-42 data for railroad emissions are based on the current generation of locomotives for which there are no emission regulations. The 1990 Clean Air Act Amendments required the EPA to promulgate regulations for new locomotives and new engines in locomotives by November 15, 1995.* Although EPA has not yet made a formal proposal as a notice of proposed rulemaking (NPRM) for locomotive emissions, it did consider the potential of such a regulation during development of a Federal Implementation Plan (FIP) for three areas in California.**

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*Section 213(a)(5) requires the EPA Administrator to set standards for "new locomotives and new engines used in locomotives." This section further states that these standards shall

achieve the greatest degree of emission reduction achievable through the application of technology which the Administrator determines will be available for the locomotives or engines to which such standards apply, giving appropriate consideration to the cost of applying such technology within the period of time available to manufacturers and to noise, energy, and safety factors associated with the application of such technology.

Sections 213(b) requires standards to take effect "at the earliest possible date considering the lead time necessary to permit the development and application of the requisite technology, giving appropriate consideration to the cost of compliance within such period and energy and safety."

Section 209 prohibits all states from adopting "any standard or other requirement relating to the control of emissions" from "new locomotives or new engines used in locomotives."

**The FIP for the South Coast, Ventura, and Sacramento areas was required as a result of a suit against EPA under the provisions of the 1977 amendments to the Clean Air Act. The proposed FIP was published in the Federal Register on May 5, 1994. The final FIP was promulgated by EPA on February 15, 1995. Before the FIP was published in the Federal Register, it was rescinded by a provision of Public Law 104-6. However, an electronic copy of the proposed text for the final FIP is available from the EPA bulletin board.

Because the main focus of the FIP was on ozone attainment, the only pollutant addressed in the FIP was NOx. EPA is likely to set emission standards for other criteria pollutants from locomotives just as it has done for other off-road engines. However, there was no discussion of these likely emission standards in the FIP.

EPA's plans for locomotive controls, as stated in the FIP,[14] call for NOx standards for both newly manufactured locomotives (in the year 2000 and later) and for existing locomotives (first built between January 1, 1973 and December 31, 1999) at the time that they are remanufactured. EPA considers both newly manufactured locomotives and remanufactured locomotive engines to be "new" within the meaning of its Clean Air Act authority. EPA expects the standards for locomotives first manufactured after January 1, 2000, to be in two tiers. The first tier, effective between 2000 and 2004, is expected to achieve a 50% reduction in NOx. The second tier, effective in 2005 and later, is expected to achieve a 65% reduction in NOx. Because of the long life of locomotives these reductions (expressed as a percent reduction in emissions from freshly manufactured engines) are not expected to be achieved over the entire locomotive fleet until 2040 to 2045.

Standards for locomotives manufactured between January 1, 1973, and December 31, 1999, are expected to reduce emissions from these locomotive by 33%. Locomotives will have to meet these standards the first time they are remanufactured after January 1, 2000. Locomotives first manufactured after January 1, 2000, will have to meet their new locomotive standards any time they are remanufactured. This will presumably apply to locomotives manufactured between January 1, 1973 and December 31, 1999. At any subsequent remanufacture, after the initial remanufacture when they meet the emission standards, these locomotives will have to achieve the same emissions level as they did at the initial remanufacture.

Any future consideration of locomotive emissions in inventory preparation will have to include the effect of these regulations in the emission forecasts. In addition, consideration of fuel-based emission factors should account for any projected improvement in fuel economy. Railroad fuel economy has increased from 235 revenue ton-miles per gallon in 1980 to 359 revenue ton-miles per gallon in 1993.[15] A linear regression of the past data has a slope of 10.05 revenue ton-miles per gallon per year with an R^2 value of 0.98. This regression forecasts a value of 435 revenue ton-miles per gallon in 2000. However, the most recent data (1991 to 1993) show a nearly constant value for fuel economy. Introduction of newer locomotives, with higher horsepower and AC traction, are likely to increase the fuel economy, but there is no formal forecast of this fuel economy as there is for trucks in the EPA PART5 model. A method for forecasting rail fuel consumption will have to be developed for predicting future rail emissions under Task 3 of this project.

Alternative Fuels for Locomotives: The debate over the use of alternative fuels in locomotives is presented in a recent report prepared by EF&EE, a contractor to CARB.[16] That report and the industry response (contained in an Appendix) take opposite sides on the feasibility of operation on liquified natural gas (LNG) fuel. Both the EF&EE report and the railroads recognize LNG as the most likely alternative fuel. The EF&EE report cites the successful operation of stationary LNG engines (with NOx levels as low as 1.5

g/bhp-hr) and the ongoing demonstration of LNG retrofits on two Burlington Northern (BN) locomotives (cited in the railroad comments as achieving 3.8 g/bhp-hr of NOx at maximum power output)* as significant evidence to justify a locomotive emission standard that is based on the use of LNG. The railroads state that additional tests are required before the feasibility of routine LNG operations in locomotives can be claimed.

Use of LNG (or compressed natural gas, CNG) in Diesel engines is possible in one of three ways:

- Conversion of the Diesel engine to a spark-ignition engine. This causes a loss in rated power of the engine.
- Use of a dual fuel engine (sometimes called low-pressure injection). In this application natural gas is injected with the combustion air, as in a spark-ignition engine. However, ignition is obtained by injecting a small amount of Diesel fuel which is ignited by the normal compression-ignition process of a Diesel engine. The BN demonstration locomotives use dual-fuel engines.
- Direct injection of natural gas (DING), in place of Diesel fuel, into the engine cylinders with compression-ignition as with Diesel fuel. This approach is likely to provide the best specific power output and efficiency, but is also likely to have the least effect on reducing NOx emissions.

At present, Union Pacific and Santa Fe are conducting demonstrations of 1,350 HP spark-ignition LNG engines on yard locomotives. In addition, Union Pacific is expecting delivery of demonstration locomotives with direct-injection natural gas engines from the Electromotive Division of General Motors and from General Electric Transportation Systems. Demonstrations of these locomotives are expected to last until at least the end of 1996

Based on the results for stationary engines, it appears that LNG operation can achieve lower NOx emissions. However, the costs and actual emission levels for LNG operation on locomotives are not known at this time (June 1995). There does not appear to be any serious consideration of other alternative fuels for locomotive applications.

Conclusions on Calculation of Rail Emissions: Calculation of rail emissions in a local area requires an estimate of the amount of yard and local train operations. This provides the information required for applying the basic EPA inventory approach. The accuracy of the emission estimate can be improved by obtaining local information on fleet composition, duty cycle, and sulfur content. Any inventory projections beyond 2000 should account for future regulations on emissions from new and remanufactured locomotives.

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*Both the EF&EE report and the railroad comments note that the reduced NOx emissions with LNG operation, for the BN retrofits, cause a significant increase in hydrocarbon emissions.

Other Freight Modes

Although truck and rail freight account for the majority of intercity freight, freight transport by air, marine vessel and pipeline accounted for 43.2% of the tonnage and 48.1% of the ton-miles of intercity freight in 1991.Error! Bookmark not defined. The emissions from marine vessels may be computed using fuel-based emission factors from AP-42.0 The rai Aircraft emissions, also from AP-42, are generally expressed in terms of the emissions on a landing-take-off (LTO) cycle. This represents the emissions that actually occur close enough to ground level to affect the air quality in an urban region. These emission rates depend on the aircraft engines and the nature of the operating cycle (i.e., the time in each operating mode including descent, landing, taxiing, takeoff and climb to altitude). Airport ground vehicle operations and local truck emissions for transporting freight from a shipper to the airport should also be considered in determining the emissions from air freight operations. Emissions from pipeline operations are associated with the stationary engines used to compress or pump the pipeline fluids. The emission calculations for these engines use fuel-based emission factors from AP-42.

The scope of this study is mainly aimed at truck and rail freight where actions of metropolitan planning organizations (MPOs) have the greatest possibility of effecting changes in emissions. Air freight and pipelines generally have captive markets which will not be affected significantly by any policy changes.

■ Determination of Emission Factors for Freight Operations

The literature review has described previous attempts to develop estimates of the emissions from freight operations. That review also discussed the potential problems associated with obtaining an accurate picture of the actual vehicle operations in intercity freight (as opposed to the EPA certification cycles which are based on urban driving). Based on the findings of the literature review, the procedures outlined below will be used to develop emission factors for Task 3.

These procedures will be applied to individual components of a freight movement. The application of these factors to a particular strategy will require the analyst to determine the specific components that are used for the freight movements affected by the proposed strategy. The individual components that will be considered include the following long-distance steps:

1. Shipper to receiver via line-haul truck,
2. Truck terminal to truck terminal via line-haul truck,
3. Rail terminal to rail terminal via line-haul rail, and
4. Shipper to receiver by bulk rail.

In addition to these long-distance steps, the following components at the start and end of intercity freight movements will be considered:

5. Shipper to truck terminal by truck,
6. Shipper to rail terminal by truck or local rail,
7. Truck terminal to receiver by truck,
8. Rail terminal to receiver by truck or local rail, and
9. Transfers between terminals by truck or rail.

Each of these freight components will be characterized by a particular vehicle fleet (truck or rail), a vehicle speed (rural, urban, congested urban), and a fleet age (normal age distribution, "older" fleet, or "newer" fleet). These characterizations are discussed further below.

The following procedure will be used to develop emission factors for the various components of intercity freight operations.

1. Determine the types of vehicles involved in each step of freight transit. The following kinds of vehicles should be considered:

    a. Heavy-duty trucks, by truck class, with a normal age distribution.

    b. Heavy-duty trucks, by truck class, with an older than normal distribution. Such vehicles may be used in drayage operations.

    c. Heavy-duty trucks, by truck class, with a newer than normal distribution. Such vehicles may be used to replace older vehicles in incentive-based strategies. Line-haul fleet may also be characterized as "newer" vehicles.

    d. Line-haul trains used in intermodal freight, mixed freight, and bulk freight.

    e. Yard and local rail operations that are required for rail freight.

    f. Alternative-fuel vehicles which may be used in incentive-based replacement strategies.

    Emissions data for each of the vehicle classes listed above should be developed for different calendar years to reflect the expected decrease in emissions with future regulations and fleet turnover. In addition to the emission factors in the MOBILE model, it will be necessary to consider the potential for new emission standards beyond the 2004 model year that will result from the recent agreement between the Diesel engine industry, CARB and EPA. This can be accommodated by reducing the emission factors from MOBILE for 2004 and later model years.

    The development of "older" and "newer" than normal truck age distributions could be done in a variety of ways. The simplest approach is to assume that an "older" fleet is typical of a truck operator who purchases only used trucks. Thus, in any calendar year, the newest truck in the "older" fleet will be Y years older than the calendar year. Similarly, the easiest approach to the "newer" age distribution is to assume that such a fleet consists of trucks that, in any calendar year, are no older than y years. Although emission factors can be developed for "newer" and "older" fleets the use of such factors should be based on specific information about the truck fleets that are characterized as newer or older. Such information would be obtained by surveys of local fleets.

The distinction between newer and older fleets for railroads can be done in terms of the locomotive use. Newer locomotives are used in line-haul applications and older locomotives are used in local and yard applications. The emission factors developed for rail emissions already incorporate these different fleet distributions.

2. For each of the truck groups (a to c) listed in step 1, it will be necessary to determine the distribution of trucks among vehicle classes. As discussed in the literature review, it is possible to generate class-specific emission factors for heavy-duty trucks. Such factors can then be weighted by the distribution of the different truck classes expected to be used in different freight operations. Table 2-3 in an earlier section indicates that Diesel-fueled Class 8B and 8A trucks account for 88.22% and 9.25%, respectively, of the long-distance freight ton-miles. Diesel-fueled Class 7 trucks account for an additional 1.20%. The remaining 1.33% are carried on a variety of truck classes with 1.08% on gasoline-fueled trucks and 0.25% on Diesel-fueled trucks.

3 These data suggest that terminal-to-terminal (or shipper-to-receiver) truck freight can be modeled as a Diesel-fueled truck fleet that consists solely of Class 7, 8A, and 8B trucks with the weights listed above. Additional examination of the truck fleet used between shippers and terminals or terminals and receivers must be considered to characterize such truck fleets. A useful initial assumption is that such truck fleets are similar to the long-distance truck fleets.

4. Develop the class-specific emission factors for the truck groups from the emissions data used to construct the MOBILE model. These can be used with the weighting factors developed in step 3 to obtain freight mode-specific emission factors. Such factors, derived from MOBILE, apply to trucks with a normal age distribution. These factors decrease with each increasing calendar year due to fleet turnover with newer trucks meeting more stringent emission standards.

   Some consideration will be given to the speed correction factors that are used for intercity freight. At a minimum, appropriate speeds will be selected and the conventional speed correction factor will be used. The results will be presented for on-highway speeds, typical urban speeds, and congested urban speeds.

5. For rail emissions it will be necessary to determine the appropriate mix of train operating modes (intermodal, mixed, bulk, local, and yard). From this distribution a set of fuel-based emission factors can be developed that reflect the appropriate mix of rail modes. In addition it will be necessary to account for the following factors in determining future rail emissions factors:

   - The expected EPA standards for new and remanufactured locomotives. These will be taken from EPA proposals in the California FIP unless the notice of proposed rulemaking (NPRM) for the locomotive emission standards is published prior to the completion of this study.

- The rate of introduction of new locomotives that meet the standard and the rate of remanufacturing of existing locomotives to meet the remanufacturing standards.

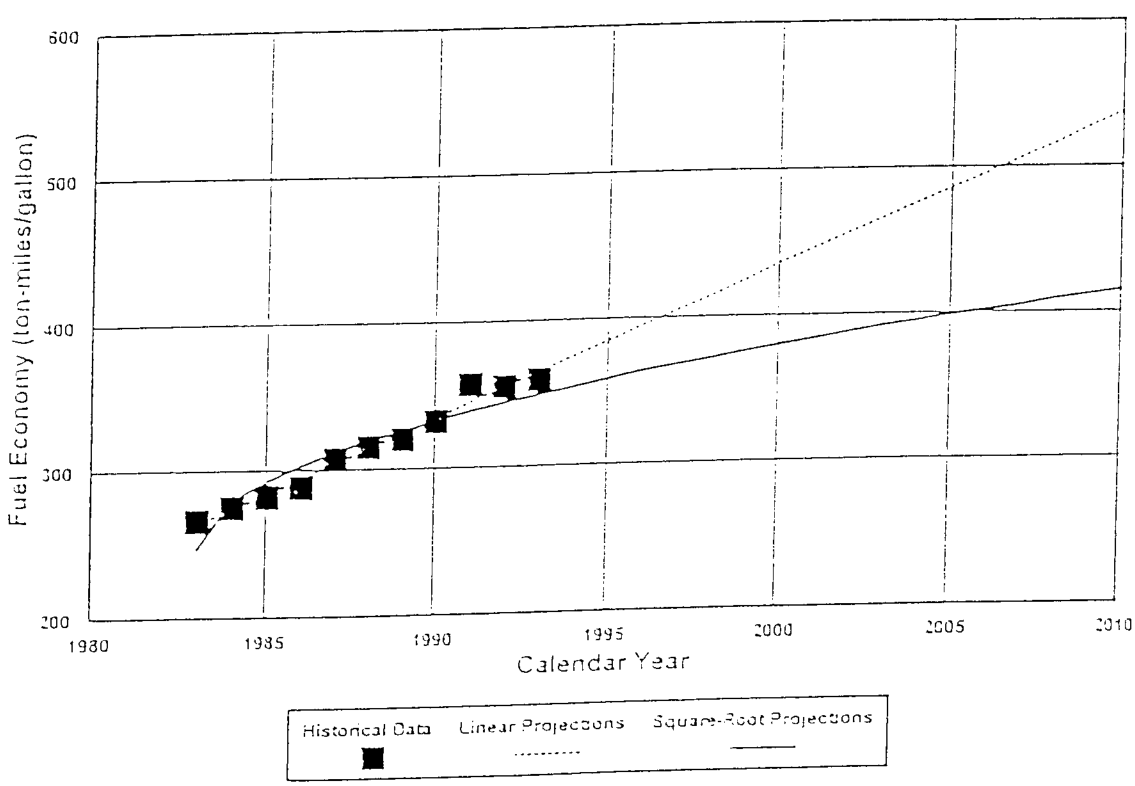
- Improvements in rail fuel economy to be used with the fuel-based emission factors for locomotive emissions. This is discussed further below

As noted in the literature review, there is no standard forecast of rail fuel economy as there is for trucks in the MOBILE model. Two possible projections for Rail fuel economy are shown in Figure 4; a linear projection and a square root projection. (The latter projection assumes that the future year fuel use is proportional to $\sqrt{(year\ -\ base\ year)}$). The linear projection has a better fit to the existing data, but the square-root projection is guided by the leveling of fuel-economy improvements in recent years. This also implies that the most significant improvements have already been made and future improvements will be less significant

The final selection of a projection methodology will be based on a consideration of expected technology to accomplish the actual reductions. (Alternatively, the choice of projection methodology could be left to the user.)

Figure 2.4

Railroad Fuel Economy with Projections



6. The emission impacts from changes in freight operations on other traffic and overall congestion levels (so-called "secondary" emissions impacts) will be evaluated using the standard speed correction factor equations. An example of this was presented in the literature review. Note that this requires some external model for predicting the speed change due to the chosen strategy.

7. The effect of load on emissions will be considered. This is necessary to evaluate the emission benefits of reducing empty backhauls.

The steps outlined above will provide a general approach to developing emission factors. This will result in specific emission factors that can be applied to the various strategies that will be considered in Task 3. These emission factors are expected to have certain assumptions about the nature of the vehicle fleets considered. The emission factor development will be presented, as well as the final results, so that individual users can substitute local data on fleet composition to obtain a more accurate picture of the emission reductions available from a particular strategy.

The proposed general approach just described should be adequate for most strategies. However, this general approach will have to be tailored for application to each specific strategy. The units used for emission factors (grams per mile, grams per ton-mile, pounds per gallon of fuel, etc.) will also be tailored to the type of data expected to be available for a particular strategy.

References

1. Stacy C. Davis, "Transportation Energy Data Book: Edition 14", Oak Ridge National Laboratory, Report ORNL-6798, May 1994.

2. "Heavy-Duty Vehicle Cycle Development," prepared by Systems Control, Inc. [Formerly Olson Laboratories], for the U.S. Environmental Protection Agency, July 1978.

3. T. Wysor, and C. France, "Selection of Transient Cycles for Heavy-Duty Vehicles," U.S. Environmental Protection Agency, June 1978.

4.C. France, "Transient Cycle Arrangement for Heavy-Duty Engine and Chassis Emission Testing," U.S. Environmental Protection Agency, August 1978.

5.M. Smith, "Heavy-Duty Vehicle Emission Conversion Factors 1962 - 1997," U.S. Environmental Protection Agency, August 1984.

6.P. Machiele, "Heavy-Duty Vehicle Emission Conversion Factors II 1962 - 2000," U.S. Environmental Protection Agency, October 1988.

7."Analysis of Heavy Duty Truck Fuel Efficiency to 2001," prepared by Energy and Environmental Analysis, Inc., for the U.S. Environmental Protection Agency, Energy Policy Branch, September 1991.

8."Technical Feasibility of Reducing NOx and Particulate Emissions from Heavy-Duty Engines," prepared by Acurex Environmental Corporation, for the California Air Resources Board, April 1993.

9."Highway Capacity Manual," Special Report 209, Transportation Research Board, National Research Council, 1985.

10."Handbook of Air Pollution Emission Factors," U.S. Environmental Protection Agency, AP-42, 1985. (With supplements A through F, 1993).

11."Locomotive Emission Factors for Inventory Guidance Document," U.S. Environmental Protection Agency Office of Mobile Sources, June 1991.

12."Locomotive Emission Study," prepared by Booz·Allen & Hamilton, Inc., for California Air Resources Board January 1991.

13.Arlene S. Rosenbaum and R.E. Rypinski, "1990 Emissions from Diesel Locomotives in Three California Federal Implementation Plan Areas," Draft Report prepared for U.S. Environmental Protection Agency, Systems Applications International, SYSAPP93/93-232, San Rafael, CA, November 5, 1993.

14."Approval and Promulgation of State and Federal Implementation Plans; California--Sacramento and Ventura Ozone; South Coast Ozone and Carbon Monoxide," Available on EPA TTN bulletin board as file CALFIPRU.ZIP, February 16, 1995.

15."Railroad Facts," Association of American Railroads, 1996, page 40.

16.Christopher S. Weaver and D.B. McGregor, "Controlling Locomotive Emissions in California," Engine, Fuel and Emissions Engineering, Inc., Report under California Air Resources Board contract numbers A032-169 and 92-917, March 29, 1995. Appendix E to this report, a separate volume, contains industry comments submitted in response to a draft final report.

A-5: Freight Emissions Factors

(authored by Sierra Research)

A-5 Freight Emission Factors

■ Introduction

The emissions from freight movements by truck or rail can be computed from the emission factors presented in this section. The basic approach to determining the emissions from freight movements consists of two steps. The first step is the determination of the activity level. This must be done for individual legs of a freight shipment from an origin to a destination. In some cases, there may be only a single step (e.g., a direct truck shipment from the origin to the destination). In other cases, there may be various legs (e.g., drayage from the origin to a rail terminal, line-haul rail from the rail terminal to an intermediate rail terminal, drayage from one intermediate rail terminal to another, line-haul rail from the second intermediate terminal to the final rail terminal, and drayage from the final rail terminal to the destination). It is necessary to determine the activity level for each leg. The activity level is determined as (1) the total miles traveled by trucks or (2) the total fuel used by rail.

The basic approach accounts only for the activity involved in the actual shipment. The effects of empty back hauls, if any, must be handled separately.

The second step, once the activity levels are determined, is to multiply the activity levels by the appropriate emission factors. These emission factors depend on the calendar year(s) considered and on additional parameters that are selected by the user as described below.

■ Calculating Emissions from Truck Freight

The truck emission factors are given in units of grams per mile. The truck activity, i.e., the total truck miles traveled in a given period (e.g., daily truck VMT), is multiplied by these emission factors and divided by the appropriate unit conversion factor (e.g., 907,180 grams per ton) to obtain the overall emissions during the period (e.g., tons/day). The following questions need to be answered in order to select the appropriate truck emission factors to be used:

1. What calendar year or years are to be considered in the calculation?
2. Is the freight operation a line-haul trip or a drayage trip?
3. Is there any reason to assume that the truck fleet is significantly older or newer than the average age?
4. What is the general traffic environment for the truck operations (congested urban, urban, or rural)?

Table 1
Line Haul and Drayage Emission Rates Based on Default Age Distribution
Valid for Speeds Corresponding to Congested Urban Conditions

Calendar Year	Line Haul Fleet					Drayage Fleet				
	VOC (g/mi)	CO (g/mi)	NOx (g/mi)	SO_2 (g/mi)	PM_{10} (g/mi)	VOC (g/mi)	CO (g/mi)	NOx (g/mi)	SO_2 (g/mi)	PM_{10} (g/mi)
1995	3.52	16.97	19.89	0.527	1.302	3.44	16.58	19.52	0.518	1.278
1996	3.46	16.94	19.02	0.522	1.199	3.39	16.55	18.67	0.513	1.178
1997	3.41	16.91	18.15	0.517	1.096	3.33	16.51	17.82	0.508	1.077
1998	3.35	16.88	17.28	0.512	0.993	3.28	16.48	16.97	0.503	0.977
1999	3.30	16.84	16.41	0.506	0.890	3.22	16.44	16.11	0.498	0.877
2000	3.24	16.81	15.55	0.501	0.787	3.17	16.41	15.26	0.492	0.777
2001	3.20	16.81	14.75	0.496	0.726	3.12	16.40	14.48	0.488	0.716
2002	3.15	16.80	13.96	0.491	0.664	3.07	16.40	13.70	0.483	0.655
2003	3.10	16.79	13.16	0.486	0.603	3.02	16.39	12.91	0.478	0.594
2004	3.05	16.79	12.37	0.481	0.541	2.98	16.38	12.13	0.473	0.533
2005	3.00	16.78	11.57	0.476	0.480	2.93	16.38	11.35	0.469	0.472
2006	2.86	16.78	10.97	0.473	0.454	2.79	16.38	10.76	0.465	0.446
2007	2.72	16.78	10.37	0.469	0.429	2.66	16.37	10.17	0.461	0.421
2008	2.58	16.77	9.77	0.465	0.404	2.52	16.37	9.58	0.458	0.396
2009	2.43	16.77	9.16	0.461	0.379	2.38	16.36	8.99	0.454	0.370
2010	2.29	16.77	8.56	0.457	0.354	2.24	16.36	8.40	0.450	0.345
2011	2.21	16.77	8.28	0.455	0.346	2.17	16.36	8.11	0.448	0.337
2012	2.13	16.77	7.99	0.453	0.338	2.09	16.36	7.83	0.446	0.329
2013	2.06	16.77	7.70	0.451	0.330	2.01	16.36	7.55	0.444	0.321
2014	1.98	16.76	7.42	0.449	0.322	1.94	16.36	7.26	0.442	0.313
2015	1.90	16.76	7.13	0.447	0.314	1.86	16.36	6.98	0.440	0.304
2016	1.85	16.76	7.00	0.446	0.313	1.81	16.36	6.85	0.439	0.303
2017	1.80	16.76	6.87	0.445	0.312	1.76	16.36	6.72	0.438	0.302
2018	1.75	16.76	6.74	0.444	0.311	1.72	16.36	6.59	0.437	0.301
2019	1.71	16.76	6.61	0.443	0.310	1.67	16.36	6.46	0.436	0.300
2020	1.66	16.76	6.48	0.442	0.309	1.62	16.36	6.33	0.435	0.299

The basic truck emission factors are present d in Table 1 for both line-haul and drayage fleets for all calendar years from 1995 to 2020. This table for a default age distribution is used for truck emission factors unless the analyst has data which show that the truck fleet is significantly older or newer than the default age distribution.* The basic truck emission factors in Table 1 are provided for congested urban conditions.** For application to other driving conditions, it is necessary to multiply the emission factors in this table by a speed correction factor. The speed correction factors for VOC, CO, and NOx in three typical traffic regimes are shown in Table 2. There are no speed correction factors for SO_2 or PM_{10}.

Table 2
Speed Correction Factors for Congested Urban Travel, Urban Travel, and Rural Travel

Congestion Level	HC	CO	NOx
Congested Urban	1.00	1.00	1.00
Urban	0.630	0.566	0.874
Rural	0.453	0.544	1.422

Note: The travel conditions described here refer to the following mean speeds: Congested Urban, 20 mph; Urban, 35 mph; Rural, 60 mph.

The following example illustrates the use of these tables. The emissions from a rural line-haul truck route that is 100 miles long with 250 trucks per day are computed for calendar year 2005 by using the following emission factors from Table 1. These factors are used since there is no reason to assume that the truck fleet is older or newer than the default fleet.

VOC = 3.00 g/mi CO = 16.78 g/mi NOx = 11.57 g/mi
SO_2 = 0.476 g/mi PM_{10} = 0.480 g/mi

These factors are then multiplied by the 25,000 daily miles traveled and divided by the unit conversion factor of 453.59 grams/lb to get the following intermediate results:

*The default age distribution is the one used in MOBILE5a. The "newer" and "older"distributions are constructed as follows. The newer distribution consists of trucks that are five years old or less; the older distribution consists of trucks that are six years old or more. More details about these distributions are given below.

**Congested urban conditions correspond to a mean speed of 20 miles per hour. Other conditions are defined in Table 2.

$VOC = 166$ lb/day $CO = 925$ lb/day $NOx = 638$ lb/day
$SO_2 = 26$ lb/day $PM_{10} = 26$ lb/day

The results for VOC, CO and NOx must be multiplied by the speed correction factors for rural routes taken from Table 2. Once this is done, the final emission results are found to be:

$VOC = 75$ lb/day $CO = 503$ lb/day $NOx = 907$ lb/day
$SO_2 = 26$ lb/day $PM_{10} = 26$ lb/day

The use of the speed correction factors in Table 2 is a necessary step in determining the final emissions. The above example shows that the results can change significantly if these speed correction factors are not applied

Consideration of Fleet Age - The results in Table 1 are based on the default truck fleet age distribution taken from the U. S. Environmental Protection Agency's mobile source inventory program, MOBILE5a. This table will normally be used in most calculations. Tables 3 and 4 are provided here to accommodate truck fleets that are known, on the basis of locally generated data, to be older or newer than the default truck fleet.

The "newer" fleet is defined to consist only of vehicles less than or equal to five years old. This would characterize a fleet where new trucks are purchased and retained for only five years. Such fleets have lower emissions because they provide the most rapid implementation of trucks meeting newer, lower emission standards.

Conversely, the "older" fleet is defined as one that consists exclusively of trucks that are at least six years old. This would characterize a truck fleet that relies on the purchase of used trucks and the long-term maintenance of those trucks. The average age of the default fleet is seven years. The average ages of the newer and older fleets are 3 years and 11 years, respectively.

The emission factors in Tables 3 or 4 are not normally used. These tables are only provided to allow individual users to account for locally obtained information that allows them to classify a truck fleet as being particularly old or new.

Table 3 Line Haul and Drayage Emission Rates Based on Newer Age Distribution Valid for Speeds Corresponding to Congested Urban Conditions										
Calendar Year	Line Haul Fleet					Drayage Fleet				
	VOC (g/mi)	CO (g/mi)	NOx (g/mi)	SO_2 (g/mi)	PM_{10} (g/mi)	VOC (g/mi)	CO (g/mi)	NOx (g/mi)	SO_2 (g/mi)	PM_{10} (g/mi)
1995	3.16	15.59	12.90	0.514	0.748	3.08	15.19	12.57	0.505	0.729
1996	3.16	15.58	12.59	0.507	0.661	3.08	15.18	12.27	0.498	0.643
1997	3.16	15.57	12.28	0.499	0.573	3.08	15.17	11.97	0.490	0.557
1998	3.16	15.56	11.97	0.492	0.485	3.08	15.16	11.67	0.483	0.471
1999	3.16	15.55	11.66	0.484	0.397	3.08	15.15	11.37	0.476	0.385
2000	3.16	15.54	11.35	0.477	0.309	3.08	15.14	11.07	0.469	0.299
2001	3.09	15.54	10.91	0.472	0.309	3.01	15.14	10.63	0.464	0.299
2002	3.02	15.53	10.46	0.467	0.309	2.94	15.14	10.19	0.460	0.299
2003	2.95	15.53	10.01	0.463	0.309	2.87	15.13	9.76	0.455	0.299
2004	2.88	15.53	9.56	0.458	0.309	2.81	15.13	9.32	0.450	0.299
2005	2.81	15.53	9.11	0.453	0.309	2.74	15.13	8.88	0.446	0.299
2006	2.56	15.53	8.54	0.451	0.309	2.49	15.13	8.32	0.444	0.299
2007	2.31	15.53	7.96	0.449	0.309	2.25	15.13	7.76	0.442	0.299
2008	2.06	15.53	7.38	0.447	0.309	2.01	15.13	7.19	0.440	0.299
2009	1.81	15.53	6.81	0.445	0.309	1.76	15.13	6.63	0.438	0.299
2010	1.56	15.53	6.23	0.443	0.309	1.52	15.13	6.07	0.436	0.299
2011	1.56	15.53	6.23	0.443	0.309	1.52	15.13	6.07	0.436	0.299
2012	1.56	15.53	6.23	0.442	0.309	1.52	15.13	6.07	0.435	0.299
2013	1.56	15.53	6.23	0.442	0.309	1.52	15.13	6.07	0.435	0.299
2014	1.56	15.53	6.23	0.441	0.309	1.52	15.13	6.07	0.434	0.299
2015	1.56	15.53	6.23	0.440	0.309	1.52	15.13	6.07	0.434	0.299
2016	1.56	15.53	6.23	0.440	0.309	1.52	15.13	6.07	0.433	0.299
2017	1.56	15.53	6.23	0.440	0.309	1.52	15.13	6.07	0.433	0.299
2018	1.56	15.53	6.23	0.440	0.309	1.52	15.13	6.07	0.433	0.299
2019	1.56	15.53	6.23	0.440	0.309	1.52	15.13	6.07	0.433	0.299
2020	1.56	15.53	6.23	0.440	0.309	1.52	15.13	6.07	0.433	0.299

Table 4 Line Haul and Drayage Emission Rates Based on Older Age Distribution Valid for Speeds Corresponding to Congested Urban Conditions										
Calendar Year	Line Haul Fleet					Drayage Fleet				
	VOC (g/mi)	CO (g/mi)	NOx (g/mi)	SO_2 (g/mi)	PM_{10} (g/mi)	VOC (g/mi)	CO (g/mi)	NOx (g/mi)	SO_2 (g/mi)	PM_{10} (g/mi)
1995	3.83	18.21	26.12	0.539	1.795	3.76	17.78	25.54	0.529	1.753
1996	3.73	18.15	24.75	0.536	1.679	3.65	17.72	24.21	0.526	1.640
1997	3.63	18.10	23.39	0.532	1.563	3.55	17.67	22.87	0.523	1.527
1998	3.53	18.05	22.02	0.529	1.447	3.45	17.61	21.54	0.519	1.415
1999	3.42	18.00	20.65	0.526	1.330	3.35	17.56	20.21	0.516	1.302
2000	3.32	17.95	19.28	0.523	1.214	3.24	17.51	18.88	0.513	1.189
2001	3.29	17.94	18.18	0.518	1.098	3.21	17.50	17.80	0.508	1.075
2002	3.26	17.93	17.08	0.512	0.981	3.19	17.49	16.72	0.503	0.962
2003	3.24	17.92	15.97	0.507	0.865	3.16	17.48	15.64	0.498	0.848
2004	3.21	17.91	14.87	0.502	0.748	3.13	17.47	14.56	0.493	0.734
2005	3.18	17.90	13.77	0.497	0.632	3.10	17.46	13.48	0.489	0.620
2006	3.13	17.90	13.14	0.492	0.584	3.05	17.45	12.86	0.483	0.573
2007	3.09	17.89	12.52	0.486	0.536	3.01	17.45	12.25	0.478	0.526
2008	3.04	17.89	11.89	0.481	0.489	2.96	17.44	11.64	0.473	0.479
2009	2.99	17.88	11.27	0.475	0.441	2.92	17.43	11.02	0.468	0.432
2010	2.94	17.88	10.64	0.470	0.393	2.87	17.43	10.41	0.462	0.384
2011	2.80	17.87	10.10	0.466	0.379	2.73	17.43	9.88	0.459	0.369
2012	2.65	17.87	9.56	0.463	0.364	2.59	17.42	9.35	0.455	0.354
2013	2.50	17.87	9.02	0.459	0.349	2.44	17.42	8.82	0.452	0.339
2014	2.35	17.87	8.48	0.455	0.334	2.30	17.42	8.29	0.448	0.324
2015	2.21	17.87	7.94	0.452	0.319	2.16	17.42	7.77	0.445	0.309
2016	2.11	17.87	7.69	0.450	0.317	2.07	17.42	7.52	0.443	0.307
2017	2.02	17.87	7.45	0.449	0.315	1.98	17.42	7.28	0.442	0.305
2018	1.93	17.87	7.20	0.447	0.313	1.89	17.42	7.04	0.440	0.303
2019	1.84	17.87	6.96	0.445	0.311	1.80	17.42	6.79	0.438	0.301
2020	1.75	17.87	6.71	0.444	0.309	1.71	17.42	6.55	0.437	0.299

Step-by-Step Approach for Computing Truck Emissions - The following steps assume that the user has already determined the necessary activity data in terms of total truck miles traveled during the period of interest. The type of traffic condition (congested urban, urban, or rural) should also be determined.

1. Use Table 1 for emission factors unless you have information that the truck fleet is significantly older or newer than the default age distribution. Use Tables 3 or 4 for fleets that are newer or older, respectively.
2. Select the major category of line-haul or drayage fleet in Table 1, 3, or 4.
3. Obtain the gram-per-mile emission factors for the calendar year(s) of interest from the table selected.
4. Multiply the gram-per-mile factors by the total truck miles traveled and divide by the appropriate conversion factor to get the final units desired.
5. Multiply the VOC, CO, and NOx results by the speed correction factors from Table 2 for the particular traffic conditions.

Steps 1 to 6 must be repeated for each leg of a freight trip that goes on truck between the origin and destination of the shipment.

Consideration of Alternative Fuels - There are currently some engines that are certified to operate at very low emission levels when running on natural gas rather than Diesel fuel. Although these engines are not required by emission standards, they may be used to provide mitigation for some projects. Table 5 shows the emission factors for natural gas engines. These factors are independent of calendar year fleet age distribution; they should only be applied to individual trucks using alternative fuels. It is still necessary to apply speed correction factors to the VOC, CO, and NOx emissions data in Table 5.

Table 5
Emission Factors for Natural Gas Heavy-Duty Vehicles
(g/mi)

Fleet	VOC	CO	NOx	SO_2	PM_{10}
Line Haul	1.55	9.36	5.28	0.0071	0.0627
Drayage	1.51	9.11	5.14	0.0070	0.0611

The factors in Table 5 are for a fleet consisting exclusively of natural-gas-fueled vehicles. The emission factors for a fleet consisting partially of natural-gas-fueled vehicles and Diesel-fueled vehicles would be found by taking the average of the emission factors weighted by the vehicle miles traveled. For example, a line haul fleet with 30% VMT from natural gas fuel and 70% from Diesel fuel would have an overall NOx emission factor, in 2005, of 0.3(5.28) + 0.7(11.57) = 9.68 g/mi. (The 2005 NOx line-haul emission factor is taken from Table 1 [on page A-53].)

Calculating Emissions Factors for Rail Freight

The standard EPA emission factors for locomotive operations are given in terms of the pounds of emissions per gallon of fuel consumed. Rail emission factors are shown in Table 6. These are composite emission factors representing the national average mix of line-haul and yard operations. The future-year emission factors shown in that table have been developed based on assumptions of future locomotive emission standards and fleet turnover. These assumptions, which are fully detailed in the section on rail emission factor calculations below, include that there will be no change in HC,* CO or SO_2 emissions. Thus, the emission factors for these species are projected to remain constant over the years shown.

The use of the emission factors in Table 6 requires the determination of the actual amount of fuel consumed in rail operations. Once this fuel use is determined, it is multiplied by emission factors for the desired calendar year (and divided by the appropriate unit conversion factor). For example, a rail shipment that requires three trains per day, each of which consumes 2,000 gallons, would have a total fuel use of 6,000 gallons per day. The emissions from these trains in 2005 are found from Table 6 to be as follows.

VOC = 0.0234 lb/gal	CO = 0.0647 lb/gal	NOx = 0.3517 lb/gal
SO_2 = 0.0360 lb/gal	PM_{10} = 0.0117 lb/gal	

The daily emissions would be found by multiplying these emission factors by the daily fuel use of 6,000 gallons. This gives the following results.

VOC = 140 lb/day	CO = 388 lb/day	NOx = 2110 lb/day
SO_2 = 216 lb/day	PM_{10} = 70 lb/day	

If data on rail fuel use are not available, but data on ton-miles of freight are, the local fuel use can be estimated from national data on locomotive fuel use. Table 7 shows projections of the locomotive fuel use per ton-mile of freight for the years 1995-2020.

In the previous example, if the rail fuel use were not known, but the freight transport in the region of interest were known (or estimated) to be 2.4 million ton-miles per day in 2005, the value of 411 ton-miles per gallon for 2005 in Table 7 could be used to estimate the rail fuel use as 5,839 gallons/day. This fuel use figure would then be used to multiply the rail emission factors to get the daily emissions.

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*Locomotive organic emissions are expressed as hydrocarbons (HC) rather than volatile organic compounds (VOC). MOBILE5a provides several measures for the emissions of organics including both HC and VOC. The latter are used in emission inventories for ozone attainment planning. Organic emissions from locomotives are generally not considered a significant source, and ozone planning inventories assume that all the locomotive HC is VOC.

Table 6 Rail Emission Factors Weighted Composite Factors for Entire Rail Fleet					
Calendar Year	Emission Factors in pounds per gallon of fuel				
	HC	CO	NOx	SO_2	PM_{10}
1995	0.0233	0.0646	0.4940	0.0360	0.0118
1996	0.0233	0.0646	0.4940	0.0360	0.0118
1997	0.0233	0.0646	0.4940	0.0360	0.0118
1998	0.0234	0.0646	0.4940	0.0360	0.0118
1999	0.0234	0.0647	0.4940	0.0360	0.0118
2000	0.0234	0.0647	0.4940	0.0360	0.0118
2001	0.0234	0.0647	0.4788	0.0360	0.0118
2002	0.0234	0.0647	0.4482	0.0360	0.0118
2003	0.0234	0.0647	0.4174	0.0360	0.0118
2004	0.0234	0.0647	0.3863	0.0360	0.0118
2005	0.0234	0.0647	0.3517	0.0360	0.0117
2006	0.0234	0.0647	0.3307	0.0360	0.0115
2007	0.0234	0.0647	0.3236	0.0360	0.0114
2008	0.0235	0.0647	0.3188	0.0360	0.0112
2009	0.0235	0.0648	0.3139	0.0360	0.0111
2010	0.0235	0.0648	0.3089	0.0360	0.0109
2011	0.0235	0.0648	0.3039	0.0360	0.0107
2012	0.0235	0.0648	0.2989	0.0360	0.0106
2013	0.0235	0.0648	0.2940	0.0360	0.0104
2014	0.0235	0.0648	0.2894	0.0360	0.0102
2015	0.0235	0.0648	0.2847	0.0360	0.0101
2016	0.0235	0.0648	0.2800	0.0360	0.0099
2017	0.0236	0.0648	0.2753	0.0360	0.0097
2018	0.0236	0.0648	0.2705	0.0360	0.0095
2019	0.0236	0.0649	0.2656	0.0360	0.0094
2020	0.0236	0.0649	0.2607	0.0360	0.0092

Table 7 Railroad Freight Fuel Economy (ton-miles per gallon) Projections to 2020													
Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Fuel	366	371	376	381	386	390	395	399	403	407	411	414	418
Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Fuel	421	425	428	431	434	437	440	443	446	449	451	454	456

Development of Emission Factors for Intercity Trucks

This section describes methods used to develop the emission factors presented in this section. It is not necessary to review this material to use the information presented earlier on the calculation of emissions from freight.

All intercity truck freight operations were assumed to come from heavy-duty Diesel vehicles (HDDV). The emission factors for HDDV (in grams per mile) were developed for all exhaust pollutants (VOC, CO, NOx, SO_2, and PM_{10}) for calendar years from 1995 to 2020 based on EPA's MOBILE5a and PART5 emissions models. Detailed emission factor calculations were prepared in five-year increments, and the intermediate years were determined by linear interpolation. The presently enacted HDDV standards for 1998 and the proposed standards for 2004 were included in this analysis. Emission factor estimates were prepared individually for Class 7, Class 8A, and Class 8B vehicles, and the results were combined (by VMT fraction) to determine separate estimates for line-haul and drayage operation. Finally, estimates were prepared for the average vehicle fleet, an "older" vehicle fleet, and a "newer" vehicle fleet.

<u>VOC, CO, and NOx Estimates</u> - The MOBILE5a model provided the basis for the VOC, CO, and NOx emission factor estimates. The model was run with the national average default fleet mix, and a speed of 20 mph was specified. (A 20 mph speed results in a speed correction factor of 1.0; accounting for different speeds is discussed later in this report.) The output format was "By Model Year" so that model-year- specific emission rates were generated for each calendar year being analyzed. As described in the interim report for this study,[1] the fleet-average calendar-year emission factor is calculated from the weighted sum of the model-year-specific emission rates as follows:

$$EF_{i,j} = \sum_{m=1}^{n} TF_m * \left(BER_{j,m} * CF_{j,m...} \right) \qquad [1]$$

where:

$EF_{i,j}$	=	fleet-average emission factor for calendar year i and pollutant j
TF_m	=	fractional VMT (i.e., travel fraction) attributed to model year m (the sum of TF_m over all model years n is unity)
$BER_{j,m}$	=	model-year-specific base emission rate for pollutant j and model year m
$CF_{j,m}$	=	correction factor(s) (e.g., temperature, speed) for pollutant j, model year m, etc.

The sum is carried out over the n model years making up the vehicle class (i.e., 25 model years for the HDDV class in MOBILE5a).

The by-model-year output from MOBILE5a contains the TF_m and $BER_{j,m}$ terms in the above equation. The MOBILE 5a input data specified a speed of 20 mph; this gives a value of one for the $CF_{j,m}$ term. (There are no temperature, fuel, or other correction factors for Diesel vehicles in the MOBILE5a model.)

Although the MOBILE5a output is in terms of grams per mile, the basic emission standards which apply to all heavy-duty engines are in terms of g/bhp-hr. MOBILE5a uses conversion factors to relate gram-per-mile emissions to g/bhp-hr emissions. These conversion factors are developed for individual truck classes and then averaged to form a single conversion factor, by model year, for the entire HDDV class.[2] The class-specific gram-per-mile emissions data presented here were computed as follows.

1. The fleet average conversion factor for each model year was used to obtain the g/bhp-hr emissions for the fleet. This value is the same for each truck class.
2. Once the g/bhp-hr emissions were known, the class-specific conversion factors were then used to compute the g/mi emissions for each class.

These two steps were done for each model year to provide class-specific gram-per-mile emission rates as a function of model year. A sample of the above calculations, for a single pollutant and model year, is shown in Table 8. This provides the NOx emission estimates for the 1995 calendar year.

The first column in Table 8 shows the consideration of model years between 1971 and 1995 for calendar year 1995. The earliest model year is assumed to account for that year and all earlier model years. The second column (i.e., the HDDV travel fraction) and the fourth column (i.e., the HDDV g/mi emission factors) came directly from the MOBILE5a by-model-year output file. Summing the product of the travel fraction and the NOx emission factors over the 25 model years making up the fleet results in 14.52 g/mi, which is the HDDV NOx emission rate obtained by simply running MOBILE5a at 20 mph for the 1995 calendar year. The third column of numbers in the table (i.e., the HDDV conversion factors) was extracted from block data statements in the MOBILE5a code. By dividing the g/mi emission rate for each model year by the conversion factor for that model year, the g/bhp-hr emission rate is obtained. For example, the 1990 model year NOx emission rate is 9.87 g/mi and its conversion factor is 2.066; thus, the g/bhp-hr emission rate for the 1990 model year (analyzed on January 1, 1995) is 9.87/2.066 = 4.777.

Once the model-year-specific g/bhp-hr emission rates were determined, new g/mi emission rates were calculated for Class 7, Class 8A, and Class 8B HDDVs (since these are the HDDV classes responsible for transporting the vast majority of freight). The model-year-specific emission rates for each class were determined by multiplying the g/bhp-hr emission rate described above (which is assumed to be constant across vehicle classes within the HDDV category) by the conversion factor applicable to each class (from reference 2 The cla). For example, the 1990 model year g/mi emission rates for the 7, 8A, and 8B classes were calculated as follows:

$$NOx_{\text{Class 7}} = 4.777 \text{ g/bhp-hr} \times 2.127 = 10.16 \text{ g/mi}$$
$$NOx_{\text{Class 8A}} = 4.777 \text{ g/bhp-hr} \times 2.987 = 14.27 \text{ g/mi}$$
$$NOx_{\text{Class 8B}} = 4.777 \text{ g/bhp-hr} \times 3.129 = 14.95 \text{ g/mi}$$

The class-specific, model-year emission rates (in g/mi) were then weighted by the model-year travel fraction associated with each of the 25 years making up the HDDV fleet, and the summation of those values resulted in the "Default Fleet Results" shown in Table 8. The travel fractions for the 7 and 8A classes came from the Medium-Heavy-Duty Diesel Vehicle category (which includes Class 6, 7, and 8A vehicles) calculated by the PART5

Table 8
Sample Calculation: Estimating 1995 Calendar Year Class-Specific HDDV Emission Factors for NOx

MOBILE5a Heavy-Duty Diesel Fleet-Weighted Parameters					Class 7-Specific Parameters			Class 8A-Specific Parameters			Class 8B-Specific Parameters		
Model Year	Travel Fraction	Conv. Factor	NOx Emissions (g/mi)	NOx Emissions (g/Bhp-hr)	Travel Fraction	Conv. Factor	NOx (g/mi)	Travel Fraction	Conv. Factor	NOx (g/mi)	Travel Fraction	Conv. Factor	NOx (g/mi)
1995	0.0000	2.039	0	0.000	0	2.127	0.000	0	2.987	0.000	0	3.129	0.000
1994	0.1068	2.033	8.13	3.999	0.089	2.127	8.506	0.089	2.987	11.945	0.1044	3.129	12.513
1993	0.1001	2.033	8.13	3.999	0.086	2.127	8.506	0.086	2.987	11.945	0.0985	3.129	12.513
1992	0.0938	2.033	8.13	3.999	0.083	2.127	8.506	0.083	2.987	11.945	0.0930	3.129	12.513
1991	0.0881	2.050	8.13	3.966	0.081	2.127	8.435	0.081	2.987	11.846	0.0877	3.129	12.409
1990	0.0901	2.066	9.87	4.777	0.085	2.127	10.161	0.085	2.987	14.270	0.0902	3.129	14.948
1989	0.0707	2.099	16.77	7.990	0.068	2.127	16.994	0.068	2.987	23.865	0.0711	3.129	24.999
1988	0.0436	2.132	16.77	7.866	0.043	2.127	16.731	0.043	2.987	23.495	0.0440	3.129	24.612
1987	0.0421	2.167	17.18	7.928	0.043	2.127	16.863	0.043	2.987	23.681	0.0425	3.129	24.807
1986	0.0493	2.214	17.56	7.931	0.052	2.127	16.870	0.052	2.987	23.691	0.0499	3.129	24.817
1985	0.0483	2.211	17.53	7.929	0.052	2.143	16.991	0.052	3.010	23.865	0.0489	3.138	24.880
1984	0.0567	2.406	19.08	7.930	0.062	2.159	17.121	0.062	3.035	24.068	0.0575	3.141	24.909
1983	0.0446	2.277	18.06	7.931	0.050	2.176	17.259	0.050	3.059	24.262	0.0452	3.150	24.984
1982	0.0436	2.376	18.84	7.929	0.050	2.193	17.389	0.050	3.089	24.494	0.0442	3.152	24.993
1981	0.0325	2.698	21.47	7.958	0.038	2.229	17.738	0.038	3.106	24.717	0.0329	3.255	25.902
1980	0.0130	2.716	21.47	7.905	0.016	2.254	17.818	0.016	3.062	24.205	0.0131	3.332	26.339
1979	0.0148	2.999	23.78	7.929	0.018	2.412	19.125	0.018	3.085	24.462	0.0150	3.307	26.222
1978	0.0171	3.187	32.937	10.335	0.022	2.616	27.036	0.022	3.126	32.307	0.0172	3.361	34.735
1977	0.0139	3.246	33.667	10.372	0.018	2.753	28.554	0.018	3.180	32.982	0.0139	3.402	35.285
1976	0.0088	3.179	33.383	10.501	0.012	2.760	28.983	0.012	3.156	33.141	0.0088	3.353	35.210
1975	0.0057	3.146	33.616	10.685	0.008	2.780	29.705	0.008	3.098	33.103	0.0057	3.299	35.251
1974	0.0044	3.213	33.837	10.531	0.006	2.775	29.224	0.006	3.104	32.689	0.0044	3.326	35.027
1973	0.0033	3.188	34.067	10.686	0.005	2.760	29.493	0.005	3.031	32.389	0.0032	3.275	34.997
1972	0.0022	3.197	34.265	10.718	0.003	2.701	28.949	0.003	3.031	32.486	0.0022	3.275	35.101
1971	0.0067	3.161	34.454	10.900	0.010	2.701	29.440	0.010	3.031	33.037	0.0065	3.275	35.697
Fleet-Weighted Results:			14.52	6.28			14.57			19.81			19.94
New Fleet Results:			8.46	4.14			8.82			12.39			12.96
Old Fleet Results:			20.09	8.24			18.81			25.27			26.23

model, and the Class 8B travel fractions came from the Heavy-Heavy-Duty Diesel Vehicle category calculated by PART5.

(MOBILE5a does not calculate class-specific travel fractions; thus, PART5 was used for this purpose.) Some uncertainty is introduced by using the Medium-Heavy-Duty Diesel Vehicle class to represent both Class 7 and Class 8A, but travel fractions specific to each class were not available for use in this project.

As shown in Table 8, three sets of calendar year, fleet-average emission rates were calculated for each vehicle class:

- one based on the default, 25-year age distribution used in MOBILE5a;
- one based on a newer vehicle fleet, which represents the average emission rate of vehicles from 0 to 5 years of age (i.e., 1990 to 1995 model years in the calendar year 1995 analysis illustrated in Table 8);* and
- one based on an older vehicle fleet, representing the average emission rate of vehicles from 6 to 24 years of age (i.e., 1971 to 1989 model years in the analysis presented in Table 8).

For the newer and older fleet-average emission estimates, the emission rates were determined by weighting each model-year-specific emission rate by that model year's travel fraction, summing over the model years included in the fleet of interest, and then dividing by the sum of the travel fraction for that fleet. For example, the newer fleet NOx result for Class 8B vehicles was calculated as follows:

$$\frac{(0.1044\times12.513 + 0.0985\times12.513 + 0.0930\times12.513 + 0.0877\times12.409 + 0.0902\times14.948)}{(0.1044 + 0.0985 + 0.0930 + 0.0877 + 0.0902)}$$

which, as shown in Table 8, is equal to 12.96 g/mi. This effectively creates a new set of travel fractions for the newer and older fleets which can be used to compare the travel fractions for a given fleet to those used in the fleet results presented here. The travel fractions for the older and newer fleet distributions are compared to the default travel fractions in Table 9.** The average age of the three fleet distributions, when the individual ages are weighted by the travel fractions shown in Table 9, are 3, 7, and 11 years for the newer, default, and older distributions, respectively.

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* Note that the 1995 model year has a travel fraction of zero in the calendar year 1995 analysis presented in Table 8. That is because MOBILE5a calculates emissions on a January 1 basis and, since the new model year for HDDVs is also introduced on January 1, it is assumed that there are no 1995 model year vehicles operating on January 1, 1995. This situation is slightly different for light-duty vehicles, in which the new model year is typically introduced on October 1 of the preceding calendar year (i.e., there are 1995 model year light-duty vehicles operating on January 1, 1995).

**The travel fractions shown in Table 9 are determined for individual truck classes, then weighted by composition of each class in the overall line-haul or drayage fleet. This weighting process is the same one used for emissions factors as discussed below.

Table 9 Travel Fractions for Truck Fleets						
Age (years)	Line Haul			Drayage		
	Newer	Default	Older	Newer	Default	Older
0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1	0.2199	0.1044	0.0000	0.2182	0.1018	0.0000
2	0.2077	0.0986	0.0000	0.2069	0.0965	0.0000
3	0.1962	0.0931	0.0000	0.1963	0.0915	0.0000
4	0.1854	0.0879	0.0000	0.1862	0.0867	0.0000
5	0.1908	0.0905	0.0000	0.1924	0.0896	0.0000
6	0.0000	0.0714	0.1360	0.0000	0.0710	0.1333
7	0.0000	0.0442	0.0842	0.0000	0.0442	0.0829
8	0.0000	0.0428	0.0815	0.0000	0.0429	0.0805
9	0.0000	0.0503	0.0958	0.0000	0.0507	0.0950
10	0.0000	0.0494	0.0940	0.0000	0.0500	0.0936
11	0.0000	0.0581	0.1106	0.0000	0.0590	0.1106
12	0.0000	0.0458	0.0871	0.0000	0.0467	0.0874
13	0.0000	0.0448	0.0853	0.0000	0.0459	0.0859
14	0.0000	0.0334	0.0636	0.0000	0.0344	0.0644
15	0.0000	0.0133	0.0254	0.0000	0.0138	0.0258
16	0.0000	0.0153	0.0290	0.0000	0.0158	0.0296
17	0.0000	0.0175	0.0334	0.0000	0.0183	0.0342
18	0.0000	0.0142	0.0270	0.0000	0.0149	0.0278
19	0.0000	0.0090	0.0170	0.0000	0.0094	0.0176
20	0.0000	0.0058	0.0111	0.0000	0.0062	0.0115
21	0.0000	0.0045	0.0085	0.0000	0.0048	0.0089
22	0.0000	0.0033	0.0063	0.0000	0.0035	0.0066
23	0.0000	0.0022	0.0042	0.0000	0.0024	0.0045
24	0.0000	0.0067	0.0128	0.0000	0.0073	0.0136

Accounting for Future Emission Standards - MOBILE5a includes an adjustment to the base emission rates to account for the HDDV 4.0 g/bhp-hr NOx emission standard that is to become effective with the 1998 model year. Those estimates were used directly in this analysis. However, MOBILE5a does not account for the proposed 2004 federal HDDV emission standards.[3] In order to model these proposed standards, the g/bhp-hr rates for 2004 and later model year vehicles were set equal to 2.0 g/bhp-hr NOx and 0.5 g/bhp-hr HC. This is consistent with Option (b), a combined NMHC + NOx standard of 2.5 g/bhp-hr and a NMHC cap of 0.5 g/bhp-hr, outlined in the "Statement of Principles" endorsed by EPA, CARB, and industry.

PM_{10} and SO_2 Estimates - EPA's PART5 model was used to estimate HDDV emission rates for PM_{10} and SO_2. As with the MOBILE5a model, it is possible to specify by-model-year output for a PART5 run. A feature of PART5 that is not included with MOBILE5a is that emission factors for the HDDV category are already segregated into four different subclasses:

- heavy-heavy-duty Diesel vehicles (Class 8B);
- medium-heavy-duty Diesel vehicles (Class 6,7,8A);
- light-heavy-duty Diesel vehicles (Class 3,4,5); and
- Class 2B heavy-duty Diesel vehicles.

Thus, the PART5 output for heavy-heavy-duty Diesel vehicles was used directly for the Class 8B PM_{10} and SO_2 emission factors used in this study. The Class 7 and Class 8A PM_{10} emission factors were based on the Class 8B factors as follows. First, the model-year-specific Class 7 and 8A exhaust PM_{10} emission factors were estimated by computing the Class 7/8A-to-Class 8B conversion factor ratio and applying it to the Class 8B g/mi emission rate, i.e.,

$$PM_{10\text{ - Class 7}} = PM_{10\text{ - Class 8B}} \times (CF_{\text{Class 7}} / CF_{\text{Class 8B}}) \qquad [2]$$

The above calculations are summarized for the 1995 calendar year in Table 10, which shows that the 1990 model year Class 8B PM_{10} emission rate is 1.215 g/mi. Since the 1990 model year Class 7 and 8B conversion factors are 2.127 and 3.129, respectively, the Class 7 PM_{10} emission rate is $1.215 \times (2.127/3.129) = 0.826$ g/mi.

The default, newer, and older fleet-average emission rates were generated as described above for VOC, CO, and NOx (i.e., for the default fleet, the travel fraction was multiplied by the model-year-specific emission rate and that product was summed over all model years; for the newer and older fleets, a similar approach was taken, except the summation was normalized by the total travel attributed to the newer and older fleets). In addition to the exhaust PM_{10} estimates, the fleet-average results at the bottom of Table 10 reflect brake-wear and tire-wear emissions. For brake-wear, PART5 assumes an average emission rate of 0.013 g/mi for all vehicles, while for tire wear, emissions are a function of the number of wheels:

$$EF_{\text{Tire-Wear}} = 0.008 \times (\#\ \text{Wheels}/4) \qquad [3]$$

For Class 8B vehicles, 18 wheels are assumed by PART5 (for an emission rate of 0.036 g/mi). For this analysis, Sierra assumed that Class 8A vehicles would have an average of 10 wheels, and Class 7 vehicles would have an average of six wheels. (As discussed above, PART5 includes Class 7 and Class 8B vehicles in the medium-heavy-duty Diesel vehicle category. For that category, which consists of Class 6, 7, and 8A trucks, PART5 assumes an average of six wheels per vehicle.)

Table 10
Sample Calculation for Calculation of Class-Specific PM_{10} and SO_2 Emission Factors from PART5 Output

Model Year	Class 7-Specific Parameters				Class 8A-Specific Parameters				Class 8B-Specific Parameters			
	Travel Fraction	Conv. Factor	SO_2 (g/mi)	PM_{10} (g/mi)	Travel Fraction	Conv. Factor	SO_2 (g/mi)	PM_{10} (g/mi)	Travel Fraction	Conv. Factor	SO_2 (g/mi)	PM_{10} (g/mi)
1995	0	2.127	0.000	0.000	0	2.987	0.000	0.000	0	3.129	0	0
1994	0.089	2.127	0.401	0.178	0.089	2.987	0.478	0.250	0.1044	3.129	0.501	0.262
1993	0.086	2.127	0.405	0.479	0.086	2.987	0.486	0.673	0.0985	3.129	0.509	0.705
1992	0.083	2.127	0.410	0.478	0.083	2.987	0.493	0.671	0.0930	3.129	0.516	0.703
1991	0.081	2.127	0.414	0.477	0.081	2.987	0.501	0.669	0.0877	3.129	0.525	0.701
1990	0.085	2.127	0.419	0.826	0.085	2.987	0.509	1.160	0.0902	3.129	0.533	1.215
1989	0.068	2.127	0.418	0.826	0.068	2.987	0.509	1.160	0.0711	3.129	0.533	1.215
1988	0.043	2.127	0.418	0.826	0.043	2.987	0.509	1.160	0.0440	3.129	0.533	1.215
1987	0.043	2.127	0.418	1.269	0.043	2.987	0.509	1.782	0.0425	3.129	0.533	1.867
1986	0.052	2.127	0.418	1.269	0.052	2.987	0.509	1.782	0.0499	3.129	0.533	1.867
1985	0.052	2.143	0.418	1.279	0.052	3.010	0.509	1.797	0.0489	3.138	0.533	1.873
1984	0.062	2.159	0.418	1.289	0.062	3.035	0.509	1.812	0.0575	3.141	0.533	1.875
1983	0.050	2.176	0.418	1.299	0.050	3.059	0.509	1.827	0.0452	3.150	0.533	1.881
1982	0.050	2.193	0.418	1.309	0.050	3.089	0.509	1.844	0.0442	3.152	0.533	1.882
1981	0.038	2.229	0.418	1.334	0.038	3.106	0.509	1.859	0.0329	3.255	0.533	1.948
1980	0.016	2.254	0.418	1.352	0.016	3.062	0.509	1.836	0.0131	3.332	0.533	1.998
1979	0.018	2.412	0.418	1.446	0.018	3.085	0.509	1.849	0.0150	3.307	0.533	1.982
1978	0.022	2.616	0.418	1.570	0.022	3.126	0.509	1.876	0.0172	3.361	0.533	2.017
1977	0.018	2.753	0.418	1.653	0.018	3.180	0.509	1.910	0.0139	3.402	0.533	2.043
1976	0.012	2.760	0.418	1.656	0.012	3.156	0.509	1.894	0.0088	3.353	0.533	2.012
1975	0.008	2.780	0.524	1.620	0.008	3.098	0.683	1.806	0.0057	3.299	0.727	1.923
1974	0.006	2.775	0.524	1.619	0.006	3.104	0.683	1.811	0.0044	3.326	0.727	1.940
1973	0.005	2.760	0.524	1.607	0.005	3.031	0.683	1.765	0.0032	3.275	0.727	1.907
1972	0.003	2.701	0.524	1.573	0.003	3.031	0.683	1.765	0.0022	3.275	0.727	1.907
1971	0.010	2.701	0.524	1.573	0.010	3.031	0.683	1.765	0.0065	3.275	0.727	1.907
Default Fleet			0.418	0.952			0.507	1.297			0.529	1.305
Newer Fleet			0.41	0.509			0.49	0.713			0.52	0.752
Older Fleet			0.42	1.278			0.52	1.727			0.54	1.803

A slightly different approach was used to generate SO_2 emission estimates for Class 7 and 8A vehicles. Since the calculation of SO_2 is based on fuel sulfur content (which is constant for all model years in a given calendar year) and vehicle fuel economy, the PART5 MHDDV SO_2 emission rates were scaled by the fuel economy differences between the entire MHDDV category and Class 7 and 8A to arrive at the model-year- specific SO_2 emission rates for Class 7 and 8A vehicles. For example, the 1990 model year MHDDV SO_2 emission rate calculated by PART5 is 0.434 g/mi, and the average fuel economy of that vehicle category is 7.28 mi/gal. Thus, the SO_2 emission rate for Class 7 vehicles is just:

$$SO_{2\text{ - Class 7}} = SO_{2\text{ - MHDDV}} \times (FE_{\text{MHDDV}}/FE_{\text{Class 7}}) \qquad [4]$$

This calculation is complicated by the fact that the PART5 model does not contain fuel economy estimates for Class 7 and Class 8A vehicles separately. Thus, those estimates were obtained by analyzing class-specific fuel economy data contained in Reference 2, and normalizing the results to the MHDDV fuel economy estimates in PART5. For example, the 1990 model year Class 6, 7, and 8A fuel economies from reference 1 are 8.47, 7.60, and 5.67 mi/gal, respectively. Weighting these values by the VMT fraction attributed to each class, the fuel economy is calculated to be 7.33 mi/gal (compared to 7.28 mi/gal for MHDDVs in PART5). Thus, for the purposes of the above calculation, the Class 7 fuel economy was assumed to be 7.60 × (7.28/7.33) = 7.55 mi/gal, and the 1990 model year Class 7 SO_2 emission rate was calculated as:

$$SO_{2\text{ - Class 7}} = 0.434 \times (7.28/7.55) = 0.418 \text{ g/mi}$$

The same calculations were performed for the remaining model years and for Class 8A vehicles, and the results for the 1995 calendar year are summarized in Table 10.

The SO_2 emission rate shown in Table 10 is constant from the 1976 to the 1990 model year. This implies that there was no change in fuel economy for those years. This is not consistent with other data sources which show a significant improvement in fuel economy for this period.[4] These results from the PART5 model output (which follow directly from the fuel economy block data statements in PART5) apparently resulted from the translation of fuel economy data into the Fortran code. These constant SO_2 emission rates were also used in the tables presented here in order to match the results one would obtain by using PART5.

Overall Class-Specific Emission Summary - The calculations described above for Class 7, Class 8A, and Class 8B vehicles are summarized in Table 11 for the "default" vehicle fleet. (Similar tables were also prepared for the "newer" and "older" fleets - those are contained in Appendix A.) Calculations were performed for calendar years 1995, 2000, 2005, 2010, 2015, and 2020, with the interim years determined by linear interpolation.

Line-Haul and Drayage Fleet Emission Rates - In addition to estimating class-specific emissions, emission rates were determined for line-haul and drayage operation by making assumptions on the VMT split among vehicle classes for each of those transportation modes. The VMT weighting factors were developed from VMT data presented in the 1992 Truck Inventory and Use Survey (TIUS),[5] a summary of which appears in Table 12. That table shows the annual VMT by weight class and mileage range. Although it is not possible to definitively determine the line-haul and drayage VMT fractions (by vehicle class) from the information presented in Table 12, it is likely that trips over 500 miles represent line-haul operation. Thus, line-haul emission factors were prepared based on a VMT split of 0.9%, 4.1%, and 95.0% for Class 7, Class 8A, and Class 8B, respectively.

Table 11
Class-Specific Emission Rates Based on Default Age Distribution

Calendar Year	Class 7 Emission Rates VOC (g/mi)	CO (g/mi)	NOx (g/mi)	SO_2 (g/mi)	PM_{10} (g/mi)	Class 8A Emission Rates VOC (g/mi)	CO (g/mi)	NOx (g/mi)	SO_2 (g/mi)	PM_{10} (g/mi)	Class 8B Emission Rates VOC (g/mi)	CO (g/mi)	NOx (g/mi)	SO_2 (g/mi)	PM_{10} (g/mi)
1995	2.54	11.98	14.57	0.418	0.952	3.45	16.45	19.81	0.507	1.297	3.53	17.04	19.94	0.529	1.305
1996	2.49	11.92	13.90	0.415	0.879	3.39	16.42	18.97	0.502	1.200	3.47	17.01	19.07	0.524	1.202
1997	2.43	11.85	13.22	0.412	0.805	3.33	16.39	18.12	0.497	1.103	3.42	16.98	18.20	0.519	1.098
1998	2.37	11.79	12.55	0.409	0.732	3.26	16.36	17.28	0.493	1.005	3.37	16.95	17.33	0.513	0.995
1999	2.31	11.73	11.88	0.406	0.659	3.20	16.33	16.43	0.488	0.908	3.31	16.91	16.46	0.508	0.892
2000	2.26	11.67	11.20	0.404	0.585	3.14	16.30	15.58	0.483	0.811	3.26	16.88	15.59	0.503	0.788
2001	2.22	11.65	10.61	0.401	0.538	3.09	16.29	14.78	0.478	0.746	3.21	16.88	14.79	0.498	0.727
2002	2.18	11.63	10.01	0.398	0.490	3.05	16.29	13.97	0.473	0.681	3.16	16.87	13.99	0.493	0.665
2003	2.14	11.62	9.42	0.396	0.443	3.00	16.28	13.17	0.469	0.616	3.11	16.87	13.20	0.488	0.604
2004	2.11	11.60	8.82	0.393	0.395	2.95	16.27	12.36	0.464	0.551	3.07	16.86	12.40	0.483	0.542
2005	2.07	11.59	8.23	0.390	0.348	2.91	16.27	11.55	0.460	0.486	3.02	16.86	11.61	0.478	0.480
2006	1.98	11.58	7.80	0.388	0.327	2.78	16.26	10.96	0.456	0.457	2.87	16.85	11.00	0.474	0.455
2007	1.89	11.58	7.38	0.386	0.306	2.65	16.26	10.36	0.452	0.428	2.73	16.85	10.40	0.470	0.430
2008	1.80	11.57	6.95	0.384	0.286	2.53	16.25	9.76	0.448	0.399	2.59	16.85	9.79	0.466	0.405
2009	1.71	11.57	6.52	0.382	0.265	2.40	16.25	9.16	0.444	0.370	2.44	16.84	9.19	0.463	0.380
2010	1.62	11.57	6.10	0.379	0.244	2.27	16.24	8.56	0.441	0.341	2.30	16.84	8.58	0.459	0.355
2011	1.56	11.57	5.88	0.378	0.237	2.20	16.24	8.25	0.438	0.331	2.22	16.84	8.30	0.457	0.347
2012	1.51	11.57	5.66	0.377	0.230	2.12	16.24	7.95	0.436	0.321	2.14	16.84	8.01	0.454	0.340
2013	1.45	11.56	5.44	0.376	0.223	2.04	16.24	7.64	0.434	0.311	2.06	16.84	7.73	0.452	0.332
2014	1.40	11.56	5.22	0.374	0.215	1.96	16.24	7.33	0.431	0.301	1.98	16.84	7.44	0.450	0.324
2015	1.34	11.56	5.00	0.373	0.208	1.89	16.24	7.02	0.429	0.290	1.91	16.84	7.16	0.448	0.316
2016	1.30	11.56	4.90	0.372	0.207	1.83	16.24	6.88	0.428	0.289	1.86	16.83	7.03	0.447	0.315
2017	1.27	11.56	4.79	0.372	0.206	1.78	16.24	6.73	0.427	0.287	1.81	16.83	6.90	0.446	0.314
2018	1.23	11.56	4.69	0.371	0.205	1.73	16.24	6.59	0.426	0.286	1.76	16.83	6.77	0.445	0.313
2019	1.19	11.56	4.59	0.370	0.204	1.67	16.24	6.44	0.425	0.285	1.71	16.83	6.64	0.444	0.312
2020	1.15	11.56	4.48	0.370	0.203	1.62	16.24	6.30	0.424	0.283	1.66	16.83	6.51	0.443	0.311

Table 12 1992 TIUS Survey Results for Annual VMT By Distance Ranges by Truck Weight								
Weight Range in Pounds	Mileage Ranges for VMT and Distribution Data							
	Less Than 50	50 to 100	100 to 200	200 to 500	Over 500	Over 200	All Miles	Over 50
	Annual VMT in Mileage Range (in millions)							
Less than 26,000	14,694	6,105	2,133	931	386	1,317	24,249	9,554
26,001 to 33,000	3,081	1,629	726	425	217	642	6,078	2,997
33,001 to 60,000	5,807	2,572	1,496	1,387	955	2,342	12,218	6,411
60,001 and greater	8,239	9,398	9,471	14,713	22,263	36,976	64,084	55,845
Total all ranges	31,822	19,704	13,826	17,456	23,821	41,277	106,629	74,807
Distribution of VMT by Weight								
Less than 26,000	46.2%	31.0%	15.4%	5.3%	1.6%	3.2%	22.7%	12.7%
26,001 to 33,000	9.7%	8.3%	5.2%	2.4%	0.9%	1.6%	5.7%	4.0%
33,001 to 60,000	18.2%	13.1%	10.8%	7.9%	4.0%	5.7%	11.5%	8.6%
60,001 and greater	25.9%	47.7%	68.5%	84.3%	93.5%	89.6%	60.1%	74.7%
Distribution of VMT by weight for Weights Greater than 26,000 pounds								
26,001 to 33,000	18.0%	12.0%	6.2%	2.6%	0.9%	1.6%	7.4%	4.6%
33,001 to 60,000	33.9%	18.9%	12.8%	8.4%	4.1%	5.9%	14.8%	9.8%
60,001 and greater	48.1%	69.1%	81.0%	89.0%	95.0%	92.5%	77.8%	85.6%

Drayage estimates are even more speculative. One might be tempted to use VMT weighting factors based on trips less than 50 or 100 miles to represent drayage operations; however, there is concern that many of those trips represent local deliveries that are not necessarily tied to inter-city freight transport. Thus, for this study, the overall VMT fractions were used to calculate drayage emission factors (i.e., 7.4%, 14.8%, and 77.8% for Class 7, 8A, and 8B, respectively). Clearly, this introduces some uncertainty into the calculations, but if the analyst has access to class-specific VMT fractions for drayage operations, those weighting factors can be used in conjunction with the class-specific emission factors given in Table 11 to generate revised drayage emission factors.

The class-specific VMT fractions described above for line-haul and drayage operations were used to develop composite emission factors for calendar years 1995 to 2020. Those factors were the ones shown in Table 1 for the "default" age distribution. Similar tables for the "newer" and "older" age distributions are given in Appendix A.

It should be noted that differences in class-specific VMT fractions used to represent drayage operations will not result in significantly different emission factors. For example, if the overall VMT fractions (i.e., 7.4%, 14.8%, and 77.8%, for Class 7, 8A, and 8B trucks, respectively) are used to calculate the drayage NOx emission rate in the year 2000, a value of 15.26 g/mi is obtained (for the "default" age distribution). If, on the other hand, trips of less than 50 miles are used to represent drayage operations (i.e., 18.0% Class 7, 33.9% Class 8A, and 48.1% Class 8B), a year 2000 NOx emission rate of 14.80 g/mi is obtained, which is only 3% less than the emission rate obtained using all vehicle miles.

Speed Correction - As discussed above, the emission factors developed for this project were based on a vehicle speed of 20 mph, because that is the speed at which the HDDV speed correction factors for HC, CO, and NOx are unity. (There are no speed corrections in PART5 for PM_{10} or SO_2.) For average vehicle speeds above or below 20 mph, all tabulated gram-per-mile truck emission factors in this report must be adjusted for vehicle operating speed. This adjustment is based on the speed correction factor equations in MOBILE5a, which are independent of model year, making it unnecessary to incorporate the speed corrections into the model-year- specific emission rates used to create the calendar-year factors in Appendix A. The HC, CO, and NOx speed correction factors are calculated from the following equation:

$$SCF = \exp(a + bs + cs^2) \qquad [5]$$

where

a,b,c = speed correction factor coefficients,
s = average vehicle speed (mph), and
exp = exponential function.

The values used in MOBILE5a for coefficients a, b, and c are summarized in Table 13, and the speed correction factors for various speeds are shown in Table 14. The speed correction factors for different traffic regimes shown in Table 2 were taken from the values in Table 14 by assuming a speed of 20 mph for congested urban travel, 35 mph for urban travel, and 60 mph for rural travel.

Table 13
Heavy-Duty Diesel Vehicle
Speed Correction Factor Coefficients Used in MOBILE5a

Pollutant	a	b	c
HC	0.924	-0.055	0.00044
CO	1.396	-0.088	0.00091
NOx	0.676	-0.048	0.00071

Table 14 Speed Correction Factors for Heavy-Duty Diesel Vehicles			
Speed (mph)	Speed Correction Factor for		
	HC	CO	NOx
5	1.935	2.661	1.574
10	1.519	1.835	1.306
15	1.219	1.324	1.123
20	1.000	1.000	1.000
25	0.839	0.790	0.923
30	0.719	0.654	0.882
35	0.630	0.566	0.874
40	0.564	0.513	0.898
45	0.517	0.486	0.955
50	0.484	0.482	1.052
55	0.463	0.501	1.202
60	0.453	0.544	1.422
65	0.453	0.619	1.743

Development of Emission Factors for Alternative-Fueled Vehicles

Because of the limited emissions data on alternative-fueled vehicles, emission factors for those vehicles are somewhat speculative; however, there is support for the use of alternative fuels in some heavy-duty applications. Since natural gas appears to be the most viable alternative fuel at this time, a summary of the most recent information on emissions from natural-gas-powered engines is presented below.

Certification Test Data - Several engine manufacturers have certified 1995 model year heavy-duty natural gas engines for sale in the U.S., which requires emission testing to demonstrate that the engines will remain below emission standards throughout the "useful life" of the engine. (The useful life of heavy-heavy-duty engines is eight years or 290,000 miles.) Although emissions during certification testing have historically been lower than emissions in customer service (at least for light-duty vehicles), there are no in-use emission data from which to develop natural gas engine emission factors. Thus, certification data have been used in this study.

Based on information received from CARB, the natural gas heavy-duty engines listed in Table 15 have been certified for sale in California for the 1995 model year and have emission standards of 1.2 g/bhp-hr nonmethane hydrocarbons (NMHC), 15.5 g/bhp-hr CO, 5.0 g/bhp-hr NOx, and 0.1 g/bhp-hr PM_{10} (for the Cummins engine) or 0.07 g/bhp-hr PM_{10} (for the Detroit Diesel and Caterpillar engines). (A number of smaller natural gas engines have also been certified, but their size would limit their use in intercity freight applications.) As shown in the table, the emission rates vary among engines, but NOx emissions are well below the average Diesel engine certified to a 5 g/bhp-hr standard.

Table 15 Summary of Natural Gas Engine Certification Data						
Manufacturer	Engine Size (l)	Emissions in g/bhp-hr for				Emission Control System Configuration
		NMHC	CO	NOx	PM_{10}	
Cummins	10.0	0.2	0.4	1.8	0.02	Oxidation Catalyst, Charge Air Cooler, Turbocharger
Detroit Diesel	8.5	0.6	2.4	2.7	0.03	Charge Air Cooler, Turbocharger
Caterpillar	10.5	0.7	6.3	0.7	0.02	Three-Way Catalyst, Oxygen Sensor, Charge Air Cooler, Turbocharger
Average g/bhp-hr		**0.5**	**3.0**	**1.7**	**0.02**	

Gram per Mile Emission Rates - As with the HDDV emission factors developed above, the g/bhp-hr emission factors shown in Table 15 were converted to a g/mi basis for Class 7, Class 8A, and Class 8B vehicles. The conversion factors used in this analysis were based on those developed in Reference 2 for 1987 and later model year Diesel vehicles: 2.127 for Class 7, 2.987 for class 8A, and 3.129 for Class 8B. Unfortunately, g/bhp-hr to g/mi conversion factors have not been developed for natural gas engines. However, according to a report prepared for CARB by Acurex Environmental Corporation,[6] both engine efficiency and vehicle fuel economy of natural gas engines are 20% to 30% worse than those of Diesel counterparts. Since the denominator of the conversion factor is the product of brake-specific fuel consumption (a measure of engine efficiency) and vehicle fuel economy, and since natural gas engine brake-specific fuel consumption would increase by approximately 25% and fuel economy would decrease by approximately 25%, these two effects offset one another in the calculation of conversion factors. Thus, the Diesel factors were used in this analysis to approximate natural gas engines. A summary of the resulting g/mi emission rates for natural gas heavy-duty vehicles is given in Table 16.

Table 16 Summary of Emission Factors for Natural Gas Heavy-Duty Vehicles (g/mi)					
Class	VOC[a]	CO	NOX	SO_2	PM_{10}
7	1.06	6.4	3.6	0.0057	0.043
8A	1.49	9.0	5.1	0.0068	0.060
8B	1.56	9.4	5.3	0.0071	0.063
[a] VOC emission rates were estimated from NMHC values contained in Table 15.					

The SO_2 emission factors in Table 16 were determined from the average SO_2 emission rate for natural gas combustion from AP-42[7] (i.e. 0.6 lb/10^6 scf), the average gross energy content of natural gas (1,040 Btu/scf), and an estimated fuel economy (in mi/Btu) for natural gas vehicles. To illustrate, the SO_2 emission rate for Class 7 trucks was calculated as described below.

From the discussion of Diesel vehicle SO_2 emission rates, the fuel economy of a 1995 Class 7 vehicle is 8.0 mi/gal. However, the gross energy content of a gallon of Diesel fuel is approximately 139,000 Btu, making the energy-based fuel economy 8.0 mi/139,000 Btu. Since the fuel economy of natural gas vehicles is approximately 25% lower than that of Diesel vehicles, the energy needed to travel the same distance is roughly 25% higher, and the energy-based fuel economy was assumed to be 8.0 mi/173,750 Btu for natural gas powered Class 7 vehicles. The SO_2 emission rate is then calculated as:

$$SO_2 = \frac{\dfrac{0.6\ lb}{10^6\ scf}\ \dfrac{453.59\ g}{lb}}{\dfrac{1040\ Btu}{scf}\ \dfrac{8\ mi}{173{,}750\ Btu}} = 0.0057\ \frac{g}{mi}$$

Similar calculations were performed for Class 8A and Class 8B vehicles to arrive at the emission rates contained in Table 16.

The class-specific emission factors in Table 16 were used to develop the emission factors for alternative-fuel vehicles in line-haul and drayage fleets shown in Table 5. The same VMT weighting factors used to convert class-specific Diesel emission factors into emission factors for the line-haul and drayage fleets were used for natural gas vehicles.

Attempts to Determine the Effect of Truck Load on Emission Rate

The usual approach to determining emission factors does not account for differences in truck operation that may be caused by the amount of freight present on the truck or on the amount of grade over the route. Two separate analyses were carried out to determine the possibility of any correction factor for these effects. The first examined the effect of the truck power on emission rate and is applicable when considering changes in truck weight and changes in grade. The second was an alternative approach to considering the effects of grade alone. Neither of these analyses provided convincing quantitative results, and no adjustment for grade or load is recommended.

Analysis using truck power requirements - The following symbols were used in this analysis:

m_i = mass flow rate (grams per hour) of species i,

V = vehicle speed (miles per hour),

B_i = Brake-specific emission rate of species i (g/bhp-hr),

P = Engine power (bhp), and

G_i = Gram per mile emission rate.

The gram per mile emission rate is the ratio of the mass flow rate to the vehicle speed; i.e.,

$$G_i = \frac{\dot{m}_i}{V} \qquad [6]$$

The mass flow rate is simply the product of the brake-specific emission rate and the engine power; i.e.,

$$\dot{m}_i = B_i \, P \qquad [7]$$

Combining these equations gives the following result:

$$G_i = \frac{B_i \, P}{V} \qquad [8]$$

At two separate operating conditions, the gram per mile emission rates can be written as $G_{i,2}$ and $G_{i,1}$. Their ratio is

$$\frac{G_{i,2}}{G_{i,1}} = \frac{\left[\frac{B_i\ P}{V}\right]_2}{\left[\frac{B_i\ P}{V}\right]_1} \qquad [9]$$

If we examine the ratio in a region where the brake specific emission rate is essentially constant at a value $B_{i,0}$, and the vehicle speed is fixed at V_0, the ratio of the gram per mile emission rates is simply given by the ratio of the engine power. This can be expressed as follows:

$$\frac{G_{i,2}(B_{i,0}, V_0, P_2)}{G_{i,1}(B_{i,0}, V_0, P_1)} = \frac{P_2}{P_1} \qquad [10]$$

The notation $G_{i,j}(B_{i,0},V_0,P_j)$ is used to emphasize the limitation of this equation to a comparison with fixed brake-specific emission rate and vehicle speed. This equation can be applied to estimating the effect of truck load on vehicle emissions in the following manner.

1. Use the conventional speed correction factor to determine the emissions at any vehicle speed compared to the emissions at the standard speed of 20 miles/hour.
2. Assume that the brake specific emissions, at a given vehicle speed, are essentially constant.
3. In order to apply this to operation on grades, compute the vehicle power at constant speed considering the power required to climb a grade.*
4. To apply this to changes in vehicle weight only, use the computed vehicle power at constant speed. This will not be valid for low speeds where the main component of the vehicle power in the driving cycle is the acceleration. Accordingly, this approach should be limited to some minimum speed.

With this approach we can write the emissions, $G_{i,1}$, at a particular speed and the base power conditions, P_1, in terms of the speed correction factor, SCF, and the tabulated emission factor (considered the reference condition), $G_{i,ref}$.

$$G_{i,1} = G_{i,ref}\ SCF \qquad [11]$$

*Details of the power computations are shown in Appendix B.

If the brake-specific emissions at the given speed are essentially constant, we can then combine equations 10 and 11 to obtain the emissions at the new power setting, P_2. This gives the following result.

$$G_{i,2} = G_{i,ref}\ SCF\ \frac{P_2}{P_1} \qquad [12]$$

Equation 12 gives the emissions at a particular speed and power, $G_{i,2}$, in terms of the FTP emissions at the reference speed of 20 miles per hour and the power ratio, P_2/P_1, where P_2 is the power required for the given load and P_1 is the power required for the base load. The values of P_1 for the various speeds were determined from the transient cycles as described below.

The transient engine dynamometer test is specified in terms of second-by-second variations in the engine speed, N, as a percent of rated speed, N_{rated}, and the engine torque, T, as a percent of maximum torque, T_{max}. These values were used to compute an average power demand for the cycle as follows:

$$\frac{P}{P_{\max}} = \frac{1}{n} \sum_{\substack{i \text{ with} \\ \frac{T}{T_{\max}} \geq 0}} \left(\frac{N}{N_{rated}}\right)_i \left(\frac{T}{T_{\max}}\right)_i \qquad [13]$$

In this equation, N/N_{rated} and T/T_{max} represent the engine dynamometer cycle specifications for speed and torque, respectively, and n is the number of points for which the power (or torque) is positive.* This gives an average value for P/P_{max} of 0.2024. For a 350 hp engine, the average power demand over the engine dynamometer cycle is 70.84 hp.

The speed correction cycles for heavy-duty vehicles were examined next. These correction cycles are individual components of the overall composite heavy-duty cycle. These components, which are named after the areas used to collect the driving data, have the following average speeds:[8]

New York non-freeway (NYNF)	7.31 mph
Los Angeles non-freeway (LANF)	16.82 mph
Los Angeles freeway (LAF)	46.91 mph

The power demands for these portions of the cycle were calculated in two ways. The first was based on the specification for the engine dynamometer cycle using the same equation that was used for the composite cycle. The second was calculated by computing the engine power for the heavy-duty chassis dynamometer cycle. This cycle was used to

*The average power calculation is restricted to points for which the torque is positive because the specification for the engine dynamometer cycle for Diesel engines does not specify a negative torque; it simply indicates that the engine is motored with a closed pump rack.

specify the vehicle speeds used to generate the speed correction factor equation. The vehicle characteristics and the equations used to calculate the power demand are given in Appendix B. The results of these calculations are shown in Table 17.

Table 17
Speed Correction Cycle Data

Cycle		NYNF	LANF	LAF
Mean Speed (mph)		7.31	16.82	46.91
		Ratio of Cycle Power to Power for Composite Cycle		
Calculated power ratio for chassis dynamometer cycle using the truck weights (in pounds (GVWR) shown	30,000	0.455	0.758	2.210
	40,000	0.486	0.796	2.159
	50,000	0.508	0.825	2.098
	60,000	0.524	0.844	2.059
	70,000	0.535	0.856	2.041
	80,000	0.544	0.867	2.016
Average chassis cycle		0.509	0.824	2.097
Engine dynamometer cycle		0.383	0.928	2.344
		Cycle Power Requirements		
P/P_{max} for engine dynamometer composite cycle		0.2024	0.2024	0.2024
Assumed P_{max} (hp)		350	350	350
Cycle power using average chassis cycle ratio		36.04	58.41	148.57
Cycle power using engine cycle ratio		27.10	65.72	166.04

Notes: Power calculations are described in Appendix B. The individual cycles are the New York non-freeway (NYNF), the Los Angeles non-freeway (LANF) and the Los Angeles freeway (LAF).

The ratio of the power demand in the speed correction chassis cycles to the power demand in the composite chassis cycle was computed for a range of truck weights between 30,000 and 80,000 pounds. These ratios are reasonably constant, considering the wide range of truck weights. The average value for this power ratio on the chassis cycle can be compared to the same result for the engine cycle. The largest difference is for the New York non-freeway cycle; there the engine cycle power ratio is 25% less than the average chassis cycle ratio. For the other two cycles, the engine cycle ratio is greater than the average chassis cycle ratio. Using the average value of 0.2024 for the ratio of P/P_{max} for the engine cycle and a maximum engine power output of 350 hp gives a base composite cycle engine power of 70.84 hp. The values of correction cycle engine power,

P_1, using both the average chassis cycle power ratio and the engine cycle power ratio, are shown in the final two lines of Table 17. These values of power are used to compute the ratio P_2/P_1 which appears in equation 12. The results are shown in Table 18.

Table 18 has three sets of data presented as a function of vehicle weight. The first set of data shows the computed wheel power demand, as a function of vehicle weight, for the various speed correction cycles. These values are used for the actual cycle power, P_2. The next two sets of data are the P_2/P_1 ratios. The first set of ratios is computed using the values of P_1 found from the chassis dynamometer power ratios in Table 17. The second set of ratios uses the values of P_1 found from the engine dynamometer ratios. (In both cases the values of P_1 shown in Table 17 are multiplied by the drive train efficiency of 90% to place both P_1 and P_2 on the basis of wheel power.)

Table 18
Estimates of P_2/P_1 for Load Correction Factor

Cycle	Gross Vehicle Weight (% of Maximum)					
	30,000 (37.5%)	40,000 (50%)	50,000 (62.5%)	60,000 (75%)	70,000 (87.5%)	80,000 (100%)
Computed Chassis Cycle Engine Power Demand (hp)						
NYNF	21.75	28.50	35.42	42.21	49.00	55.79
LANF	36.21	46.70	57.56	68.00	78.44	88.89
LAF	105.54	126.70	146.34	165.92	186.93	206.64
P_2/P_1 Using Average Chassis Dynamometer Power Ratios						
NYNF	0.671	0.879	1.092	1.301	1.511	1.720
LANF	0.689	0.888	1.095	1.294	1.491	1.691
LAF	0.789	0.948	1.094	1.241	1.398	1.545
P_2/P_1 Using Engine Dynamometer Power Ratios						
NYNF	0.892	1.168	1.452	1.731	2.009	2.288
LANF	0.612	0.789	0.973	1.150	1.326	1.503
LAF	0.706	0.848	0.979	1.110	1.251	1.383

The data in Table 18 do show the consistent trend expected for the increase in power demand with weight. The values of P_2/P_1 are different for the different speeds and for the choice of chassis dynamometer or engine dynamometer power ratios. The data do show that the proposed load correction factor, P_2/P_1, is less than one for nearly empty trucks and greater than one for loaded trucks.

To assess the utility of the results in Table 18, actual data on the effect of truck load on speed were evaluated. Dietzmann and Warner-Selph[9] obtained data on several heavy-duty engines using both the engine dynamometer transient test and a chassis dynamometer version of the transient test cycle. The results were placed on a comparable grams per kilometer basis by assuming that the engine dynamometer test corresponded to a distance of 10.3 km. For two of the engines, they examined the effect of increasing load on emissions measured using the chassis dynamometer test. The results for these engines, in units of grams/km, are shown in Table 19.

A review of the data shown in Table 19 leads to the following observations:

Table 19
Truck Emission Rates (grams/kilometer) as a Function of Truck Load

IHC C09670 Chassis, Single Axle Tractor, Cummins NTC-300 Engine					IHC Transtar II Chassis, Dual Axle Tractor, Detroit Diesel 8V-92TA Engine				
Load	HC	CO	NOx	PM_{10}	Load	HC	CO	NOx	PM_{10}
61%	3.33	3.79	8.37	1.22	55%	1.71	3.36	14.40	1.14
70%	3.16	3.70	8.99	1.19	70%	1.62	4.67	17.80	1.35
80%	3.54	4.15	10.4	1.31	86%	1.65	5.81	19.80	1.26
93%	3.14	4.20	10.8	1.26	97%	1.66	7.62	21.50	1.41
Engine	2.80	5.55	14.6	0.93	Engine	1.36	6.66	16.70	1.14

Notes: Load is expressed as a percent of gross vehicle weight (%GVW).
Engine refers to engine dynamometer test results converted to grams/km by assuming that the engine dynamometer test is equivalent to a drive of 10.3 km.

- Emissions in gm/km may increase, decrease or remain nearly constant as the weight on the truck increases. A consistent increase with load is seen for NOx and CO.
- Even when emissions increase, the relative increase in emissions is less than the relative increase in load.
- The two different engines respond differently to increases in load.
- The chassis tests, at a particular load, may give the same result as the engine dynamometer test, but the load point at which this occurs is not the same for all pollutants or for both engines. In some cases, the engine and chassis tests do not match at any load.

The data in reference 9 obtained show that the load does have some effect on emissions; however, except for NOx, this effect is usually much less than the proportional increase predicted by the model described above. In addition, this model applies the same load correction factor to all pollutants. This is obviously not the case. Consequently, no further work was done on this model and its application is not recommended. Additional chassis dynamometer tests on trucks are required to quantify the effect of load on emissions.

<u>Alternative Analysis of Grade Effect</u> - A simplified analysis, using the assumptions listed below, was developed to estimate the effect of road grade on NOx emissions.

- A trip over a one-way distance, D, is assumed to consist of D_F miles of flat terrain and D_G miles of constant grade with a slope, b.

- The vehicle operates at three speeds: V_F on flat terrain, V_{up} to climb the grade, and V_{down} on the downgrade for the return trip.
- There are three corresponding NOx emission rates (mass per unit time): the rate on level terrain is $\dot{m}_{NOx,F}$; the presumably higher rate for climbing a grade is $\dot{m}_{NOx,up}$; and the rate on a downgrade is $\dot{m}_{NOx,down}$.
- The engine uses maximum engine power, P_{max}, to climb a grade.
- The effect of grade is considered for a round trip with the same weight on both legs of the trip. This is done to account for the effects of downgrade as well as upgrade.

The total mass of NOx, m_{NOx}, is the sum of the NOx generated on a level road plus the NOx generated on the grade. This depends on the time spent in each type of terrain, which can be related to the distance and speed in each. The times spent driving on level (flat) ground, climbing a grade, and going down a grade are denoted as t_F, t_{up}, and t_{down}, respectively. Similarly, the speeds during these times are denoted as v_F, v_{up}, and v_{down}. With this notation, the total mass of NOx over a round trip, m_{NOx}, is given by the following equation.

$$m_{NOx} = \dot{m}_{NOx,F}\; t_F + \dot{m}_{NOx,up}\; t_{up} + \dot{m}_{NOx,down}\; t_{down} \qquad [14]$$

$$m_{NOx} = \dot{m}_{NOx,F}\frac{2\;D_F}{v_F} + \dot{m}_{NOx,up}\frac{D_G}{v_{up}} + \dot{m}_{NOx,down}\frac{D_G}{v_{down}} \qquad [15]$$

The grams per mile for the trip can be found by dividing by the total round-trip distance, 2D. This gives the following equation.

$$\frac{m_{NOx}}{2\,D} = \frac{\dot{m}_{NOx,F}}{v_F}\frac{D_F}{D} + \frac{1}{2}\left[\frac{\dot{m}_{NOx,up}}{v_{up}} + \frac{\dot{m}_{NOx,down}}{v_{down}}\right]\frac{D_G}{D} \qquad [16]$$

This equation can be simplified if the fraction of the route distance that is grade is defined as f.

$$f = \frac{D_G}{D} = \frac{D_G}{D_F + D_G} \qquad \frac{D_F}{D} = \frac{D - D_G}{D} = 1 - f \qquad [17]$$

This gives the grams per mile of NOx for the round trip distance, 2D, as

$$\frac{m_{NOx}}{2\,D} = \frac{\dot{m}_{NOx,F}}{v_F}(1 - f) + \frac{1}{2}\left[\frac{\dot{m}_{NOx,G}}{v_{up}} + \frac{\dot{m}_{NOx,down}}{v_{down}}\right]f \qquad [18]$$

If there is no grade on the route, f equals 0, and the equation is reduced to the following:

$$\left[\frac{m_{NOx}}{2\,D}\right]_{no\ grade} = \frac{\dot{m}_{NOx,F}}{v_F} \qquad [19]$$

Dividing this equation into the previous gives the ratio of grams per mile of NOx with a grade to grams per mile of NOx without the grade.

$$r_{NOx} = \frac{\dfrac{m_{NOx}}{2\,D}}{\left[\dfrac{m_{NOx}}{2\,D}\right]_{no\ grade}} = (1 - f) + \frac{1}{2}\left[\frac{\dot{m}_{NOx,up}}{\dot{m}_{NOx,F}}\,\frac{v_F}{v_{up}} + \frac{\dot{m}_{NOx,down}}{\dot{m}_{NOx,F}}\,\frac{v_F}{v_{down}}\right] f \qquad [20]$$

This equation for r_{NOx} can be written as

$$r_{NOx} = 1 + f\,G(W,b) \qquad [21]$$

where G(W,b), the grade-NOx factor, accounts for all the effects of grade except the fraction of the total distance that is grade; this is accounted for by the variable, f. The grade-NOx factor is

$$G(W,b) = \frac{1}{2}\left[\frac{\dot{m}_{NOx,up}}{\dot{m}_{NOx,F}}\,\frac{v_F}{v_{up}} + \frac{\dot{m}_{NOx,down}}{\dot{m}_{NOx,F}}\,\frac{v_F}{v_{down}}\right] - 1 \qquad [22]$$

In order to compute this factor, it is necessary to determine v_{up}, which is the speed for climbing an upgrade under maximum engine power. This is done by solving for the power demand equation for the velocity that consumes the maximum power for a given truck weight and grade. The details of the analysis used to determine v_{up} are shown in Appendix B. The specific values that were used to determine the parameters in the computation of the grade-NOx factor were based on an analysis done by a task force of the American Society of Mechanical Engineers (ASME)[10] which evaluated the emission implications of the truck-rail fuel comparison study done by Abacus Technologies, Inc.[11] They used NOx emission rates from test data on a Caterpillar 3406 engine, which provided NOx data as a function of engine load and speed.[12] The data values used in computing G(W,b) are listed below.

v_F	=	55 mph (assumed)
$m_{Nox,F}$	=	1435 grams/hour used by ASME Task Force for road load
$m_{Nox,up}$	=	2740 grams/hour at maximum power (test data on Caterpillar 3406)
$v_{Nox,down}$	=	211 grams/hour (average of lowest load point at 1100 and 1800 RPM from test data on 3406)
v_{down}	=	30 mph (assumed)

The values for the grade NOx factor, G(W,b), are shown in Table 20 for a range of truck weights and grades. For low grades, this factor is not defined because the truck is able to climb the grade at the same speed assumed for driving on level terrain without using the maximum engine power. For a 7% grade with an 80,000 pound truck, the grade-NOx factor is 1.89. If this grade were present for 5% of the total trip, the ratio of NOx with a grade to NOx without the grade would be 1 + 1.89 (0.05) = 1.0945. This means that the amount of NOx, for the entire round trip, would be 9.45% greater than it would be if the entire trip were on level ground.

The results here have been based on one typical engine for heavy-heavy-duty trucks. They show that assumed operation at maximum engine power to climb grades produces significant increases in NOx. However, the results in actual practice will be route- and vehicle-specific. The values in Table 20 could be applied to portions of the route with different grades to get a route specific factor, but this would require detailed data on the grade over the entire route.

<u>Conclusions on the Effect of Truck Load and Grade</u> - The analyses presented here represent a first attempt to develop simple models for the effects of load and grade on truck emissions. Although they provide a directional indication of these effects, their quantitative value is limited. Additional data on modal emissions from heavy-duty trucks are required to develop factors that can properly account for the effects of load and grade. Even if these modal emission data were available, it would still be necessary to obtain route-specific grade data to analyze the effect of grade.

Table 20
Grade NOx Factor

Grade	Factor for Truck Weights (in Pounds) Shown Below					
	30,000	40,000	50,000	60,000	70,000	80,000
2%					0.16	0.25
3%			0.15	0.28	0.41	0.54
4%		0.17	0.32	0.49	0.67	0.86
5%	0.11	0.30	0.51	0.73	0.96	1.20
6%	0.21	0.44	0.70	0.97	1.25	1.54
7%	0.31	0.60	0.91	1.23	1.55	1.89
8%	0.42	0.76	1.11	1.48	1.86	2.24
9%	0.53	0.92	1.33	1.74	2.16	2.59
10%	0.65	1.09	1.54	2.00	2.47	2.94
11%	0.77	1.26	1.76	2.27	2.78	3.29
12%	0.89	1.43	1.97	2.53	3.09	3.65
13%	1.02	1.60	2.19	2.79	3.40	4.00
14%	1.14	1.77	2.41	3.06	3.71	4.35
15%	1.27	1.95	2.63	3.32	4.02	4.71

■ Development of Emission Factors for Rail Freight

Two different sets of data on the Class I national locomotive fleet were used in developing the emission factors. The locomotive fleet used by EPA in developing a national rail inventory is shown in Table 21.

Table 21
National Locomotive Fleet Used in EPA Inventory [6]

Mfg	Engine	HP	Yard	Line	Total	%Yard	%Line	%Total
EMD	12-567BC	1,200	131		131	2.85%		0.92%
EMD	16-567C	1,500	1,279		1,279	27.87%		8.95%
EMD	8-645E	1,100	1		1	0.02%		0.01%
EMD	12-645E	1,500	1,216		1,216	26.50%		8.51%
EMD	16-645E	2,000	1,763		1,763	38.42%		12.34%
EMD	12-645E3	2,300	32		32	0.70%		0.22%
EMD	16-645E3	3,000		1,562	1,562		16.10%	10.93%
EMD	20-645E3	3,800		723	723		7.45%	5.06%
EMD	12-645E3B	2,500	125		125	2.72%		0.87%
EMD	16-645E3B	3,000		2,693	2,693		27.76%	18.84%
EMD	8-645E3C	1,650	42		42	0.92%		0.29%
EMD	16-645F3	3,500		232	232			1.62%
EMD	16-645F3B	3,600		400	400		4.12%	2.80%
EMD	12-710G3	3,200		2	2		0.02%	0.01%
EMD	16-710G3	3,600		537	537		5.53%	3.76%
EMD	12-710G3A	3,200		34	34		0.35%	0.24%
EMD	16-710G3A	3,600		250	250		2.58%	1.75%
GE	12-FDL(Dash-7)	2,500		843	843		8.69%	5.90%
GE	12-FDL(Dash-7)	3,000		145	145		1.49%	1.01%
GE	16-FDL(Dash-7)	3,000		801	801		8.26%	5.60%
GE	16-FDL(Dash-7)	3,600		451	451		4.65%	3.16%
GE	16-FDL(Dash-8)	4,100		1,029	1,029		10.61%	7.20%
Total Engines (Avg HP)		**2,756**	**4,589**	**9,702**	**14,291**			

The total number of locomotives is different from the number obtained from the Association of American Railroads (AAR).[13] The AAR data for locomotives in service and new locomotive purchases are shown in Table 22.

There is a discrepancy between the EPA figures showing 14,291 locomotives and the AAR data showing 18,835 locomotives in 1990. The EPA data were obtained by contacting individual railroads in 1990.[14] The AAR data were obtained directly from reports filed with the Interstate Commerce Commission by the railroads. The discrepancy in the total numbers is not important so long as the relative fleet composition is obtained accurately.

Table 22 AAR Locomotive Statistics[12]						
Year	Total Locomotives	Year-to-Year Change	New Locomotives	Percent New	Locomotives Retired	Retirement Rate
1980	28,094		1,480	5.27%		
1983	25,448		200	0.77%		
1984	24,117	-5.23%	436	1.81%	1,767	7.33%
1985	22,548	-6.51%	522	2.32%	2,091	9.27%
1986	20,790	-7.80%	280	1.35%	2,038	9.80%
1987	19,647	-5.50%	131	0.67%	1,274	6.48%
1988	19,364	-1.44%	356	1.84%	639	3.30%
1989	19,015	-1.80%	609	3.20%	958	5.04%
1990	18,835	-0.95%	530	2.81%	710	3.77%
1991	18,344	-2.61%	472	2.57%	963	5.25%
1992	18,004	-1.85%	323	1.79%	663	3.68%
1993	18,161	0.87%	524	2.89%	367	2.02%
1994	18,505	1.89%	781	4.22%	437	2.36%

Data on total locomotives and new locomotives taken from *Railroad Facts*. Other data in table computed from this information. For each year, the total locomotives represent the locomotives in service as of December 31.

It is the relative fleet composition which is used to weight the emission factors for individual locomotives to obtain the fleet emission factors. For this analysis, the AAR data on total locomotives were used and total locomotive fuel consumption was used. The EPA data were used to determine the fraction of the total locomotives that were yard locomotives and the fuel consumption by individual yard locomotives.

In order to determine the future emission factors for locomotive fleets it is necessary to forecast the items listed below. Further details on each of these items are provided below.

- the number of new locomotive purchases,
- the number of locomotives retired,
- the future locomotive standards,
- the rate at which existing locomotives are remanufactured, and
- the amount of fuel used in new locomotives as compared to the fuel used in existing locomotives.

The forecasts of these items are subject to large uncertainties. However, the main objective of the forecasts is to obtain the *relative* distribution of the future railroad fleet. Thus, even if there is significant uncertainty in the number of new locomotive purchases in any future year, there is less uncertainty in the average percent of the fleet, in any given year, which will be new. In addition, the changes in locomotive emission factors which have occurred historically are relatively small, and the major effect to be considered in future railroad emission factors is the effect of the national railroad rulemaking required by the 1990 Clean Air Act Amendments.

New Locomotive Purchases - The data in Table 22 show a wide variation in locomotive purchases with no clear trend. The unusually large number of locomotives purchased in 1980 was due to a forthcoming change in the investment tax credit. The large number of locomotive retirements in the 1983-1990 time frame was due to considerable internal restructuring on the part of individual railroads. This led them to eliminate little-used locomotives from their fleets. An individual railroad's decision to retire or purchase new locomotives is based on the business outlook for that railroad, and the fluctuations in the overall purchase rate reflects the variation in this business outlook. In addition, the relatively small number of railroads purchasing locomotives (as compared to the number of individuals and companies purchasing cars or trucks) provides no clear trend over time. In the six-year period from January 1, 1989, to December 31, 1994, the average number of new locomotives purchased was 540 per year. Reports for new locomotive orders indicate that fleet additions may be as large as 1,000 locomotives in 1995.[15]

The Table 22 data provide the *number* of locomotives; no information is given about the *size* of the locomotives. New locomotives are larger than existing locomotives. Typical new line-haul locomotives are 4,000 hp and above as compared to the (EPA) fleet average of 2,756 hp. There is a generally acknowledged trend to even larger locomotives to increase overall train efficiency.5 Rather than predict the future size of locomotives, the projections in this report considered the equivalent number of new locomotives of the current size (4,000 hp) that are purchased. This served two purposes: (1) it avoided the need to project the future locomotive size, and (2) it avoided the need to predict the annual fuel use of the new, larger horsepower locomotives.

For purposes of this projection, the number of new locomotive purchases was assumed to remain constant at the equivalent of 600 new 4,000-hp locomotives per year.

Number of Locomotives Retired - Table 22 data show a significant reduction in the overall number of locomotives since 1980. This is due to the retirement of older locomotives which were under-utilized, small in size, and less efficient. The gradual decrease in the number of locomotives retired per year is an indication that the railroads have almost completed the retirement of little-used units and future retirements will not be so large as they have been in past years. For purposes of the projections here, the future retirement rate was assumed constant at 400 locomotives per year.

Locomotives in Service - The following procedure was used to determine the locomotives in service each year.

- The starting point was the most recent AAR locomotive inventory for December 31, 1994, which shows a total of 18,505 locomotives.
- The fraction of locomotives that are yard locomotives was taken from the EPA inventory document. This shows a yard locomotive percentage of 32.11%, giving 5,691 yard locomotives on December 31, 1994.

- The number of yard locomotives was assumed to remain constant. Any yard locomotives that are sold or scrapped are replaced by a retired line-haul locomotive.
- Line-haul locomotives in service on January 1, 2001, were assumed to be remanufactured over a five-year period with the same number being remanufactured each year.
- Yard locomotives in service on January 1, 2001, were assumed to be modified over an eight-year period with the same number being remanufactured each year.
- New locomotives and retired locomotives were assumed to be in service for an average of six months in the year they are purchased or retired. Similarly, remanufactured locomotives were assumed to operate six months a year under both the new and the old emission levels.

<u>Emission Factors of Future Locomotives</u> - The 1990 Clean Air Act Amendments required the EPA to promulgate regulations for new locomotives and new engines in locomotives by November 15, 1995. Although EPA has not yet made a formal proposal as a notice of proposed rulemaking (NPRM) for locomotive emissions, it did consider the potential of such a regulation during development of a Federal Implementation Plan (FIP) for three areas in California.* Because the main focus of the FIP was on ozone attainment and because HC emissions from locomotives are not a significant source, the only species considered for control (from locomotives) in the FIP was NOx. EPA is likely to set emission standards for other criteria pollutants from locomotives just as it has done for other off-road engines. However, there was no discussion of these likely emission standards in the FIP.

EPA's plans for locomotive controls, as stated in the FIP,[16] call for NOx standards for both newly manufactured locomotives (in the year 2000 and later) and for existing locomotives (first built between January 1, 1973, and December 31, 1999) at the time that they are remanufactured. EPA considers both newly manufactured locomotives and remanufactured locomotive engines to be "new" within the meaning of its Clean Air Act authority. EPA expects the standards for locomotives first manufactured after January 1, 2000, to be in two tiers. The first tier, effective between 2000 and 2004, is expected to achieve a 50% reduction in NOx. The second tier, effective in 2005 and later, is expected to achieve a 65% reduction in NOx. Because of the long life of locomotives, these reductions (expressed as a percent reduction in emissions from freshly manufactured engines) are not expected to be achieved over the entire locomotive fleet until 2040 to 2045.

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*The FIP for the South Coast, Ventura, and Sacramento areas was required as a result of a suit against EPA under the provisions of the 1977 amendments to the Clean Air Act. The proposed FIP was published in the Federal Register on May 5, 1994. The final FIP was promulgated by EPA on February 15, 1995. Before the FIP was published in the Federal Register, it was rescinded by a provision of Public Law 104-6. However, an electronic copy of the proposed text for the final FIP is available from the EPA bulletin board.

The FIP proposal also discussed standards for locomotives manufactured between January 1, 1973, and December 31, 1999. These standards are expected to reduce emissions from these locomotives by 33%. Locomotives would have to meet these standards the first time they are remanufactured after January 1, 2000. Because of the long life of locomotives, EPA also proposed that locomotive engines that have conformed to an emission standard continue to do so in subsequent remanufactures. This applies to both

- locomotives first manufactured after January 1, 2000, at each remanufacture; and
- locomotives manufactured before January 1, 2000, which are initially remanufactured to comply with the 33% reduction standard, at each subsequent remanufacture.

The proposals for national emission controls discussed in the previous paragraph have not yet been proposed formally by EPA. Although the deadline for enacting the locomotive regulation is November 15, 1995, it now appears that the NPRM for the locomotive emission regulation will not be published in the *Federal Register* until early 1996. If this is correct, the final rule will not be promulgated until early 1997, and the implementation date for the emission regulation may be delayed beyond the January 1, 2000 date contemplated when the FIP was published. In addition, EPA may revise its proposal in response to comments received during its formal consideration of the rule to change the emission levels from the ones proposed in the FIP. Finally, EPA is considering special standards for remanufactured yard locomotives which will allow a higher emission level and is also considering a reduction in particulate matter for Tier II locomotives.[17]

For purposes of the projections in this report, the following assumptions were made:

- Line-haul locomotives manufactured between January 1, 2001, and December 31, 2004, (Tier I locomotives) will have NOx emissions that are reduced by 50% from current levels.
- Line-haul locomotives manufactured after January 1, 2005, (Tier II locomotives) will have NOx emissions reduced by 65% over current levels.
- Line-haul locomotives in service on January 1, 2001, will have their emissions reduced by 33_% the first time they are rebuilt after that date.
- Yard locomotives in service on January 1, 2001, will have their NOx emissions reduced by 15% the first time they are rebuilt after that date.
- No changes were assumed in the emission rates for hydrocarbons, CO or SO_2 in any locomotive classes. PM_{10} emissions were assumed to be the same for remanufactured and Tier I locomotives and were assumed to have a 50% reduction for Tier II locomotives.

- The reduction levels listed above refer to the actual emission levels before and after control, not to the reduction implied by the eventual standards.*

In order to account for the phase-in of these standards, the fuel-based NOx emission factors of 0.493 pounds per gallon of fuel burned for line-haul locomotives and 0.504 pounds per gallon for yard locomotives were reduced by the appropriate percentages. Six categories of locomotives were used: (1) non-modified yard; (2) modified yard; (3) non-modified, pre-2001 line-haul; (4) modified pre-2001 line-haul, (5) Tier I; and (6) Tier II. The fleet average emission factor, e_{avg}, will be calculated by multiplying the emission factor for each category, e_i, by its fuel use and dividing by the total fuel use. If the symbols N_i and f_i are used for the number of locomotives and the fuel use per locomotive, respectively, in each locomotive category, the overall average emission factor will be given by the following equation:

$$e_{avg} = \frac{\sum_{i=1}^{6} N_i \; f_i \; e_i}{\sum_{i=1}^{6} N_i \; f_i} \qquad [23]$$

The same approach can be used for particulate matter, except that the only class of locomotive with changes in the emission factor will be the Tier II locomotives. There will be no changes in the fuel-based emission factors for HC, CO or SO_2. Variations of equation 23, where the sum is extended only over line-haul or only over yard locomotives, can be used to compute separately the average emissions of these locomotives.

<u>Assumptions about Locomotive Fuel Use</u> - The data and assumptions used to project the fuel use per locomotive are outlined below. The data in Table 22 show that there were 18,505 locomotives in service at the end of 1994. Using the value of 32.11% for the percentage of yard locomotives from EPA data gives 5,942 yard locomotives and 12,563 line-haul locomotives. The AP-42 emission factors for yard locomotives are based on a fuel consumption of 226 gallons per 24-hour day. Assuming an annual average operation for each yard engine of five days out of seven (or 71% of the total hours in a year) gives an annual fuel consumption of 58,921 gallons per yard engine. This was rounded to 60,000 gallons per year.

AAR data on fuel consumption give a total fuel consumption of 3,334 million gallons for 1994. Subtracting the yard fuel use of 60,000 gallons per year for 5,942 yard locomotives gives a line-haul fuel use of 2,977 million gallons per year. This is equivalent to 0.237 million gallons per year for a line-haul locomotive. Although this average applies to all existing locomotives, there is a significant variation in

*Mobile source emission levels are typically designed to be less than the standard to account for variability in individual vehicle emissions. This is recognized in emission inventories. For example, EPA's MOBILE model assumes that the actual emissions from heavy-duty Diesel trucks will be 20% less than the applicable standard and will be constant over the lifetime of the truck.

the amount per locomotive. Newer locomotives are larger and more fuel efficient, are used more in actual service, and will have a higher annual fuel use than average. Based on discussions with railroad operating personnel, an annual average fuel use of 350,000 gallons per year was assumed for an equivalent new locomotive (i.e., one with 4,000 horsepower). The assumptions on locomotive fuel use used to project emission factors are summarized below.

- An equivalent new locomotive burns 350,000 gallons per year of fuel.
- An existing line-haul locomotive burns 237,000 gallons per year of fuel.
- A yard locomotive burns 60,000 gallons per year of fuel.

The assumptions outlined above provide values for N_i, the number of locomotives in each emission category, and the fuel used by that locomotive, f_i. These are then used in equation 23 to compute the average emission factor for the year.

The assumptions made here seem reasonable given the historical data on new locomotive purchases and retirements. A series of calculations with alternative assumptions were made to determine the sensitivity of the forecast NOx emission factors to the assumptions listed above. The NOx emission factors from the basic set of assumptions are shown in Figure 1. Figures 2 to 6 show the variation in the NOx emission factor as the assumptions are changed. The different sets of assumptions are listed in the lower left area of the chart. Changing the number of locomotives purchased and retired has about a 10% effect on the NOx emission factor. Changing the fuel use assumptions has almost no effect in later years. Changing the assumed period for all pre-2001 locomotives to comply with their standards changes only the timing of the drop in early years caused by the emission reductions from these locomotives. These charts show that the average NOx emission factor is not very sensitive to the assumptions made.

Figure 1

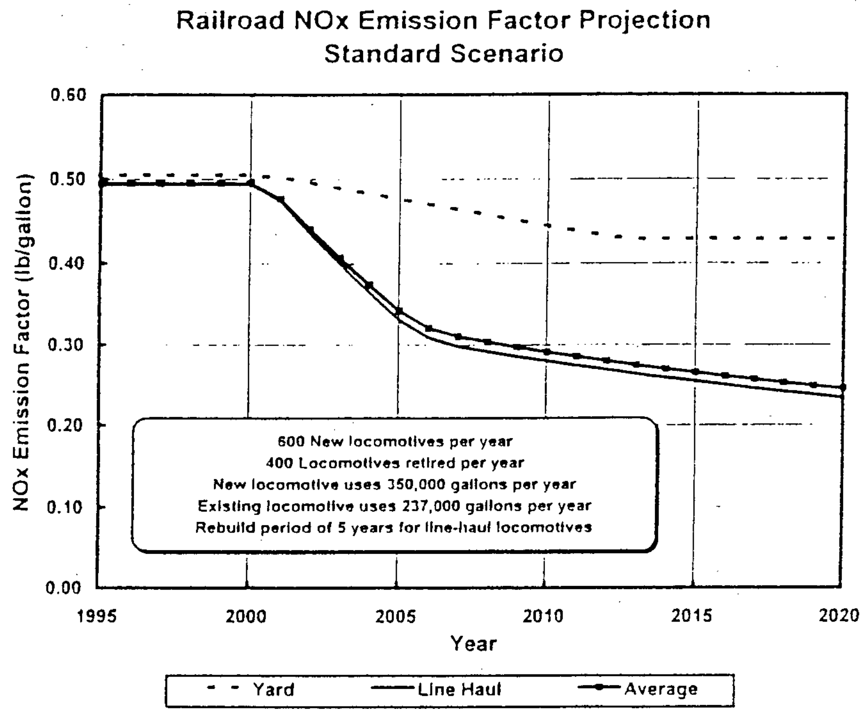


Figure 2

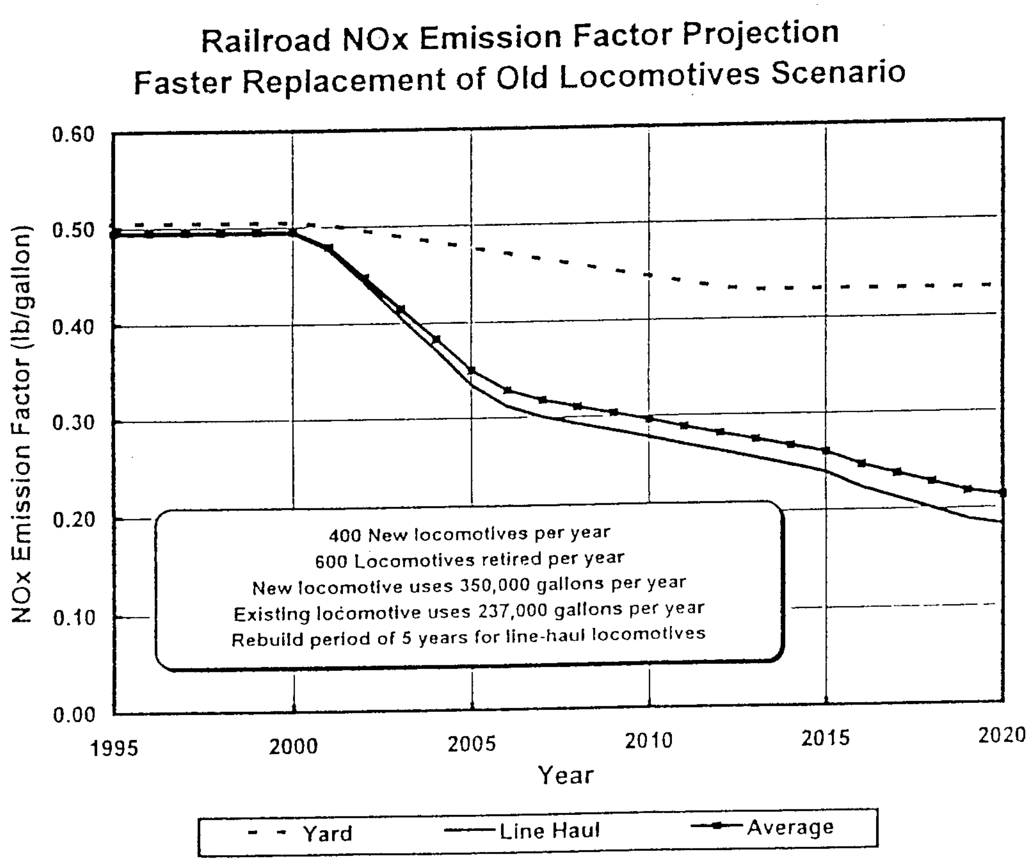


Figure 3

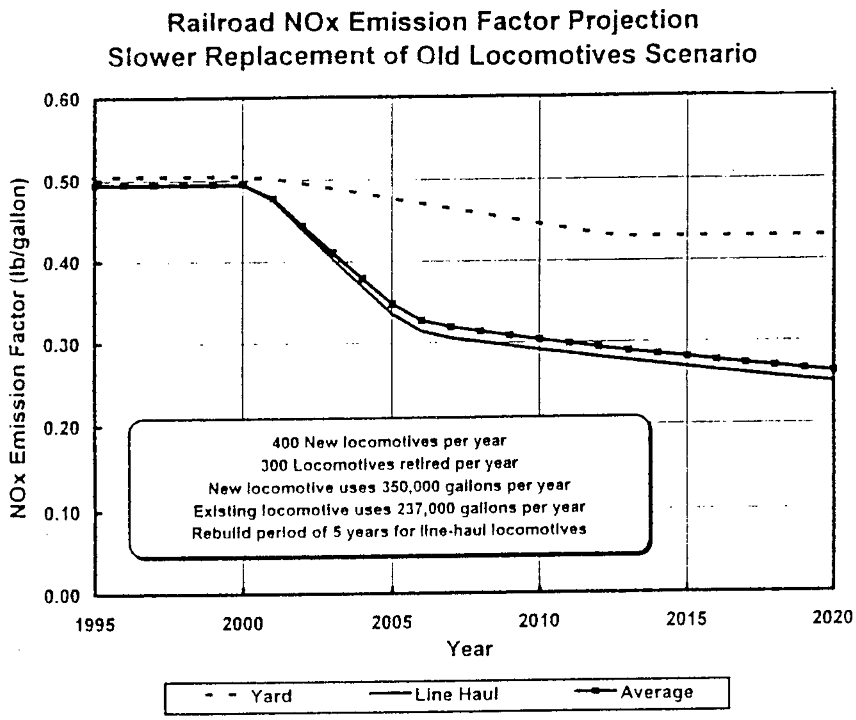


Figure 4

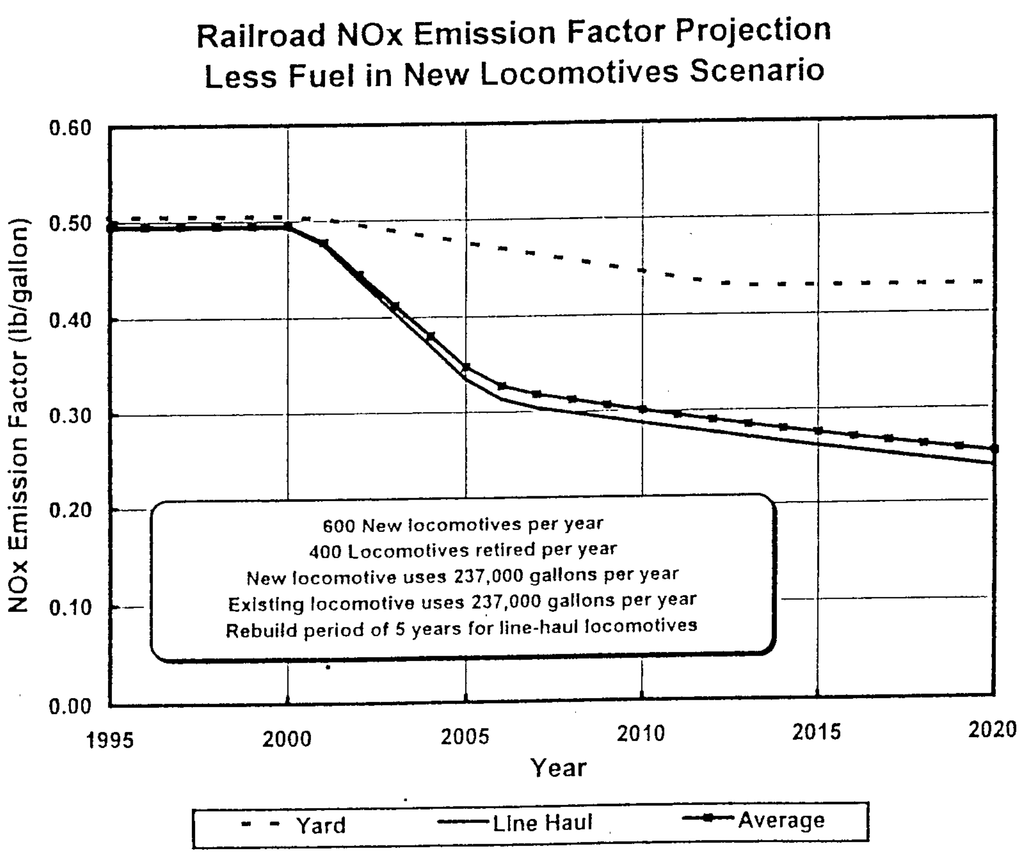


Figure 5

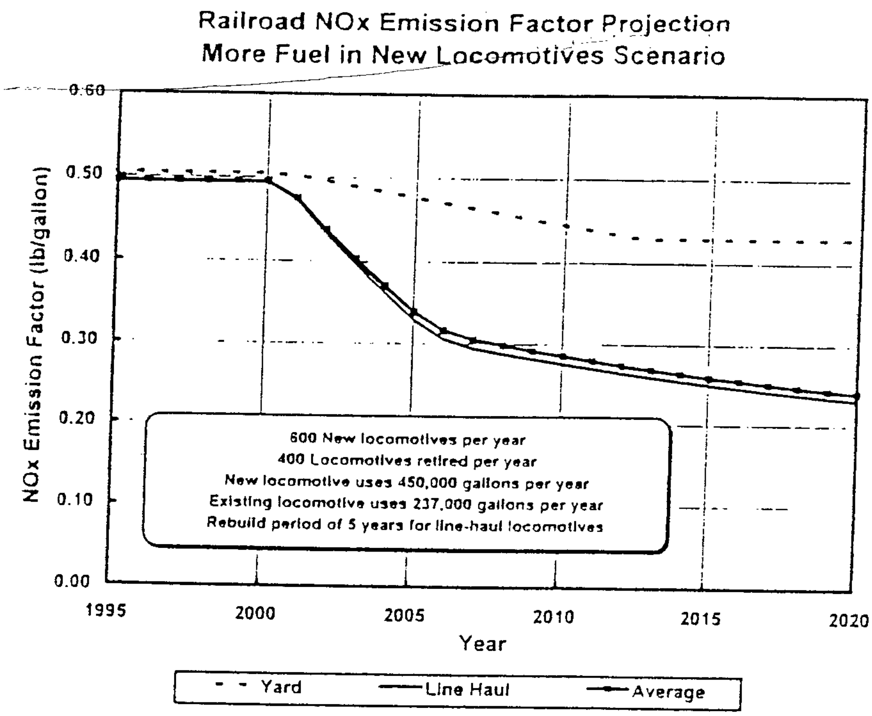
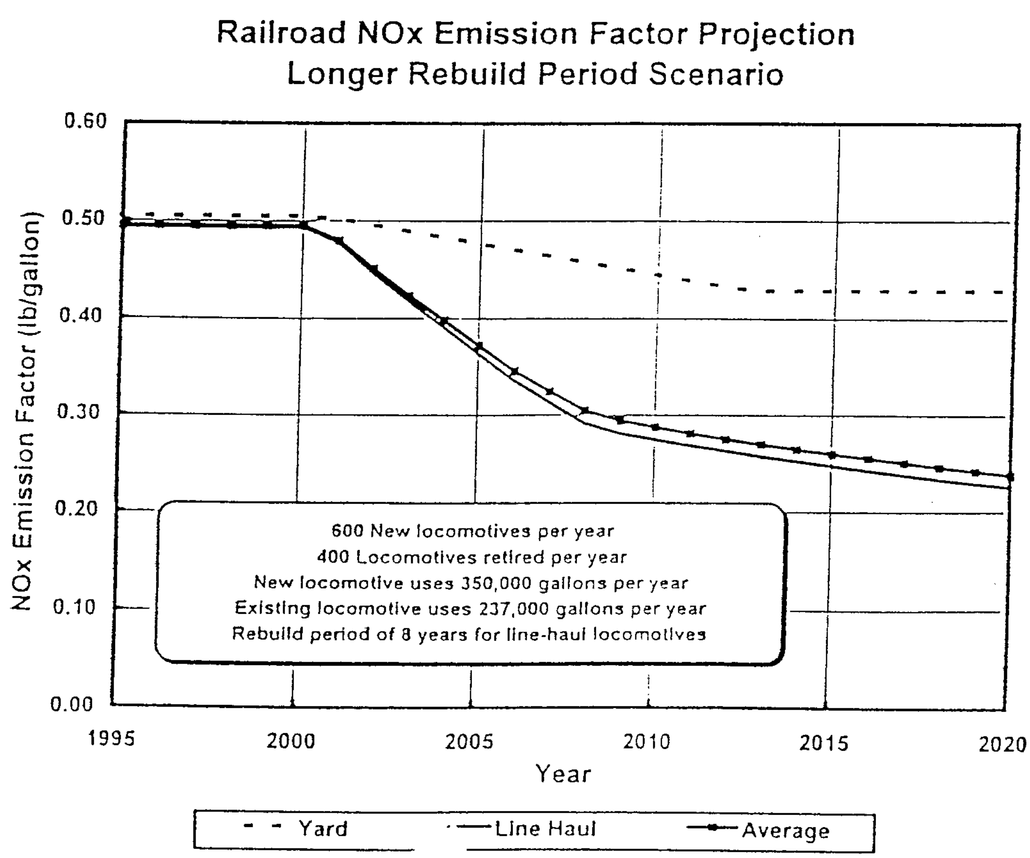


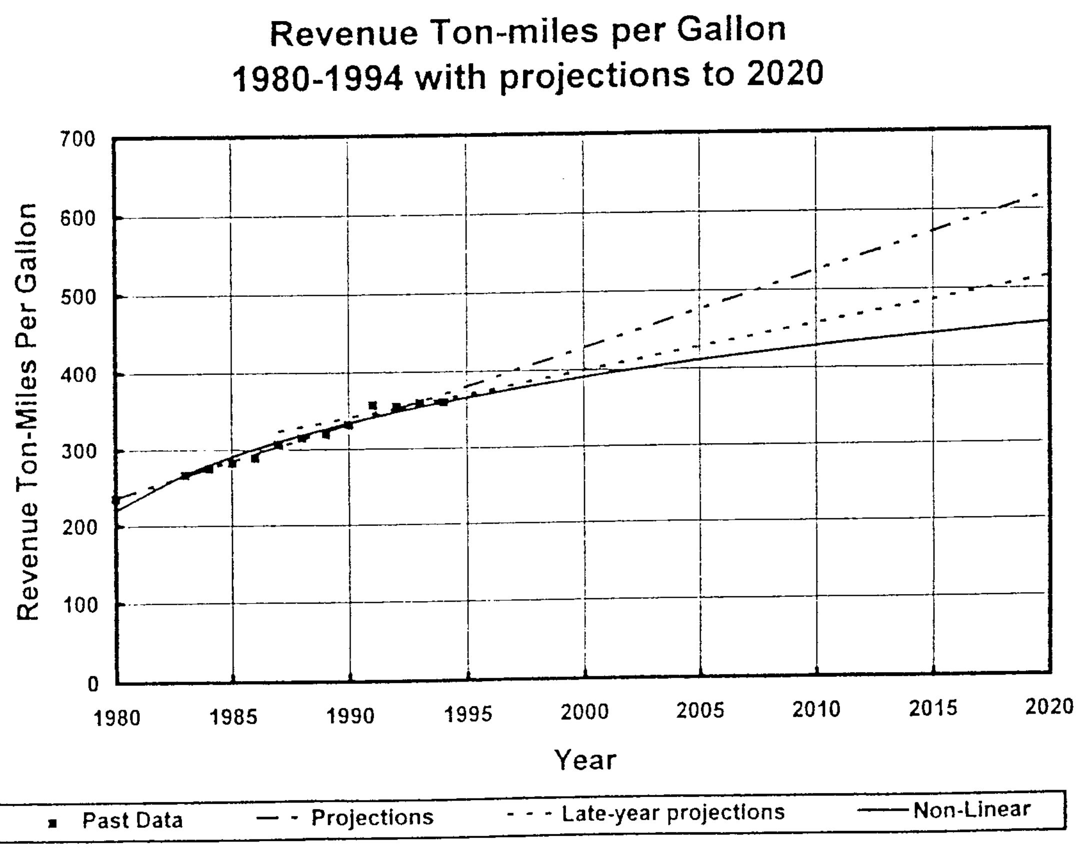
Figure 6



In addition to the forecast emission factors described above, any consideration of fuel-based emission factors should account for any projected improvement in fuel economy. Railroad fuel economy has increased from 235 revenue ton-miles per gallon in 1980 to 360 revenue ton-miles per gallon in 1994.3 The AAR A linear regression of the data for these years has a slope of 10.05 revenue ton-miles per gallon per year with an R^2 value of 0.98. This regression forecasts a value of 435 revenue ton-miles per gallon in 2000. However, the most recent data (1991 to 1993) show a nearly constant value for fuel economy. Introduction of newer locomotives, with higher horsepower and alternating current (AC) traction motors, is likely to increase the fuel economy, but there is no formal forecast of this fuel economy as there is for trucks in the EPA PART5 model.

In addition to the linear forecast of 1980-1994 data mentioned above, two alternative forecasts were considered. These were a linear forecast based on 1990-1994 data, and a nonlinear forecast based on 1980-1994 data. (The R^2 values for these two forecasts are 0.96 and 0.97, respectively.) The actual data and the three separate forecasts are shown in Figure 7. The nonlinear forecast was selected to provide the recommended future data on locomotive freight fuel efficiency shown in Table 7. This forecast was selected because it is similar to other data on improved energy efficiency which show greater improvements in early years, with diminishing improvements in later years.[18] This is consistent with the trend observed in the locomotive fuel use data. The forecast based on 1990-1994 data has a lower slope than the one based on 1980-1994 data. The fuel use data for 1991-1994 show almost no change.

Figure 7



Improving the Accuracy of Emission Factors

The emission factors presented above have been based on reasonable estimates using the best national data available at the time the factors were prepared (mid-1995). The accuracy of these factors as they are applied to different localities can be improved by obtaining data on local conditions that affect the development of the factors. The various approaches that can be taken to improve the factors are described in this section. This discussion presumes a familiarity with the previous discussion on the development of the basic rail and freight emission factors.

Determining the Age Distribution of the Truck Fleet - The usual approach would be to use the emission factors in Table 1 for the default fleet distribution. If there is any information about the actual age distribution, the analyst can elect to use the distributions in Tables 3 or 4 for newer or older age distributions, respectively. There are two likely applications of these alternative distributions: (1) the use of a newer fleet distribution to represent a line-haul fleet in areas where line-haul operators routinely turn their fleet over in a few years, and (2) the use of an older fleet distribution to represent drayage fleets in an area where drayage operators typically purchase used trucks and maintain them for a long period of time. The use of the older or newer fleet distributions should be based on an analysis which compares the expected age distribution of the truck fleet being analyzed with the typical age distributions for the older, default and newer fleets shown in Table 10.

Using Midyear Truck Emission Factors - The MOBILE5a emission factors used in this study are based on the fleet composition as of January 1 in each calendar year. These January 1 factors were used to obtain the model-year output data required to get the class-specific emission factors necessary for developing the truck emission factors. MOBILE5a also produces midyear (July 1) emission factors for a given calendar year. These are found simply by averaging the January 1 factors for the given calendar year and the subsequent calendar year. This averaging technique could also be applied to the tabulated truck emission factors presented in this report. To obtain the July 1 truck emission factors for a given calendar year, simply average the emission factors for that year and the subsequent year. For example, the emission factors for VOC emissions in 2005 and 2006 for a line-haul fleet with a default age distribution are 3.00 and 2.86 g/mi, respectively. The July 1 emission factor for 2005 VOC emissions in this fleet is simply the average, 2.93 g/mi.

Changing the Mix of the Truck Fleets - The exact mix of various truck classes in the line-haul or drayage fleet can be changed by determining the correct fleet mix for the local area of interest. The relative amounts of mileage by truck classes 7, 8A, and 8B would have to be determined. Once this was done, the class-specific emission factors in Appendix A could be multiplied by the travel fractions and summed. This will produce small changes in the overall results and is not likely to be worth the effort of a special study. If the data are available, however, this is a calculation that can be readily performed.

Improving the Speed Correction Factor - The speed correction factors for the three traffic classes shown in Table 2 can be replaced by more accurate speed correction factors from Table 14 provided that the actual speeds are known. For actual speeds between the ones listed in Table 14, it is possible to use interpolation between the values in this table or to calculate the desired speed correction factor from the coefficients in Table 13.

It is also possible to develop a weighted speed correction factor from data on distribution of vehicle speeds. If data are available on the fraction, f_i, of truck miles that are traveled in a speed range around a mean speed, s_i, it is possible to calculate an overall speed correction factor, $SCF_{overall}$, from the following equation.

$$SCF_{overall} = \sum_{i=1}^{N} f_i \; SCF(s_i) \qquad [24]$$

In this equation, N is the total number of data points in the speed distribution and $SCF(s_i)$ is the speed correction factor for the speed, s_i. Values of $SCF(s_i)$ can be interpolated from Table 14 or calculated from equation 5.

Accounting for Different Rail Fleets - Table 23 shows the emission factors for both line-haul and yard operations. The rail emission factors shown in Table 5 represent a weighted combination of the factors in Table 23. The emission factors in Table 23 can be used to separately compute the emissions from line-haul and from rail. This could be significant in a local area with a large amount of yard operations.

Using Local Data for Rail Fuel Efficiency - This improvement can be used when data are not directly available on rail fuel use and the fuel use is estimated from the local ton miles of freight using the freight fuel efficiency data in Table 7. If data are available which give the actual freight fuel efficiency for the local area these data can be used instead of the Table 7 data to provide a more accurate estimate for the emissions from rail freight.

Using Actual Data for Rail Fuel Sulfur Content - The EPA emission factors for SO_2 are based on a fuel sulfur content of 0.25% by weight fuel sulfur. If data are available for the average fuel sulfur content used by locomotives in the region, this value can be used to modify the SO_2 emission factors by a simple scaling. The modified SO_2 emission factor, EF_{SO2}, is found from the emission factor in the table, $EF_{SO2,Table}$, by the following equation.

$$EF_{SO}2 = EF_{SO2,Table} \frac{wt\%\ Fuel\ Sulfur}{0.25} \qquad [25]$$

For example, if the fuel sulfur is 0.20%wt, then the SO_2 emission factor is 0.0288 lb/gallon. This emission factor is the same for both line-haul and yard locomotives.

Table 23 Rail Emission Factors (pounds per gallon) Projected to 2020										
Calendar Year	Yard Emission Factors					Line-Haul Emission Factors				
	HC	CO	NOx	SO2	PM_{10}	HC	CO	NOx	SO2	PM_{10}
1995	0.0506	0.0894	0.5044	0.0360	0.0138	0.0211	0.0626	0.4931	0.0360	0.0116
1996	0.0506	0.0894	0.5044	0.0360	0.0138	0.0211	0.0626	0.4931	0.0360	0.0116
1997	0.0506	0.0894	0.5044	0.0360	0.0138	0.0211	0.0626	0.4931	0.0360	0.0116
1998	0.0506	0.0894	0.5044	0.0360	0.0138	0.0211	0.0626	0.4931	0.0360	0.0116
1999	0.0506	0.0894	0.5044	0.0360	0.0138	0.0211	0.0626	0.4931	0.0360	0.0116
2000	0.0506	0.0894	0.5044	0.0360	0.0138	0.0211	0.0626	0.4931	0.0360	0.0116
2001	0.0506	0.0894	0.5012	0.0360	0.0138	0.0211	0.0626	0.4769	0.0360	0.0116
2002	0.0506	0.0894	0.4949	0.0360	0.0138	0.0211	0.0626	0.4443	0.0360	0.0116
2003	0.0506	0.0894	0.4886	0.0360	0.0138	0.0211	0.0626	0.4114	0.0360	0.0116
2004	0.0506	0.0894	0.4823	0.0360	0.0138	0.0211	0.0626	0.3781	0.0360	0.0116
2005	0.0506	0.0894	0.4760	0.0360	0.0138	0.0211	0.0626	0.3411	0.0360	0.0115
2006	0.0506	0.0894	0.4697	0.0360	0.0138	0.0211	0.0626	0.3187	0.0360	0.0113
2007	0.0506	0.0894	0.4634	0.0360	0.0138	0.0211	0.0626	0.3115	0.0360	0.0112
2008	0.0506	0.0894	0.4571	0.0360	0.0138	0.0211	0.0626	0.3067	0.0360	0.0110
2009	0.0506	0.0894	0.4508	0.0360	0.0138	0.0211	0.0626	0.3019	0.0360	0.0108
2010	0.0506	0.0894	0.4445	0.0360	0.0138	0.0211	0.0626	0.2970	0.0360	0.0106
2011	0.0506	0.0894	0.4382	0.0360	0.0138	0.0211	0.0626	0.2921	0.0360	0.0105
2012	0.0506	0.0894	0.4319	0.0360	0.0138	0.0211	0.0626	0.2871	0.0360	0.0103
2013	0.0506	0.0894	0.4287	0.0360	0.0138	0.0211	0.0626	0.2820	0.0360	0.0101
2014	0.0506	0.0894	0.4287	0.0360	0.0138	0.0211	0.0626	0.2769	0.0360	0.0099
2015	0.0506	0.0894	0.4287	0.0360	0.0138	0.0211	0.0626	0.2718	0.0360	0.0097
2016	0.0506	0.0894	0.4287	0.0360	0.0138	0.0211	0.0626	0.2666	0.0360	0.0095
2017	0.0506	0.0894	0.4287	0.0360	0.0138	0.0211	0.0626	0.2613	0.0360	0.0093
2018	0.0506	0.0894	0.4287	0.0360	0.0138	0.0211	0.0626	0.2560	0.0360	0.0091
2019	0.0506	0.0894	0.4287	0.0360	0.0138	0.0211	0.0626	0.2506	0.0360	0.0089
2020	0.0506	0.0894	0.4287	0.0360	0.0138	0.0211	0.0626	0.2452	0.0360	0.0087

References

1. Cambridge Systematics, Inc. with Jack Faucett Associates, Inc. and Sierra Research, "Interim Report. Air Quality Issues in Intercity Freight," prepared for Federal Railroad Administration, Federal Highway Administration, and Environmental Protection Agency, September 15, 1995.

2. P. Machiele, "Heavy Duty Vehicle Emission Conversion Factors II: 1962 - 2000," U.S. Environmental Protection Agency, October 1988.

3. "EPA, California Air Resources Board, and Manufacturers of Heavy-Duty Engines Sign 'Statement of Principles'," Environmental Fact Sheet, U.S. Environmental Protection Agency, EPA420-F-95-010a, July 1995.

4. Stacy C. Davis, "Transportation Data Book: Edition 14," Oak Ridge National Laboratory, Report ORNL-6798, May 1994.

5. "1992 Census of Transportation - Truck Inventory and Use Survey," U.S. Department of Commerce, Bureau of the Census, May 1995.

6. "Technical Feasibility of Reducing NOx and Particulate Emissions from Heavy-Duty Engines," Prepared by Acurex Environmental Corporation for the California Air Resources Board, April 30, 1993.

7. U. S. Environmental Protection Agency, "Compilation of Air Pollution Emission Factors" (Fifth Edition), Report AP-42, January 1995.

8. K. G. Duleep, "Emission and Energy Characteristics of Heavy-Duty Diesel-Powered Trucks and Buses," Appendix A in *Expanding Metropolitan Highways - Implications for Air Quality and Energy Use*, Transportation Research Board, Special Report 245, National Research Council, National Academy Press, 1995.

9. Harry E. Dietzmann and Mary Ann Warner-Selph, "Comparison of Emissions from Heavy-Duty Engines and Vehicles During Transient Operation," American Society of Mechanical Engineers Paper 85-DGP-10 at Energy Sources and Technology Conference and Exhibition, Dallas, Texas, February 17-21, 1985.

10. Statement on Surface Transportation of Intercity Freight, prepared by the Task Force of the Internal Combustion Engine Division of the Council on Engineering of the American Society of Mechanical Engineers, 1828 L Street NW, Suite 906, Washington, D. C. 20036-5104, May 18, 1992.

11. Abacus Technology Corporation, "Rail vs Truck Fuel Efficiency: The Relative Fuel Efficiency of Truck Competitive Rail Freight and Truck Operations Compared in a Range of Corridors," 5454 Wisconsin Ave., Suite 1100, Chevy Chase, MD 20590, Report FRA-RRP-91-02 for Federal Railroad Administration, April 1991.

12. D. J. Waldman, "Heavy-Duty Liquid and Gaseous Fuel Emissions Database Test Results from Four Alternative Fuel Configurations of the Caterpillar 3406 Engine," Report NRNL/Sub/86-SB195/1, Oak Ridge National Laboratory, June 1990.

13. Association of American Railroads, *Railroad Facts*, Washington, D. C., September 1995.

14. Peter Okarusky, California Environmental Associates (formerly with U. S. EPA), telephone conversation, September 28, 1995.

15. Gus Welty, "1995: A 1,000-plus year," *Railway Age*, v. 196, no. 7, pp. 31-38 & 64, July 1995.

16. "Approval and Promulgation of State and Federal Implementation Plans; California--Sacramento and Ventura Ozone; South Coast Ozone and Carbon Monoxide," Available on EPA TTN bulletin board as file CALFIPRU.ZIP, February 16, 1995.

17. Peter Hutchins, EPA, Personal Communication.

18. R. M. Heavenrich, et al., "Light-Duty Automotive Fuel Economy and Technology Trends Through 1987," Society of Automotive Engineers Paper 871088, Government/Industry Meeting, Washington, DC, May 18-21, 1987.

Appendix A

Emission Factors for Heavy-Duty Diesel Vehicles 1995 - 2020

Class-Specific Emission Rates Based on Normal Age Distribution

Calendar Year	Class 7 Emission Rates VOC (g/mi)	CO (g/mi)	NOx (g/mi)	SO2 (g/mi)	PM (g/mi)	Class 8A Emission Rates VOC (g/mi)	CO (g/mi)	NOx (g/mi)	SO2 (g/mi)	PM (g/mi)	Class 8B Emission Rates VOC (g/mi)	CO (g/mi)	NOx (g/mi)	SO2 (g/mi)	PM (g/mi)
1995	2.54	11.98	14.57	0.418	0.952	3.45	16.45	19.81	0.507	1.297	3.53	17.04	19.94	0.529	1.305
1996	2.49	11.92	13.90	0.415	0.879	3.39	16.42	18.97	0.502	1.200	3.47	17.01	19.07	0.524	1.202
1997	2.43	11.85	13.22	0.412	0.805	3.33	16.39	18.12	0.497	1.103	3.42	16.98	18.20	0.519	1.098
1998	2.37	11.79	12.55	0.409	0.732	3.26	16.36	17.28	0.493	1.005	3.37	16.95	17.33	0.513	0.995
1999	2.31	11.73	11.88	0.406	0.659	3.20	16.33	16.43	0.488	0.908	3.31	16.91	16.46	0.508	0.892
2000	2.26	11.67	11.20	0.404	0.585	3.14	16.30	15.58	0.483	0.811	3.26	16.88	15.59	0.503	0.788
2001	2.22	11.65	10.61	0.401	0.538	3.09	16.29	14.78	0.478	0.746	3.21	16.88	14.79	0.498	0.727
2002	2.18	11.63	10.01	0.398	0.490	3.05	16.29	13.97	0.473	0.681	3.16	16.87	13.99	0.493	0.665
2003	2.14	11.62	9.42	0.396	0.443	3.00	16.28	13.17	0.469	0.616	3.11	16.87	13.20	0.488	0.604
2004	2.11	11.60	8.82	0.393	0.395	2.95	16.27	12.36	0.464	0.551	3.07	16.86	12.40	0.483	0.542
2005	2.07	11.59	8.23	0.390	0.348	2.91	16.27	11.55	0.460	0.486	3.02	16.86	11.61	0.478	0.480
2006	1.98	11.58	7.80	0.388	0.327	2.78	16.26	10.96	0.456	0.457	2.87	16.85	11.00	0.474	0.455
2007	1.89	11.58	7.38	0.386	0.306	2.65	16.26	10.36	0.452	0.428	2.73	16.85	10.40	0.470	0.430
2008	1.80	11.57	6.95	0.384	0.286	2.53	16.25	9.76	0.448	0.399	2.59	16.85	9.79	0.466	0.405
2009	1.71	11.57	6.52	0.382	0.265	2.40	16.25	9.16	0.444	0.370	2.44	16.84	9.19	0.463	0.380
2010	1.62	11.57	6.10	0.379	0.244	2.27	16.24	8.56	0.441	0.341	2.30	16.84	8.58	0.459	0.355
2011	1.56	11.57	5.88	0.378	0.237	2.20	16.24	8.25	0.438	0.331	2.22	16.84	8.30	0.457	0.347
2012	1.51	11.57	5.66	0.377	0.230	2.12	16.24	7.95	0.436	0.321	2.14	16.84	8.01	0.454	0.340
2013	1.45	11.56	5.44	0.376	0.223	2.04	16.24	7.64	0.434	0.311	2.06	16.84	7.73	0.452	0.332
2014	1.40	11.56	5.22	0.374	0.215	1.96	16.24	7.33	0.431	0.301	1.98	16.84	7.44	0.450	0.324
2015	1.34	11.56	5.00	0.373	0.208	1.89	16.24	7.02	0.429	0.290	1.91	16.84	7.16	0.448	0.316
2016	1.30	11.56	4.90	0.372	0.207	1.83	16.24	6.88	0.428	0.289	1.86	16.83	7.03	0.447	0.315
2017	1.27	11.56	4.79	0.372	0.206	1.78	16.24	6.73	0.427	0.287	1.81	16.83	6.90	0.446	0.314
2018	1.23	11.56	4.69	0.371	0.205	1.73	16.24	6.59	0.426	0.286	1.76	16.83	6.77	0.445	0.313
2019	1.19	11.56	4.59	0.370	0.204	1.67	16.24	6.44	0.425	0.285	1.71	16.83	6.64	0.444	0.312
2020	1.15	11.56	4.48	0.370	0.203	1.62	16.24	6.30	0.424	0.283	1.66	16.83	6.51	0.443	0.311

Class-Specific Emission Rates Based on Newer Age Distribution

Calendar Year	Class 7 Emission Rates VOC (g/mi)	CO (g/mi)	NOx (g/mi)	SO2 (g/mi)	PM (g/mi)	Class 8A Emission Rates VOC (g/mi)	CO (g/mi)	NOx (g/mi)	SO2 (g/mi)	PM (g/mi)	Class 8B Emission Rates VOC (g/mi)	CO (g/mi)	NOx (g/mi)	SO2 (g/mi)	PM (g/mi)
1995	2.16	10.66	8.82	0.410	0.509	3.03	14.97	12.39	0.493	0.713	3.17	15.66	12.96	0.516	0.752
1996	2.16	10.65	8.61	0.405	0.448	3.03	14.96	12.10	0.486	0.627	3.17	15.65	12.65	0.509	0.664
1997	2.16	10.65	8.41	0.401	0.387	3.03	14.95	11.80	0.479	0.541	3.17	15.64	12.34	0.501	0.576
1998	2.16	10.64	8.20	0.397	0.326	3.03	14.94	11.51	0.472	0.455	3.17	15.63	12.03	0.494	0.488
1999	2.16	10.63	7.99	0.393	0.264	3.03	14.93	11.22	0.464	0.369	3.17	15.62	11.72	0.486	0.399
2000	2.16	10.63	7.78	0.389	0.203	3.03	14.92	10.92	0.457	0.283	3.17	15.61	11.41	0.479	0.311
2001	2.11	10.62	7.47	0.386	0.203	2.96	14.92	10.49	0.453	0.283	3.10	15.61	10.96	0.474	0.311
2002	2.07	10.62	7.17	0.384	0.203	2.90	14.92	10.06	0.448	0.283	3.03	15.61	10.51	0.469	0.311
2003	2.02	10.62	6.86	0.381	0.203	2.84	14.92	9.63	0.443	0.283	2.96	15.61	10.06	0.464	0.311
2004	1.97	10.62	6.55	0.378	0.203	2.77	14.91	9.20	0.439	0.283	2.89	15.60	9.61	0.459	0.311
2005	1.93	10.62	6.25	0.375	0.203	2.71	14.91	8.78	0.434	0.283	2.82	15.60	9.15	0.455	0.311
2006	1.76	10.62	5.85	0.374	0.203	2.46	14.91	8.21	0.432	0.283	2.57	15.60	8.58	0.453	0.311
2007	1.58	10.62	5.45	0.373	0.203	2.22	14.91	7.65	0.430	0.283	2.32	15.60	8.00	0.451	0.311
2008	1.41	10.62	5.05	0.372	0.203	1.98	14.91	7.09	0.428	0.283	2.07	15.60	7.42	0.449	0.311
2009	1.24	10.62	4.65	0.372	0.203	1.74	14.91	6.53	0.426	0.283	1.82	15.60	6.84	0.447	0.311
2010	1.06	10.62	4.25	0.371	0.203	1.49	14.91	5.97	0.425	0.283	1.56	15.60	6.26	0.445	0.311
2011	1.06	10.62	4.25	0.370	0.203	1.49	14.91	5.97	0.424	0.283	1.56	15.60	6.26	0.444	0.311
2012	1.06	10.62	4.25	0.370	0.203	1.49	14.91	5.97	0.423	0.283	1.56	15.60	6.26	0.444	0.311
2013	1.06	10.62	4.25	0.370	0.203	1.49	14.91	5.97	0.423	0.283	1.56	15.60	6.26	0.443	0.311
2014	1.06	10.62	4.25	0.369	0.203	1.49	14.91	5.97	0.422	0.283	1.56	15.60	6.26	0.442	0.311
2015	1.06	10.62	4.25	0.369	0.203	1.49	14.91	5.97	0.422	0.283	1.56	15.60	6.26	0.442	0.311
2016	1.06	10.62	4.25	0.369	0.203	1.49	14.91	5.97	0.422	0.283	1.56	15.60	6.26	0.442	0.311
2017	1.06	10.62	4.25	0.369	0.203	1.49	14.91	5.97	0.422	0.283	1.56	15.60	6.26	0.442	0.311
2018	1.06	10.62	4.25	0.369	0.203	1.49	14.91	5.97	0.421	0.283	1.56	15.60	6.26	0.441	0.311
2019	1.06	10.62	4.25	0.368	0.203	1.49	14.91	5.97	0.421	0.283	1.56	15.60	6.26	0.441	0.311
2020	1.06	10.62	4.25	0.368	0.203	1.49	14.91	5.97	0.421	0.283	1.56	15.60	6.26	0.441	0.311

Class-Specific Emission Rates Based on Older Age Distribution

Calendar Year	Class 7 Emission Rates VOC (g/mi)	Class 7 CO (g/mi)	Class 7 NOx (g/mi)	Class 7 SO2 (g/mi)	Class 7 PM (g/mi)	Class 8A Emission Rates VOC (g/mi)	Class 8A CO (g/mi)	Class 8A NOx (g/mi)	Class 8A SO2 (g/mi)	Class 8A PM (g/mi)	Class 8B Emission Rates VOC (g/mi)	Class 8B CO (g/mi)	Class 8B NOx (g/mi)	Class 8B SO2 (g/mi)	Class 8B PM (g/mi)
1995	2.83	12.95	18.81	0.424	1.278	3.76	17.54	25.27	0.518	1.727	3.85	18.28	26.23	0.541	1.803
1996	2.73	12.85	17.79	0.422	1.196	3.65	17.50	24.02	0.515	1.621	3.74	18.23	24.85	0.538	1.686
1997	2.63	12.74	16.77	0.420	1.114	3.54	17.45	22.77	0.511	1.516	3.64	18.18	23.47	0.534	1.569
1998	2.53	12.64	15.76	0.418	1.031	3.44	17.40	21.52	0.508	1.411	3.54	18.13	22.10	0.531	1.452
1999	2.43	12.54	14.74	0.416	0.949	3.33	17.36	20.27	0.505	1.305	3.44	18.08	20.72	0.528	1.335
2000	2.33	12.43	13.72	0.414	0.867	3.22	17.31	19.02	0.501	1.200	3.33	18.03	19.35	0.525	1.218
2001	2.30	12.40	12.91	0.412	0.784	3.19	17.30	17.93	0.497	1.087	3.31	18.02	18.24	0.519	1.101
2002	2.27	12.38	12.11	0.409	0.702	3.16	17.29	16.85	0.492	0.974	3.28	18.01	17.13	0.514	0.984
2003	2.24	12.35	11.30	0.406	0.619	3.12	17.29	15.77	0.487	0.862	3.25	18.00	16.03	0.509	0.867
2004	2.21	12.32	10.49	0.404	0.537	3.09	17.28	14.68	0.483	0.749	3.22	17.99	14.92	0.504	0.750
2005	2.18	12.30	9.69	0.401	0.454	3.06	17.27	13.60	0.478	0.636	3.19	17.98	13.81	0.499	0.633
2006	2.15	12.29	9.24	0.398	0.418	3.01	17.26	12.97	0.473	0.585	3.15	17.98	13.19	0.493	0.585
2007	2.12	12.29	8.79	0.395	0.382	2.97	17.25	12.35	0.468	0.535	3.10	17.97	12.56	0.488	0.538
2008	2.09	12.28	8.35	0.392	0.346	2.93	17.24	11.72	0.463	0.484	3.05	17.97	11.93	0.482	0.490
2009	2.06	12.27	7.90	0.389	0.310	2.89	17.23	11.09	0.458	0.434	3.00	17.96	11.31	0.477	0.443
2010	2.03	12.27	7.45	0.386	0.274	2.85	17.23	10.46	0.452	0.383	2.96	17.96	10.68	0.471	0.395
2011	1.93	12.27	7.07	0.384	0.262	2.71	17.22	9.93	0.449	0.366	2.81	17.96	10.14	0.468	0.380
2012	1.84	12.26	6.69	0.382	0.250	2.58	17.22	9.40	0.445	0.348	2.66	17.95	9.60	0.464	0.365
2013	1.74	12.26	6.31	0.380	0.237	2.44	17.22	8.86	0.442	0.331	2.51	17.95	9.05	0.461	0.351
2014	1.64	12.26	5.93	0.378	0.225	2.31	17.22	8.33	0.438	0.313	2.36	17.95	8.51	0.457	0.336
2015	1.55	12.26	5.55	0.376	0.212	2.17	17.22	7.80	0.434	0.296	2.21	17.95	7.97	0.453	0.321
2016	1.48	12.26	5.37	0.375	0.210	2.08	17.22	7.54	0.433	0.293	2.12	17.95	7.72	0.452	0.319
2017	1.42	12.26	5.19	0.374	0.209	1.99	17.22	7.29	0.431	0.291	2.03	17.95	7.48	0.450	0.317
2018	1.35	12.26	5.01	0.373	0.207	1.90	17.22	7.04	0.429	0.288	1.94	17.95	7.23	0.448	0.315
2019	1.29	12.26	4.83	0.372	0.205	1.80	17.22	6.79	0.427	0.286	1.85	17.95	6.98	0.447	0.313
2020	1.22	12.26	4.65	0.371	0.203	1.71	17.22	6.53	0.426	0.283	1.75	17.95	6.74	0.445	0.311

Line Haul and Drayage Emission Rates Based on Normal Age Distribution

Calendar Year	Line Haul VOC (g/mi)	Line Haul CO (g/mi)	Line Haul NOx (g/mi)	Line Haul SO2 (g/mi)	Line Haul PM (g/mi)	Drayage VOC (g/mi)	Drayage CO (g/mi)	Drayage NOx (g/mi)	Drayage SO2 (g/mi)	Drayage PM (g/mi)
1995	3.52	16.97	19.89	0.527	1.302	3.44	16.58	19.52	0.518	1.278
1996	3.46	16.94	19.02	0.522	1.199	3.39	16.55	18.67	0.513	1.178
1997	3.41	16.91	18.15	0.517	1.096	3.33	16.51	17.82	0.508	1.077
1998	3.35	16.88	17.28	0.512	0.993	3.28	16.48	16.97	0.503	0.977
1999	3.30	16.84	16.41	0.506	0.890	3.22	16.44	16.11	0.498	0.877
2000	3.24	16.81	15.55	0.501	0.787	3.17	16.41	15.26	0.492	0.777
2001	3.20	16.81	14.75	0.496	0.726	3.12	16.40	14.48	0.488	0.716
2002	3.15	16.80	13.96	0.491	0.664	3.07	16.40	13.70	0.483	0.655
2003	3.10	16.79	13.16	0.486	0.603	3.02	16.39	12.91	0.478	0.594
2004	3.05	16.79	12.37	0.481	0.541	2.98	16.38	12.13	0.473	0.533
2005	3.00	16.78	11.57	0.476	0.480	2.93	16.38	11.35	0.469	0.472
2006	2.86	16.78	10.97	0.473	0.454	2.79	16.38	10.76	0.465	0.446
2007	2.72	16.78	10.37	0.469	0.429	2.66	16.37	10.17	0.461	0.421
2008	2.58	16.77	9.77	0.465	0.404	2.52	16.37	9.58	0.458	0.396
2009	2.43	16.77	9.16	0.461	0.379	2.38	16.36	8.99	0.454	0.370
2010	2.29	16.77	8.56	0.457	0.354	2.24	16.36	8.40	0.450	0.345
2011	2.21	16.77	8.28	0.455	0.346	2.17	16.36	8.11	0.448	0.337
2012	2.13	16.77	7.99	0.453	0.338	2.09	16.36	7.83	0.446	0.329
2013	2.06	16.77	7.70	0.451	0.330	2.01	16.36	7.55	0.444	0.321
2014	1.98	16.76	7.42	0.449	0.322	1.94	16.36	7.26	0.442	0.313
2015	1.90	16.76	7.13	0.447	0.314	1.86	16.36	6.98	0.440	0.304
2016	1.85	16.76	7.00	0.446	0.313	1.81	16.36	6.85	0.439	0.303
2017	1.80	16.76	6.87	0.445	0.312	1.76	16.36	6.72	0.438	0.302
2018	1.75	16.76	6.74	0.444	0.311	1.72	16.36	6.59	0.437	0.301
2019	1.71	16.76	6.61	0.443	0.310	1.67	16.36	6.46	0.436	0.300
2020	1.66	16.76	6.48	0.442	0.309	1.62	16.36	6.33	0.435	0.299

Line Haul and Drayage Emission Rates Based on Newer Age Distribution

Calendar Year	Line Haul VOC (g/mi)	Line Haul CO (g/mi)	Line Haul NOx (g/mi)	Line Haul SO2 (g/mi)	Line Haul PM (g/mi)	Drayage VOC (g/mi)	Drayage CO (g/mi)	Drayage NOx (g/mi)	Drayage SO2 (g/mi)	Drayage PM (g/mi)
1995	3.16	15.59	12.90	0.514	0.748	3.08	15.19	12.57	0.505	0.729
1996	3.16	15.58	12.59	0.507	0.661	3.08	15.18	12.27	0.498	0.643
1997	3.16	15.57	12.28	0.499	0.573	3.08	15.17	11.97	0.490	0.557
1998	3.16	15.56	11.97	0.492	0.485	3.08	15.16	11.67	0.483	0.471
1999	3.16	15.55	11.66	0.484	0.397	3.08	15.15	11.37	0.476	0.385
2000	3.16	15.54	11.35	0.477	0.309	3.08	15.14	11.07	0.469	0.299
2001	3.09	15.54	10.91	0.472	0.309	3.01	15.14	10.63	0.464	0.299
2002	3.02	15.53	10.46	0.467	0.309	2.94	15.14	10.19	0.460	0.299
2003	2.95	15.53	10.01	0.463	0.309	2.87	15.13	9.76	0.455	0.299
2004	2.88	15.53	9.56	0.458	0.309	2.81	15.13	9.32	0.450	0.299
2005	2.81	15.53	9.11	0.453	0.309	2.74	15.13	8.88	0.446	0.299
2006	2.56	15.53	8.54	0.451	0.309	2.49	15.13	8.32	0.444	0.299
2007	2.31	15.53	7.96	0.449	0.309	2.25	15.13	7.76	0.442	0.299
2008	2.06	15.53	7.38	0.447	0.309	2.01	15.13	7.19	0.440	0.299
2009	1.81	15.53	6.81	0.445	0.309	1.76	15.13	6.63	0.438	0.299
2010	1.56	15.53	6.23	0.443	0.309	1.52	15.13	6.07	0.436	0.299
2011	1.56	15.53	6.23	0.443	0.309	1.52	15.13	6.07	0.436	0.299
2012	1.56	15.53	6.23	0.442	0.309	1.52	15.13	6.07	0.435	0.299
2013	1.56	15.53	6.23	0.442	0.309	1.52	15.13	6.07	0.435	0.299
2014	1.56	15.53	6.23	0.441	0.309	1.52	15.13	6.07	0.434	0.299
2015	1.56	15.53	6.23	0.440	0.309	1.52	15.13	6.07	0.434	0.299
2016	1.56	15.53	6.23	0.440	0.309	1.52	15.13	6.07	0.433	0.299
2017	1.56	15.53	6.23	0.440	0.309	1.52	15.13	6.07	0.433	0.299
2018	1.56	15.53	6.23	0.440	0.309	1.52	15.13	6.07	0.433	0.299
2019	1.56	15.53	6.23	0.440	0.309	1.52	15.13	6.07	0.433	0.299
2020	1.56	15.53	6.23	0.440	0.309	1.52	15.13	6.07	0.433	0.299

Line Haul and Drayage Emission Rates Based on Older Age Distribution

Calendar Year	Line Haul VOC (g/mi)	Line Haul CO (g/mi)	Line Haul NOx (g/mi)	Line Haul SO2 (g/mi)	Line Haul PM (g/mi)	Drayage VOC (g/mi)	Drayage CO (g/mi)	Drayage NOx (g/mi)	Drayage SO2 (g/mi)	Drayage PM (g/mi)
1995	3.83	18.21	26.12	0.539	1.795	3.76	17.78	25.54	0.529	1.753
1996	3.73	18.15	24.75	0.536	1.679	3.65	17.72	24.21	0.526	1.640
1997	3.63	18.10	23.39	0.532	1.563	3.55	17.67	22.87	0.523	1.527
1998	3.53	18.05	22.02	0.529	1.447	3.45	17.61	21.54	0.519	1.415
1999	3.42	18.00	20.65	0.526	1.330	3.35	17.56	20.21	0.516	1.302
2000	3.32	17.95	19.28	0.523	1.214	3.24	17.51	18.88	0.513	1.189
2001	3.29	17.94	18.18	0.518	1.098	3.21	17.50	17.80	0.508	1.075
2002	3.26	17.93	17.08	0.512	0.981	3.19	17.49	16.72	0.503	0.962
2003	3.24	17.92	15.97	0.507	0.865	3.16	17.48	15.64	0.498	0.848
2004	3.21	17.91	14.87	0.502	0.748	3.13	17.47	14.56	0.493	0.734
2005	3.18	17.90	13.77	0.497	0.632	3.10	17.46	13.48	0.489	0.620
2006	3.13	17.90	13.14	0.492	0.584	3.05	17.45	12.86	0.483	0.573
2007	3.09	17.89	12.52	0.486	0.536	3.01	17.45	12.25	0.478	0.526
2008	3.04	17.89	11.89	0.481	0.489	2.96	17.44	11.64	0.473	0.479
2009	2.99	17.88	11.27	0.475	0.441	2.92	17.43	11.02	0.468	0.432
2010	2.94	17.88	10.64	0.470	0.393	2.87	17.43	10.41	0.462	0.384
2011	2.80	17.87	10.10	0.466	0.379	2.73	17.43	9.88	0.459	0.369
2012	2.65	17.87	9.56	0.463	0.364	2.59	17.42	9.35	0.455	0.354
2013	2.50	17.87	9.02	0.459	0.349	2.44	17.42	8.82	0.452	0.339
2014	2.35	17.87	8.48	0.455	0.334	2.30	17.42	8.29	0.448	0.324
2015	2.21	17.87	7.94	0.452	0.319	2.16	17.42	7.77	0.445	0.309
2016	2.11	17.87	7.69	0.450	0.317	2.07	17.42	7.52	0.443	0.307
2017	2.02	17.87	7.45	0.449	0.315	1.98	17.42	7.28	0.442	0.305
2018	1.93	17.87	7.20	0.447	0.313	1.89	17.42	7.04	0.440	0.303
2019	1.84	17.87	6.96	0.445	0.311	1.80	17.42	6.79	0.438	0.301
2020	1.75	17.87	6.71	0.444	0.309	1.71	17.42	6.55	0.437	0.299

Appendix B

Computation of Truck Engine Power Requirements

Computation of Truck Engine Power Requirements

The wheel power demand can be computed in terms of individual components due to rolling friction, aerodynamic drag, acceleration, and grade climbing:[1]

$$P_{wheel} = P_{roll\,fric} + P_{aero\,drag} + P_{accel} + P_{grade} \qquad \text{[B-1]}$$

The individual terms in this equation are given by the following equations.

$$P_{roll\,fric} = f_R\, W\, v \qquad \text{[B-2]}$$

$$P_{aero\,drag} = \rho_{air}\, C_D\, A_F\, \frac{v^3}{2} \qquad \text{[B-3]}$$

$$P_{accel} = k\, W \frac{a}{g}\, v \qquad \text{[B-4]}$$

$$P_{grade} = \frac{b\, W\, v}{\sqrt{1 + b^2}} \qquad \text{[B-5]}$$

The variables used in these equations are listed below.

P_{wheel} = The power demand at the wheels
f_R = The coefficient of rolling friction for the tires
W = The vehicle weight
v = The vehicle speed
ρ_{air} = The density of air at ambient conditions
C_D = The aerodynamic drag coefficient of the vehicle
A_F = The frontal area of the vehicle
k = A correctional factor to account for rotational inertia of the drivetrain
a = The vehicle acceleration
g = The acceleration of gravity
b = The grade

The engine power output and wheel power demand are related by the drivetrain efficiency, η_{dt}.

$$P_{wheel} = \eta_{dt}\, P_{engine} \qquad \text{[B-6]}$$

[1]Bosch, *Automotive Handbook* (First English edition), Robert Bosch GmbH, 1976, pp 218-221.

The engine and wheel power calculations in this section used the following parameters which are typical for Class 8B trucks:

f_R = Coefficient of Rolling Friction = 0.006
A_F = Frontal Area = 108 ft^2 (12.75 ft by 8.5 ft wide)
C_D = Aerodynamic Drag Coefficient = 0.63
η_{dt} = Drive-train efficiency = 0.90
P_{max} = Maximum Engine Power = 350 hp

In the calculations of the power requirements for the heavy-duty chassis cycle, the velocity-time trace was used to calculate the acceleration at time t by central differences; i.e.,

$$a(t) = \frac{v(t + \Delta t) - v(t - \Delta t)}{2\Delta t} \qquad [B\text{-}7]$$

(The acceleration at the start and end of the cycle was zero so special equations were not required for the acceleration at these points.) In the calculations of engine or wheel power for the chassis cycle, all the variables are known and the power is computed directly. In the calculations of the grade-NOx factor, it is necessary to solve equations B-1 to B-5 for the velocity. Newton's method was used to solve the cubic equation for velocity. The results of those calculations are shown in Table B-1. These velocity values were used to compute the grade-NOx factors shown in Table 20 of the main report.

Table B-1 Maximum Truck Speed on a Grade						
Grade	Maximum Speed for Truck Weights Shown					
	30,000 lb	40,000 lb	50,000 lb	60,000 lb	70,000 lb	80,000 lb
0%	83.31	81.89	80.48	79.07	77.67	76.28
1%	76.87	73.38	69.94	66.59	63.33	60.19
2%	70.59	65.23	60.13	55.37	50.99	46.99
3%	64.55	57.68	51.48	46.03	41.31	37.27
4%	58.87	50.94	44.21	38.65	34.10	30.39
5%	53.62	45.08	38.28	32.95	28.78	25.46
6%	48.87	40.10	33.50	28.55	24.78	21.84
7%	44.62	35.91	29.66	25.11	21.71	19.09
8%	40.86	32.39	26.53	22.36	19.29	16.93
9%	37.56	29.42	23.96	20.14	17.34	15.21
10%	34.66	26.91	21.83	18.31	15.74	13.80
11%	32.11	24.76	20.03	16.77	14.41	12.63
12%	29.88	22.92	18.49	15.47	13.29	11.64
13%	27.90	21.31	17.17	14.35	12.32	10.79
14%	26.15	19.91	16.02	13.38	11.49	10.06
15%	24.59	18.68	15.01	12.54	10.76	9.42
16%	23.20	17.59	14.12	11.79	10.12	8.86
17%	21.95	16.61	13.33	11.13	9.55	8.36
18%	20.82	15.74	12.63	10.53	9.04	7.91
19%	19.80	14.95	11.99	10.00	8.58	7.51
20%	18.87	14.24	11.41	9.52	8.16	7.14

Assumptions: Truck has a 350 hp engine with a 90% efficient drivetrain. Rolling friction and aerodynamic drag coefficients are 0.006 and 0.63, respectively. Frontal area is 108 ft^2.

Figure 1

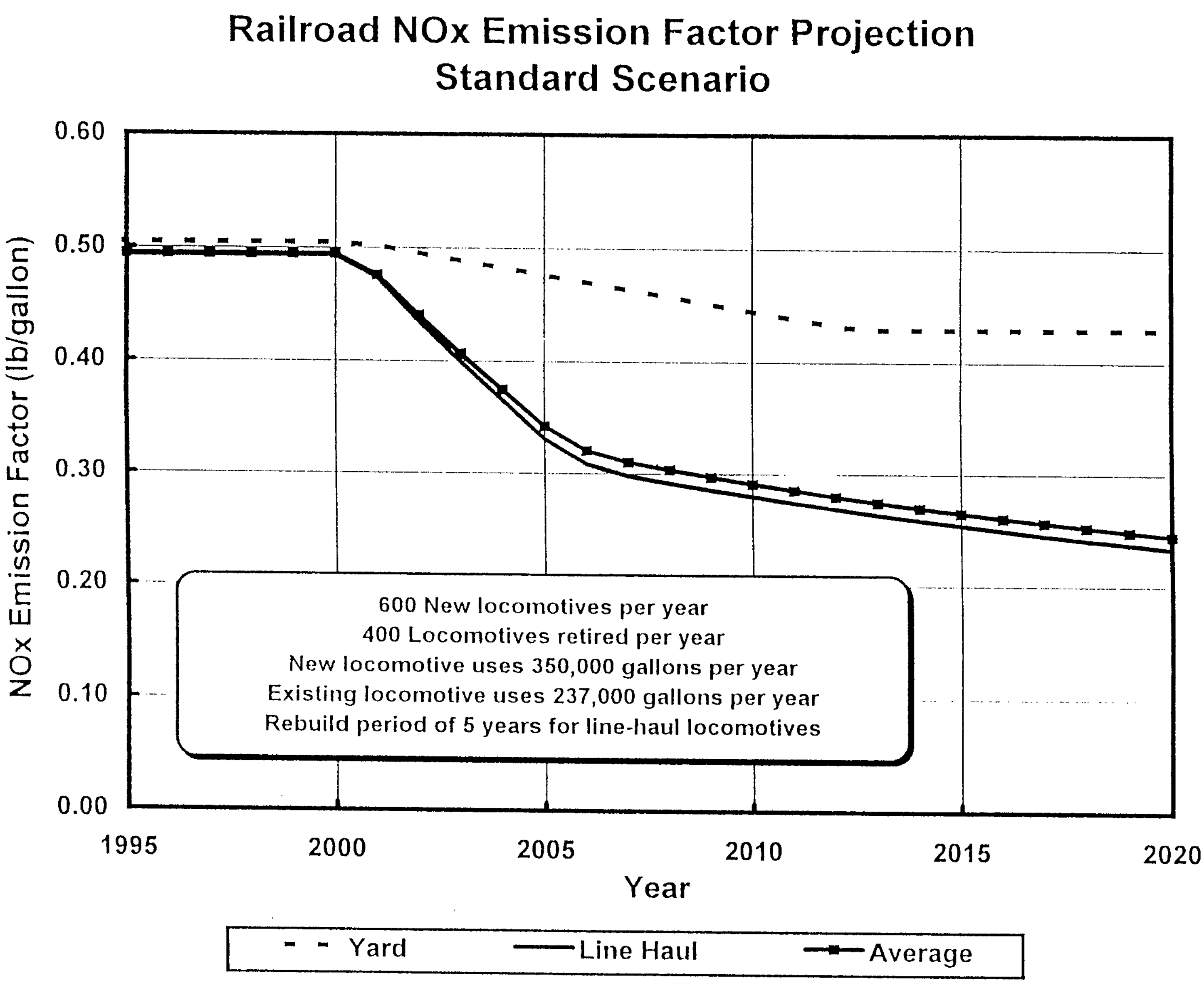
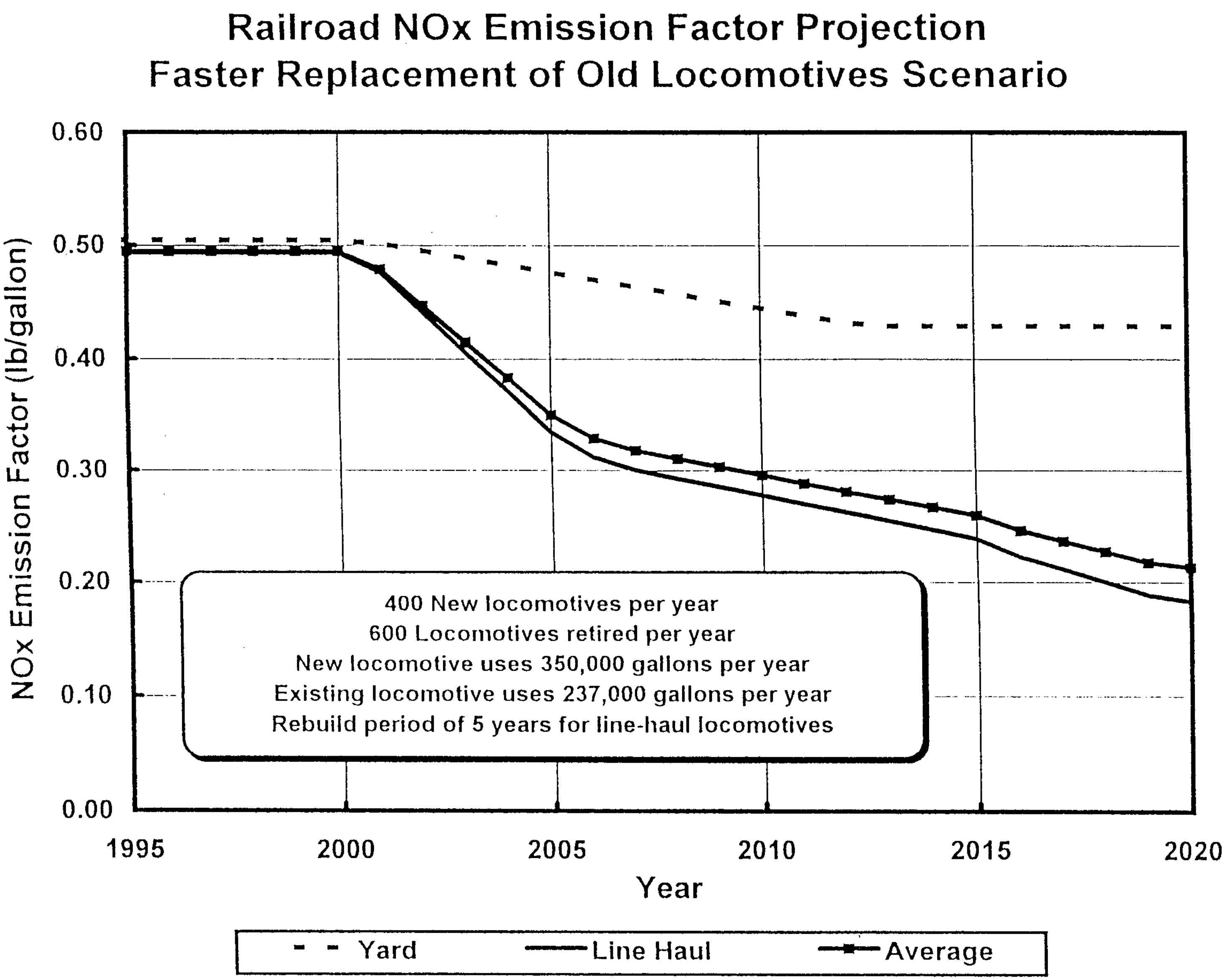
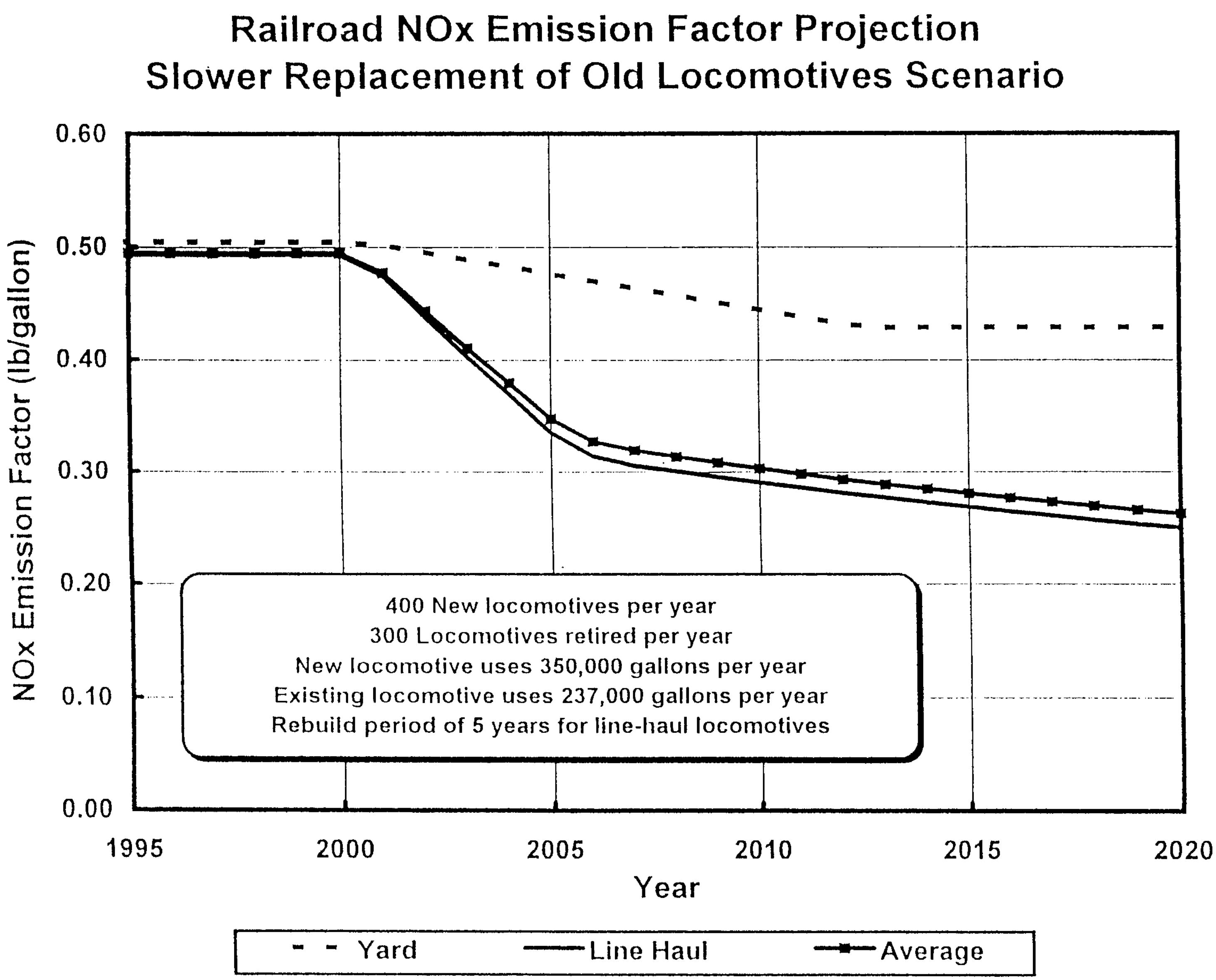

Railroad NOx Emission Factor Projection
Standard Scenario
NOx Emission Factor (lb/gallon)
0.60
0.50
0.40
0.30
0.20
0.10
0.00
1995
2000
2005
2010
2015
2020
Year
600 New locomotives per year
400 Locomotives retired per year
New locomotive uses 350,000 gallons per year
Existing locomotive uses 237,000 gallons per year
Rebuild period of 5 years for line-haul locomotives
Yard
Line Haul
Average

Figure 2



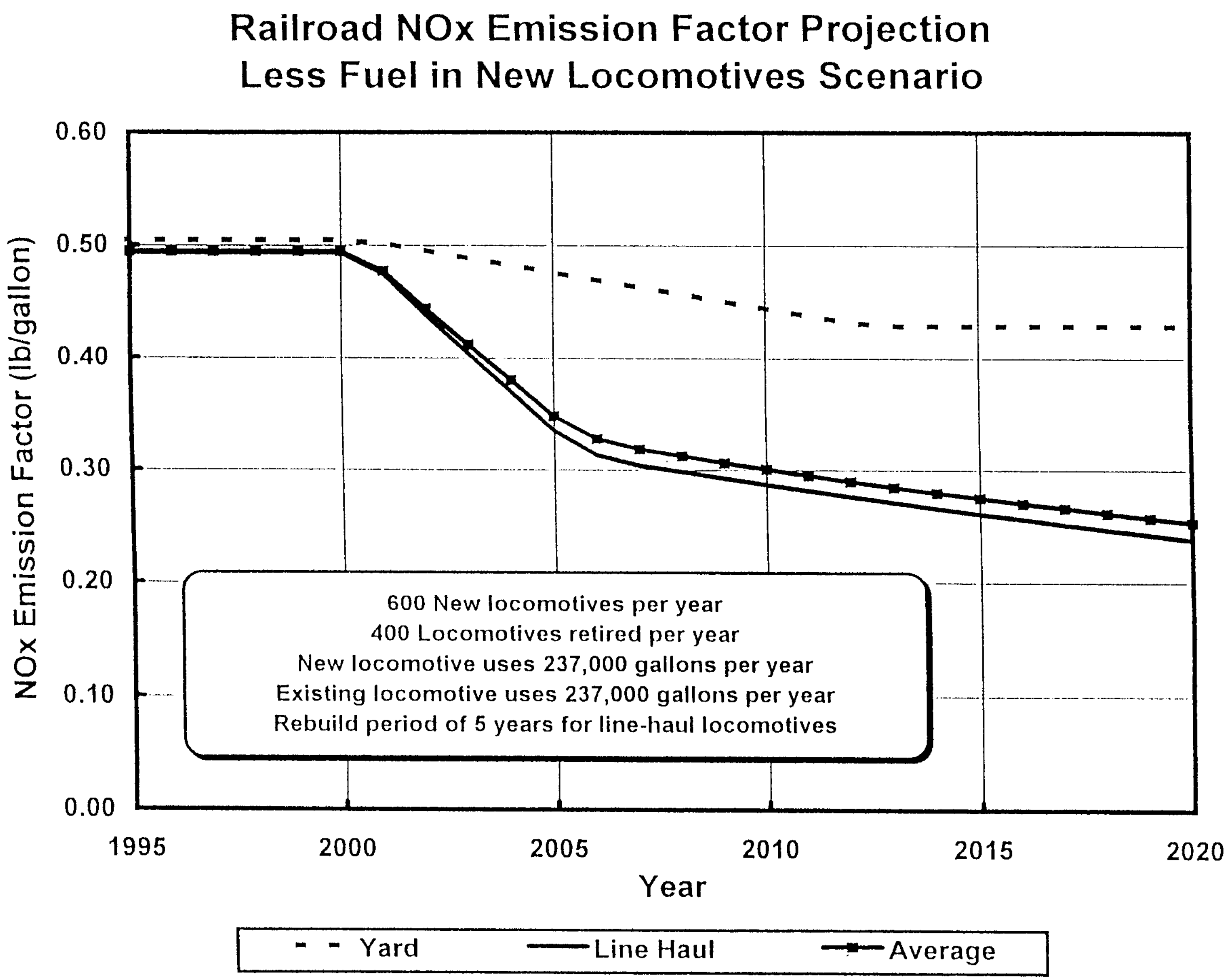
Railroad NOx Emission Factor Projection
Faster Replacement of Old Locomotives Scenario
NOx Emission Factor (lb/gallon)
0.60
0.50
0.40
0.30
0.20
0.10
0.00
1995
2000
2005
2010
2015
2020
Year
400 New locomotives per year
600 Locomotives retired per year
New locomotive uses 350,000 gallons per year
Existing locomotive uses 237,000 gallons per year
Rebuild period of 5 years for line-haul locomotives
Yard
Line Haul
Average

Figure 3



Railroad NOx Emission Factor Projection
Slower Replacement of Old Locomotives Scenario
NOx Emission Factor (lb/gallon)
0.60
0.50
0.40
0.30
0.20
0.10
0.00
1995
2000
2005
2010
2015
2020
Year
400 New locomotives per year
300 Locomotives retired per year
New locomotive uses 350,000 gallons per year
Existing locomotive uses 237,000 gallons per year
Rebuild period of 5 years for line-haul locomotives
Yard
Line Haul
Average

Figure 4



Railroad NOx Emission Factor Projection
Less Fuel in New Locomotives Scenario
NOx Emission Factor (lb/gallon)
0.60
0.50
0.40
0.30
0.20
0.10
0.00
1995
2000
2005
2010
2015
2020
Year
600 New locomotives per year
400 Locomotives retired per year
New locomotive uses 237,000 gallons per year
Existing locomotive uses 237,000 gallons per year
Rebuild period of 5 years for line-haul locomotives
Yard
Line Haul
Average

Figure 5

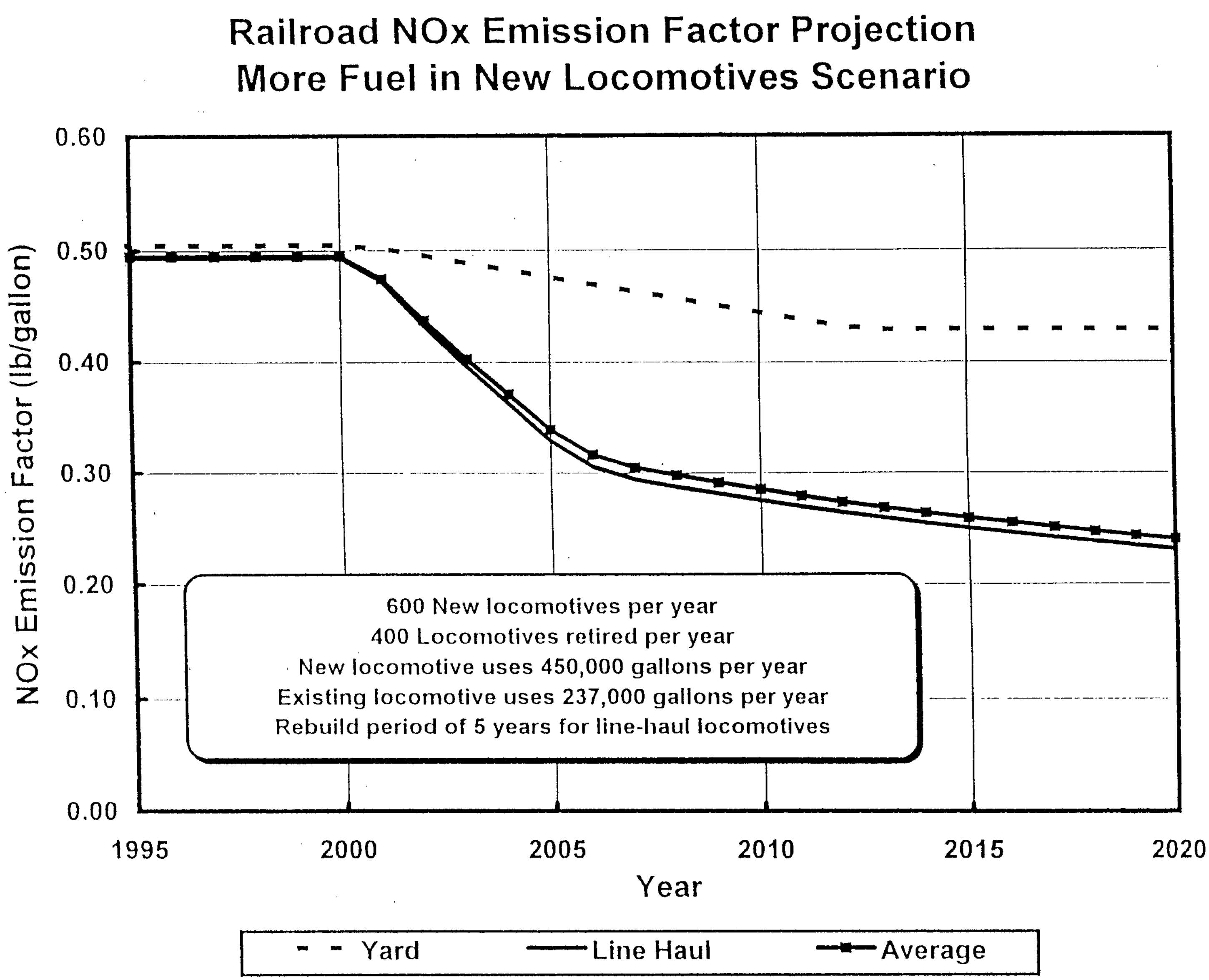

Railroad NOx Emission Factor Projection
More Fuel in New Locomotives Scenario
0.60
0.50
0.40
0.30
0.20
0.10
0.00
NOx Emission Factor (lb/gallon)
1995
2000
2005
2010
2015
2020
Year
600 New locomotives per year
400 Locomotives retired per year
New locomotive uses 450,000 gallons per year
Existing locomotive uses 237,000 gallons per year
Rebuild period of 5 years for line-haul locomotives
Yard
Line Haul
Average

Figure 6

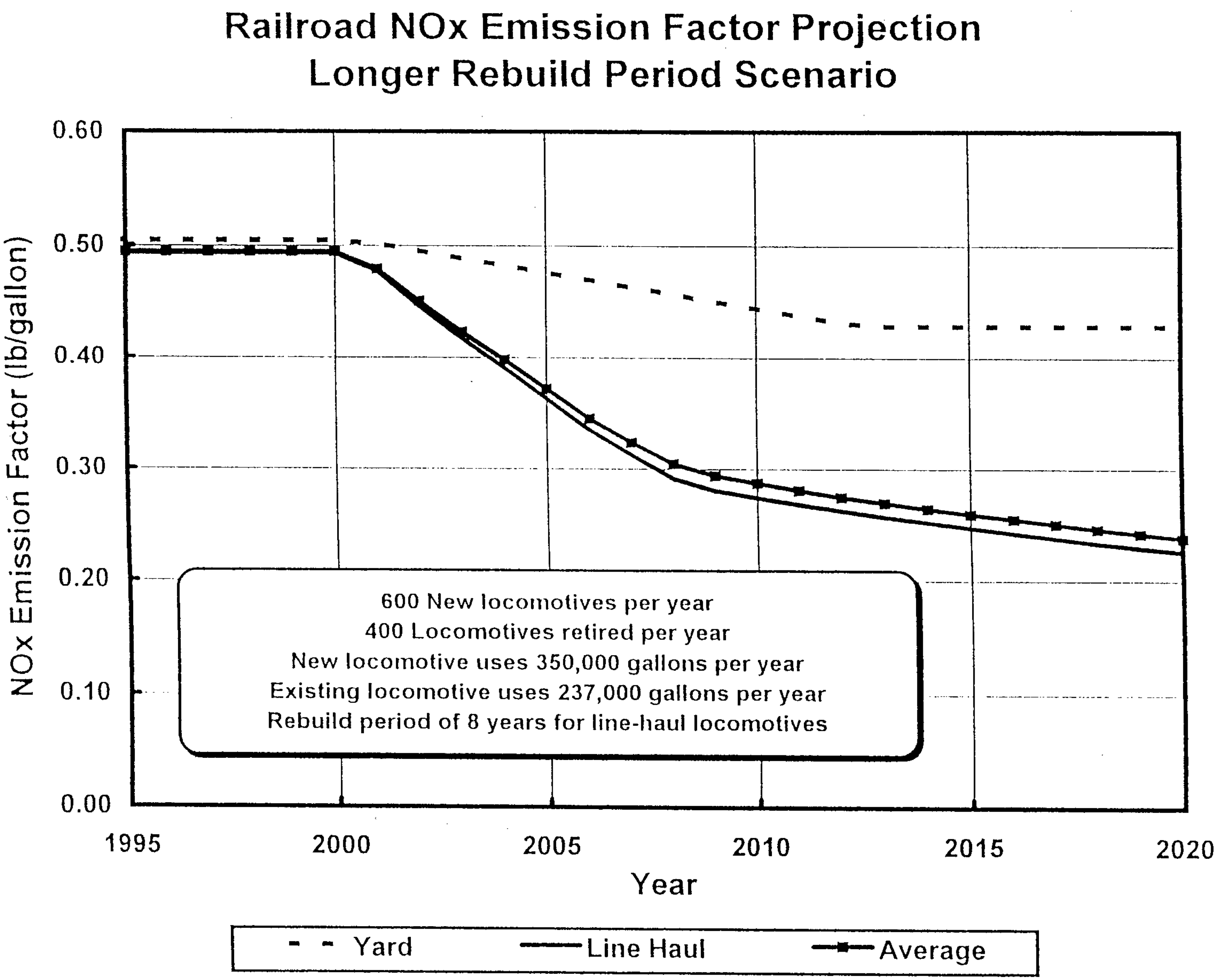
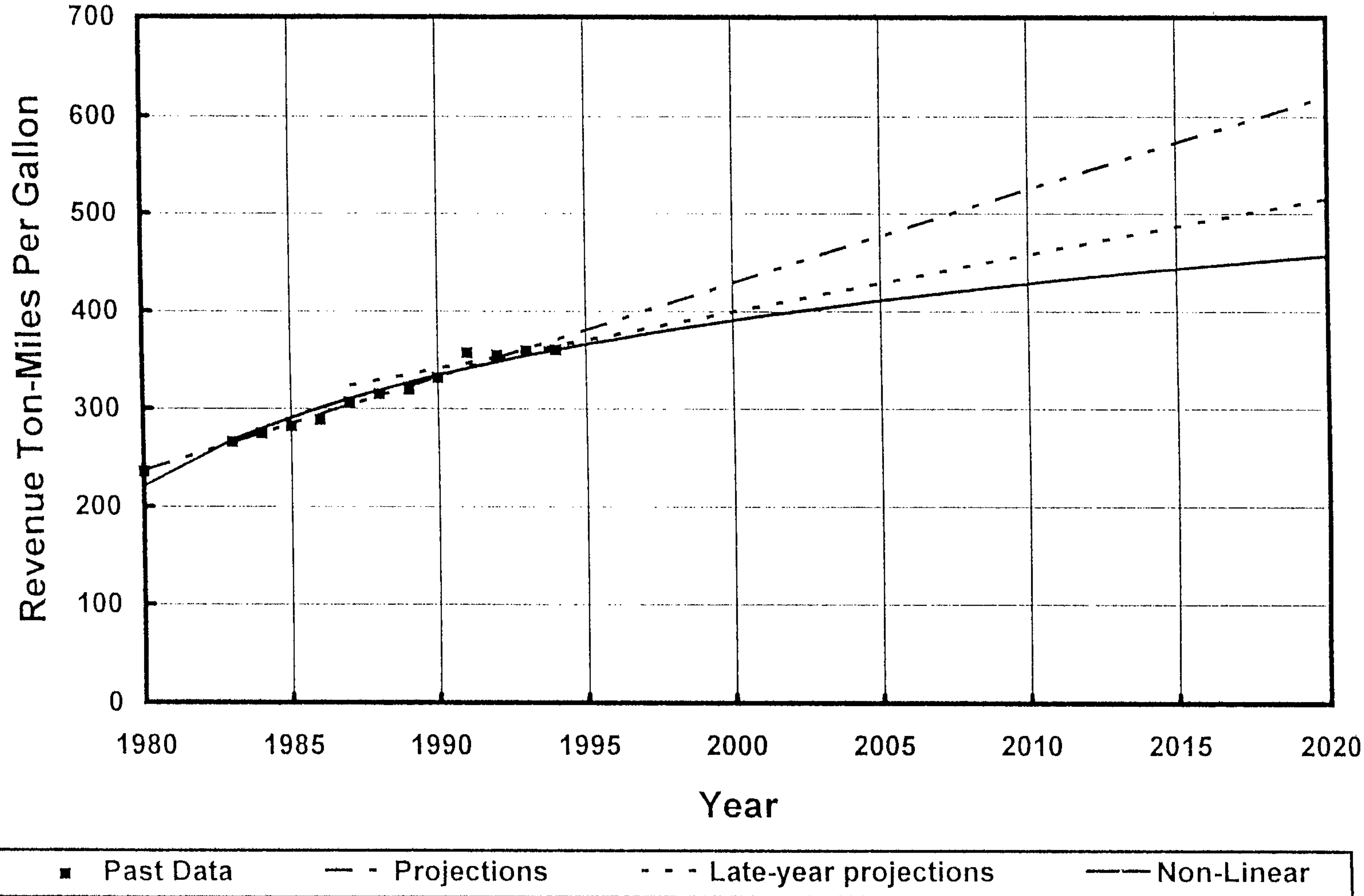

Railroad NOx Emission Factor Projection
Longer Rebuild Period Scenario
0.60
0.50
0.40
0.30
0.20
0.10
0.00
NOx Emission Factor (lb/gallon)
1995
2000
2005
2010
2015
2020
Year
600 New locomotives per year
400 Locomotives retired per year
New locomotive uses 350,000 gallons per year
Existing locomotive uses 237,000 gallons per year
Rebuild period of 8 years for line-haul locomotives
Yard
Line Haul
Average

Figure 7

Revenue Ton-miles per Gallon
1980-1994 with projections to 2020



Appendix B Detailed Case Study Site Profiles

B-1: Philadelphia

B-2: Chicago

B-3: Los Angeles

B-1: Freight Activity and Emissions Profile: Philadelphia Region

B.1. Freight Activity and Emissions Profile: Philadelphia

The following is a summary of findings obtained in the course of discussion on May 12, 1995 with the staff of the Delaware Valley Regional Planning Commission in response to a series of questions designed to elicit an understanding of the region's freight related air quality issues, freight characteristics, planning capabilities, and strategies under consideration for enhancing freight activity. DVRPC staff supplying information included Ted Dahlburg (Manager, Urban Goods Program), Ron Roggenburk (Manager, Air Quality Planning), and Thomas Walker (Manager, Office of Systems/Corridor Planning). The objective of the interview was to address the following requirements from the work scope:

> *Review air quality issues relating to intercity freight in nonattainment areas. Identify the area's overall air quality issues and estimate the relative contribution of rail, drayage for intermodal service, and over the road truck. Identify areas where freight congestion (truck or rail) contributes to secondary air pollution.*

The following questions were posed to elicit this information:

1. What is the Area's Current and Projected Air Quality Status?

DVRPC comprises a 9-county region centered on the City of Philadelphia, and includes 5 counties in Pennsylvania and 4 in New Jersey. As an air quality nonattainment area (NAA), DVRPC is included in a region which spans 4 states, including parts of Pennsylvania, New Jersey, Delaware and Maryland. However, DVRPC's responsibility for air quality improvement measures only covers its Pennsylvania territory and four of six counties in the New Jersey portion of the NAA.

The DVRPC region is a Severe NonAttainment area for ozone, and is required to reach attainment by 2005. This status was determined as a result of readings obtained in 1988. However, the designation of severe status has been challenged by the PENJERDEL Council (tri-state economic development collaborative) since "severe" levels were detected at only 1 count station, and on only 1 occasion. The region has shown regular progress toward reducing its ozone levels, and expects to be in attainment by the 2005 target year DVRPC is included in the Northeast Ozone Transport Zone, which extends from Virginia through Maine.

Philadelphia and Camden Counties are also classified as a moderate nonattainment area for CO. The region is presently in attainment for PM-10.

2. Principal Contributors to Emissions by Source (stationary, mobile, area), Current and Future

The table below provides a breakdown of VOC emissions by source as documented in the inventory accompanying the 1993 SIP revision for the Philadelphia nonattainment area. The focus on VOCs in this inventory, as distinct from NOx and CO, is because the 1993 SIP is specifically directed at achieving a 15% reduction in VOCs by 1996 over 1990 levels.

VOC Emissions by Source for Philadelphia Ozone NonAttainment Area
(Anthropogenic Sources Only)

	1990 VOCs (Tpd)		1996 Proj. VOCs (tpd)		1990-1996 Change	
Source	PA Only	Tot. NAA	PA Only	Tot. NAA	PA Only	NAA
Point	175 (25.7%)	353 (28.7%)	182 (26.8%)	343 (28.6%)	+7 (+1.1%)	-10 (-0.1%)
Area	226 (33.2%	378 (30.8%)	229 (33.7%)	381 (31.8%)	+3 (+0.5%)	+3 (1.0%)
Mobile	118 (27.6%)	342 (27.9%)	176 (25.9%)	315 (26.3%)	-12 (-1.7%)	-17 (-1.6%)
Off-Hwy	91 (13.3%)	155 (12.6%)	92 (13.5%)	160 (13.3%)	+1 (+0.2%)	+5 (0.9%)
Total	**680**	**1,228**	**680**	**1,199**	**0**	**-19**
Emissions Budget			550	980		
Target Reduction			137	227		
Highway Sources			74 (54%)	129 (57%)		
Other Sources			63 (46%)	98 (43%)		

What these inventory data show is that Mobile Sources make up about 28% of year 1990 VOC emissions, both for the entire nonattainment area and for the Pennsylvania portion only, and are projected to decline (before application of active control measures) to 26% by 1996. This suggests that Mobile Sources are the 3rd largest contributor, behind Area and Point, and show the only projected *reduction* on trend of any group, or about 1.6/1.7%. All other sources are projected to increase between 1990 and 1996.

Of the proposed 1990-1996 emissions reductions, approximately 57% of the total VOC reduction is expected to come from highway sources (though highway is only 26% of total VOCs), due to the post-1990 control measures of enhanced I/M, reformulated gasoline, and employer trip reduction programs. (It should be noted that rail, air and marine modes are included in Off-Highway.

Contribution of Mobile Sources to NOx and CO, the other precursor pollutants to Ozone, were not immediately accessible (i.e., not in DVRPC's possession), and are being acquired directly from Pennsylvania Department of Environmental Resources. At present, an estimate of contributions of sources to individual pollutants is available only as a <u>statewide</u> summary as follows:

1990 Ozone Precursors for State of Pennsylvania
Contributions by Source

	VOCs		NOx		CO	
Source	tpd	Pct.	tpd	Pct.	tpd	Pct.
Point	484	21.9%	2,235	66.2%	1,845	19.9%
Area	775	35.1%	73	2.1%	369	4.0%
Mobile	781	35.3%	788	23.3%	5,101	54.9%
Off-Road	165	7.5%	279	8.3%	1,974	21.2%
Total	**2,209**	**100%**	**3,375**	**100%**	**9,298**	**100%**

It is not clear how accurately the state-level distribution above represents the character of the Philadelphia metropolitan area. The state distribution suggests that Mobile and Area sources are the leading contributors to VOCs, while Point sources are the leading contributor to NOx and Mobile sources are the leading contributor to CO. Generally, Mobile Sources are the commanding portion of NOx emissions in urbanized areas.

3. Proportion of Emissions Related to Freight & Perceived Importance in Regional Efforts to Achieve Attainment

Not surprisingly, DVRPC does not break out the specific contributions of freight modes to the regional emissions inventory. Typically, MPOs do not attempt to isolate the emissions of an individual sector. The MPO is generally responsible only for the Mobile Source portion of regional emissions. Truck freight movements are accounted for within Mobile Sources. Rail, Marine and Air freight emissions are contained in Off-Road sources, and these are typically estimated by the state environmental agencies.

An approximation of the freight-related highway emissions can be made by examining the Heavy Duty Gas and Diesel Vehicle classes (HDGV and HDDV) in the MOBILE model, which is run by DVRPC to estimate emissions. There are generally 8 vehicle classes represented in MOBILE:

LDGV: Light-duty gasoline vehicles

LDDV: Light-duty diesel vehicles

MC: Motorcycle

LDGT1: Light-duty gasoline trucks (under 6000 lbs. GVW)

LDGT2: Light-duty gasoline trucks (6000 to 8500 lbs GVW)

LDDT: Light-duty diesel trucks (under 8500 lbs GVW)

HDGV: Heavy-duty gasoline vehicles (over 8500 lbs GVW)

HDDV: Heavy-duty diesel trucks (over 8500 lbs GVW)

The following table shows a breakdown of 1990 Mobile Source emissions, by mode, for the 5-county Pennsylvania-only portion of the DVRPC region:

1990 Summer Ozone Precursor Emissions for DVRPC Region
(Pennsylvania portion only)
Mobile Source Contributions by Mode

(All Kg. x 1,000)

Source	Kg/d	Pct.	Kg/d	Pct.	Kg/d	Pct.
LDGV	136.3	75.0%	76.7	49.0%	827.8	72.8%
LDDV	0.1	0.1%	0.3	0.2%	0.3	0.0%
LDGT1	18.5	10.2%	11.2	7.1%	133.2	11.7%
LDGT2	11.7	6.4%	6.4	4.1%	73.5	6.5%
LDDT	0.1	0.1%	0.4	0.2%	0.3	0.0%
HDGV	7.6	4.2%	7.1	4.5%	69.4	6.1%
HDDV	5.8	3.2%	54.3	34.7%	28.3	2.5%
MC	1.5	0.8%	0.2	0.1%	4.2	0.4%
Total	**181.9**	**100%**	**156.5**	**100%**	**1,137.7**	**100%**

Using HDDV and HDGV as a rough approximation for freight modes, the table above indicates that these two classes account for 7.4% of Mobile Source VOC emissions, 39.2% of NOx emissions, and 8.6% of CO emissions. Looking at emissions produced by these modes in relation to their share of travel, it can be seen in the table below that the emissions contributed by HDDV + HDGV vehicles is almost proportionate to their VMT (6.9%) for VOCs (7.4%) and CO (8.6%), but *much* greater for NOx (39.2%).

1990 Summer VMT by MOBILE Vehicle Class
Pennsylvania Portion of DVRPC Region Only

Mode	Daily VMT	Percent
	51.2 mil	79.4%
LDDV	0.2	0.3%
LDGT1	5.4	8.4%
LDGT2	3.0	4.7%
LDDT	0.2	0.3%
HDGV	1.2	1.9%
HDDV	3.2	5.0%
MC	0.2	0.3%
Total	**64.5 mil**	**100.0%**

4. Efforts to Break Out Intercity Component of Freight Emissions

Intercity truck freight, both Line-Haul and Dray, is carried primarily by combination trucks with 3-or-more axles, weighing over 33,000 lbs. GVW. The vast majority of these truck units are diesel powered, and hence are contained in the HDDV class. Using data compiled from HPMS and TIUS on combination diesel truck VMT (Table 4.3 in Main Report), it is estimated that 69.5% of all HDDV VMT in the Philadelphia region is by combination truck. If we use this proportion to represent Intercity Truck emissions as a subset of HDDV emissions, the following is the estimated contribution of Intercity Truck:

	Daily VMT (millions)	VOC (10^3kg/day)	NOx (10^3kg/day)	CO (10^3kg/day)
HDDV	3.2 (5.0%)	5.8 (3.2%)	54.3 (34.7%)	28.3 (2.5%)
Intercity Truck	2.2 (3.5%)	4.0 (2.2%)	37.7 (24.1%)	19.7 (1.7%)

From this display, it becomes evident that intercity truck is primarily a concern with respect to NOx, which it emits at about 8 times its share of regional VMT. Estimating the importance of these emissions within the total regional inventory across all sources, the above percentages are reduced by the Mobile Source share of each pollutant.

	VOC	NOx	CO
Mobile Source	35.3%	23.3%	54.9%
Intercity Truck pct. of Mobile Source	2.2%	24.1%	1.7%
Intercity Truck pct of Total Emissions	0.8%	5.6%	0.9%

Using these source contribution relationships taken from the state inventory, the contribution of Intercity Truck to regional emissions would appear to be a minor concern, though the NOx contribution of 5.6% still draws interest. However, it should be noted that the state's ***average*** source contribution relationships for Mobile Sources are ***very low*** compared to other places, and one would expect Philadelphia would be much different from the state as a whole.

The other freight modes -- rail, air, and marine -- are all Off-Road Sources and their emissions are estimated by the Pennsylvania Department of Environmental Resources. To date, sufficient information to estimate these contributions has not been available.

Obviously, given the coarseness of this estimating process, distinguishing among the freight *submodes* (i.e. drayage truck or rail switching) is problematic.

5. Nature of Regional Freight Operations

Given Philadelphia's function as a port, it has a dual identity in terms of intercity freight: that activity related to the port, most of which by definition is "intermodal", and the conventional shipments of intercity freight by truck and rail into, out of, and through the area.

Much of the region's and the state's attention is on the port activity. For the state, Philadelphia represents a gateway for Pennsylvania business to access overseas markets, and the state has been instrumental in engineering strategic modifications to make the main Conrail (east-west) and Canadian-Pacific (north-south) lines double-stack compatible. For the region, the port is also a focus for economic development interest, enhanced (and encouraged) by the state's involvement.

The Philadelphia port occupies both sides of the Delaware river, sharing the activity with sites in New Jersey. Port plans and activities are now coordinated through a joint port authority, which was considered a major institutional breakthrough. Attachment 1 illustrates the location of the public port facilities, which consist of 10 terminals and piers, 8 of which are in Pennsylvania. There are numerous other private port terminals and petroleum facilities in the port area.

Philadelphia is the largest freshwater port in the world. The major commodities transacted through the port are crude oil, coffee and cocoa beans, containerized shipments, fruit and other perishable food products, steel products, automobiles, and wood and paper products.

There is some debate over whether Philadelphia's port serves predominantly a regional or national market. The port has a natural disadvantage in that access is via the Delaware bay, which is an 8-hour voyage from the Atlantic Ocean. This makes the coastal ports (especially New Jersey) much more attractive to east-west trans-Atlantic traffic, and somewhat defines Philadelphia's orientation to traffic from South America. A proposal now under development involves a "fast ships" connection between Philadelphia and Belgium that could greatly change the travel time balance and "quadruple" the traffic volume through the port.

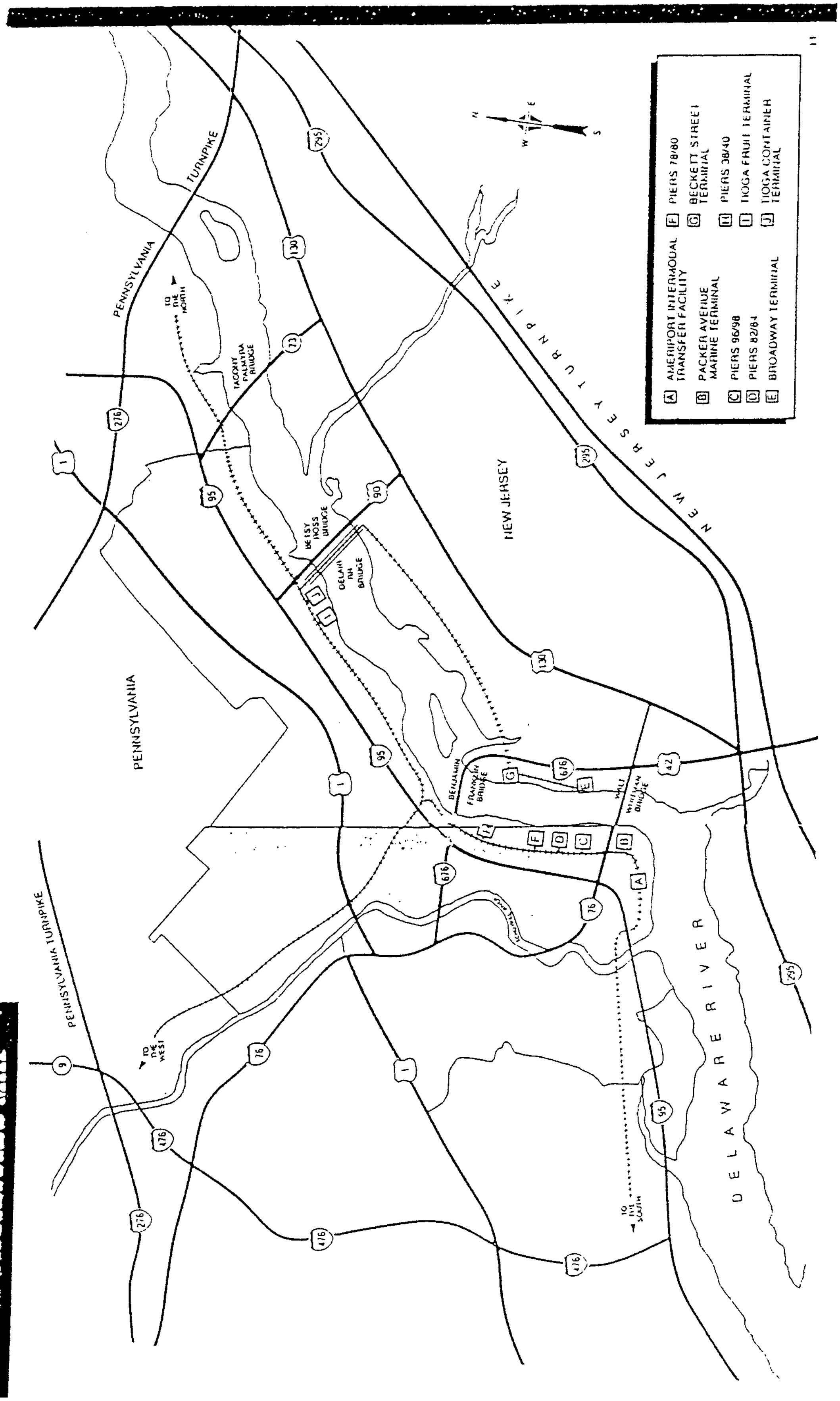
It is estimated that about 87% of the freight entering the port reaches its final destination by truck (this is one reason for suggesting that a regional market is served). The remainder is transported by rail, mostly via container. None of the rail intermodal terminals are located at the port facilities; they all require truck drayage to the rail facility. Typically, this involves truck travel along I-95, which runs parallel to the river/port through this area. Drayage trips from port to terminal can range from one-half to 30 miles in length

There are three Class I railroads that serve Philadelphia (Attachment 2): Canadian-Pacific which serves the northern and western US and Canada; Conrail, which serves the northeast and the midwest; and CSX, which serves the southeastern US (Philadelphia is its northern terminus). Each is serviced by its own terminals, the locations of which appear to be based on history and for convenient connection with movements through other corridors.

It appears that use of Philadelphia as a port is not only discouraged by the 8-hour Delaware River/Atlantic Ocean connection, but costs are generally higher because of the drayage handling -- mainly attributable to terminal turnaround time. **This is also an air quality issue because of yard-based drayage operations, principally idling emissions.**

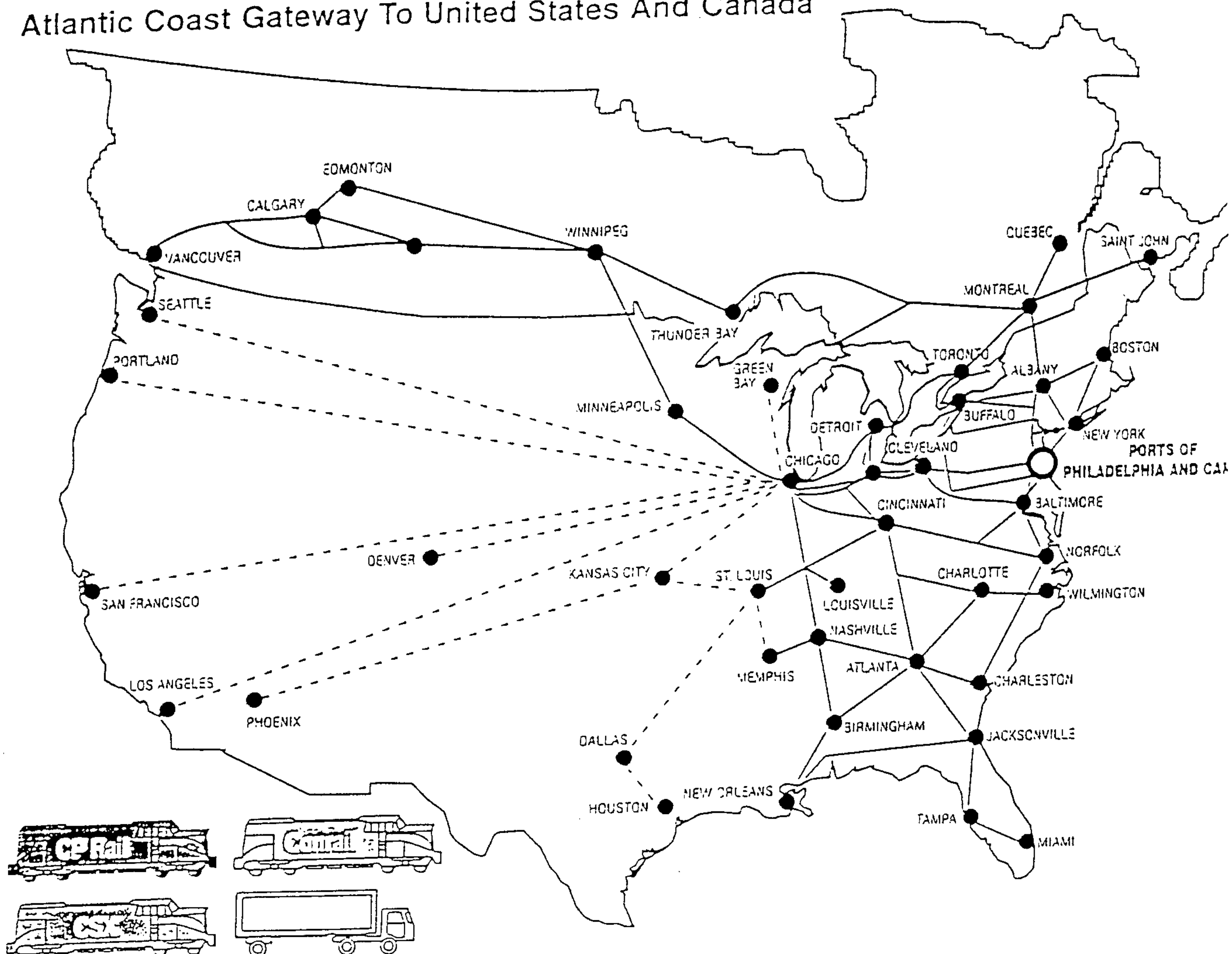
The conventional intercity freight flows through the region -- which presumably constitutes the majority of roadway traffic -- does not appear to have attracted as much attention as the port. Philadelphia is a major point in the northeast grid, between Baltimore/Washington in the south and New York/New England to the north, with Interstate connections of I-76 (east-west) and I-95 (north-south). However, not much information was uncovered on the magnitude or nature of these operations.

PORT FACILITIES MAP



Major Market Location/Distance Map

Ports Of Philadelphia And Camden
Atlantic Coast Gateway To United States And Canada



DISTANCE FROM THE PORTS OF PHILADELPHIA AND CAMDEN

Market	Miles	Km	Market	Miles	Km	Market	Miles	Km	Market	Miles	Km
Albany	257	414	Cleveland	413	665	Memphis	1,000	1,609	Saint John	765	1,231
Atlanta	741	1,192	Dallas	1,452	2,336	Miami	1,230	1,979	San Francisco	2,866	4,611
Baltimore	102	164	Denver	1,691	2,721	Minneapolis	1,143	1,839	Seattle	2,751	4,426
Birmingham	869	1,398	Detroit	573	922	Montreal	483	777	St. Louis	868	1,397
Boston	296	476	Edmonton	2,495	4,015	Nashville	792	1,274	Tampa	1,044	1,680
Buffalo	360	579	Green Bay	945	1,521	New Orleans	1,211	1,949	Thunder Bay	1,271	2,045
Calgary	2,405	3,870	Houston	1,508	2,426	New York	101	163	Toronto	507	816
Charleston	482	776	Jacksonville	845	1,360	Norfolk	272	438	Vancouver	2,898	4,663
Charlotte	544	875	Kansas City	1,118	1,799	Phoenix	2,374	3,820	Wilmington	542	872
Chicago	738	1,187	Los Angeles	2,706	4,354	Portland	2,821	4,539	Winnipeg	1,614	2,597
Cincinnati	567	912	Louisville	668	1,075	Quebec	642	1,033			

6. Characteristics of Regional Environment that Affect Freight Operations

As enumerated above, these include:

- Location within the northeast corridor, serviced by I-95.
- Pennsylvania Turnpike (I-76/276) a major corridor to the mid-west.
- Double-stack clearance on main rail lines north and west may substantially increase intermodal activity (though may also work to the advantage of New Jersey ports).
- All port facilities are located in South Philadelphia. While the major rail lines run roughly parallel to the port area, most of the rail-intermodal terminals (where the trains are actually assembled) are located elsewhere. There are 3 primary rail intermodal terminals: the Conrail terminal in Morrisville, located in Bucks County near Trenton (NJ), the Packer Avenue Ameriport Marine Terminal which serves all the rail systems, and the CSX facility at Oregon Avenue. Of these, only the Ameriport facility and Oregon Avenue terminals offer "direct" vessel-to-rail transfer (although not within the same yard). All others require over-the-road drayage to the rail yards, with the transfer distances ranging from 1/2 to 30 miles (Morrisville). Most of this dray traffic occurs on I-95, which also parallels the port/rail corridor.

7. Strategies Considered to Improve Freight Operations or Reduce Emissions

In 1993, Pennsylvania and New Jersey port interests unified into a single entity, the "Ports of Philadelphia and Camden, Inc., thereby combining objectives and resources toward common goals and investments in the port's livelihood and potential This organization is endeavoring to bring the latest technology and intermodal facilities to the area.

The state of Pennsylvania entered into a joint project with Conrail and CP Rail System in 1992 to improve clearances (20' min.) at 163 sites along the state's main rail lines west to Pittsburgh and north to New York in order to make the entire way double-stack compatible. The work will be completed in 1995. The state approved $38.1 million for the project and the railroads are funding the remaining $80 million. The improvement project is expected to result in a 50% increase in intermodal cargo to the port of Philadelphia by 2000 (containerized cargo through Philadelphia grew by 70% between 1991 and 1992 alone), and also open up Pittsburgh as a western gateway. Among other cargoes, shipment of autos on covered cars is expected to increase. Double stack is the most economic alternative for many shippers and is seen as the way of the future.

The "Fast Ships" concept being developed by Holt Cargo Systems, Inc., with cooperation from the DRPA, will need a new terminal in South Philadelphia. Plans are to take over a portion of the old Navy Yard, as the mothball fleet is dissolved and the space is now becoming available. The demands of this new terminal -- both location and potential traffic -- are causing DVRPC to look carefully at the land side impacts and strategies to accommodate the new traffic.

8. Freight Contributions to Congestion and Secondary Pollution

A firm answer could not be obtained. There did not seem to be a high level of concern or consciousness about freight impacts on overall traffic and emissions. Because of the port/intermodal focus in intercity freight, the bulk of traffic impacts was seen as occurring in the I-95 corridor adjacent to the freight yards and not judged to be a major impact (< 1% of daily regional VMT). No problems with drayage operations clogging up local streets or arterials was indicated. While there may be problems of trucks impacting traffic conditions elsewhere through the region, these problems were not identified. The travel modeling system does not specifically flag these problems as "truck related", so some combination of empirical knowledge (known "hotspots" or bottlenecks) and model results would be necessary to isolate and quantify these problems. However, the influence of truck was not mentioned as a specific, high-visibility problem.

9. Analytic Tools/Data to Evaluate Enhancement Strategies

DVRPC 's modeling tools, like most MPOs, are greatly limited in addressing freight traffic and likewise the effectiveness of enhancement strategies. They do have trip tables for heavy and light truck that were developed from a gravity model using trip length as the criteria (12.3 miles for heavy truck, 9.4 miles for light truck) **(DVRPC: source of data/time period for development of trip tables?)** Presumably these are loaded with the other trip tables onto the regional network as part of the traffic assignment process. The models are not focused on trucks, however, and are not "policy sensitive" in a way that enhancement strategies could be directly evaluated. Also rail is not included as an alternative to truck.

DVRPC has available 1990 Census data and numerous additional economic activity data coded to a TAZ level. They have a version of their highway network which is coded to 254 "MCDs", or districts, as an alternative to the entire zonal system. They conducted an extensive Cordon Line survey in 1988, determining the origin/destination and vehicle type of trips entering and/or leaving the region, which could be very valuable for intercity freight assessments. They also have truck classification counts for many facilities on file.

It was noted that New Jersey has developed an exclusive multi-regional state truck network. Pennsylvania/Philadelphia does not have such a system identified/coded.

DVRPC does the emissions estimates for highway sources using the transportation planning models and MOBILE. However, rail and other freight modes are handled as off-road sources and their effect on emissions is determined by the PA Department of Environmental Resources. There is no active interplay among modes in a planning context.

10. Suggestions for Most Effective Strategies

A Delaware Valley Goods Movement Task Force has been established to "*Maximize the Delaware Valley's goods movement capability by sharing information and technology among public and private freight interests, promoting the region's intermodal capabilities and capacity, and developing and implementing a regional goods movement strategy.*" The task force covers the 9-county DVRPC region, meets for topical presentations, discussion and decisionmaking every 2 to 3 months, and includes membership from all freight sectors (operators and associations), state departments of transportation, MPOs, commercial interests, and federal and county agencies and authorities. The task force has been meeting since December 1992 and has a membership of about 100. DVRPC and PennDOT share the chairmanship. This committee is described by the ATA as one of the better MPO freight/intermodal planning groups.

The Task Force has identified a number of projects which are focused on regional intermodal freight improvements. The first group of projects was prepared in 1994 as part of the DVRPC Long Range Plan. These are listed in Attachment 3 as Candidate Freight Improvements Update. Of the measures in the list, the following are in actual stages of advancement:

1. Alleviation of turning radii restrictions for Westmoreland Street northbound ramp onto I-95.
2. Improvement of directional signage in the vicinity of the Tioga and Packer Terminals
3. Re-timing of signals controlling truck movements Allegheny Avenue onto and from I-95.
4. Surfacing and circulation improvements on the east side of Old Delaware Avenue.

A second, more expansive set of projects, listed in Attachment 4, has recently come forward under the DVRPC *Intermodal Freight Plan.* These projects address each of the major modes -- rail, port, highway and air -- separately for Pennsylvania and New Jersey. Various technical studies were also identified in the process, and also a set of proposed passenger transportation improvements that likely to be of interest to the freight community because of their potential impact on intermodal operations. The plan is intended to bring together all known projects which have the potential to facilitate the movement of goods at regionally significant intermodal sites. There was no attempt to limit the projects to only those known to be eligible for particular public or private funding, and in fact, it was acknowledged that various (possibly new) funding arrangements would be required if the plan was to be fully realized. Many of the listed projects have already been programmed on documents such as the regional TIP. Most are designed to upgrade and improve existing facilities, with a few special projects directed at increasing capacity. Several of the projects will be investigated as part of major investment (MIS) planning studies, which indicates that the precise nature of the improvements has yet to be defined and subjected to thorough technical analysis.

In conjunction with the fast ships proposal, DVRPC planned to conduct a survey in summer 1995 which would contact facility operators in the vicinity of the proposed fast ships terminal (Packer Avenue, Ameriport, CSX and CP facilities) to gain understanding of current patterns of final shipment of commodities from the port to final destinations.

Definition of problems associated with more conventional intercity freight operations (other than intermodal or port-related) or development of related strategies has not garnered as much interest or visibility as the intermodal and port functions, though obviously, a number of the strategies in Attachments 3 and 4 would affect regional freight in general.

It was suggested that economic measures like tolls, taxes or fees might have applicability and potential, and would probably be among the most effective at changing travel and emissions, but had not been mentioned or evaluated in the process to date..

Attachment 3

DRAFT

CANDIDATE FREIGHT IMPROVEMENTS UPDATE

1. **Increase turning radii, I-95 northbound exit ramp at Westmoreland Street.**
   Turning radii is tight for trucks and curbing protrudes.
   Ramp is adjacent to baseball field.
   Examine PennDOT right-of-way and Section 4(f) requirements.

2. **Improve directional signage, Tioga and Packer Terminal Areas.**
   Signage is inadequate between the interstate system and port and intermodal facilities.
   Issue must be coordinated among various agencies.
   Communicate concerns to the City of Philadelphia, the Port Community, and PennDOT.

3. **Retime signal, I-95 southbound ramps and Allegheny Avenue.**
   Delay is reported for trucks entering and exiting southbound I-95.
   Some truck traffic is seasonal.
   Contact City of Philadelphia to examine signal retiming.

4. **Improve circulation patterns, Delaware Avenue and Tioga Marine Terminals.**
   Conflicts exist between terminal movements and through traffic.
   Promote discussions and possible traffic study.

5. **Improve truck routes, Bridesburg area.**
   Truck traffic from terminals and generators conflicts with residential areas.
   Develop conceptual work program to encourage truck traffic along certain routes.

6. **Improve east side of Old Delaware Avenue, Oregon Avenue to McKean Street.**
   Improvements needed are surfacing and circulation patterns.
   Coordinate improvements with Delaware Avenue Improvement Project.

7. **Improve intermodal site access, Delaware and Snyder Avenues.**
   Some turning movements are difficult (e.g., from the facility to northbound Delaware Ave.).
   Investigate further in collaboration with CSX.

8. **Improve facility connections, Pier 96 and 98 Annex at Delaware and Oregon Avenues.**
   Transport of new autos is impeded by entry onto city streets.
   Attempt to address in context of Delaware Avenue Improvement Project.

9. **Improve truck rest area, South Philadelphia**
   Current facility is over-capacitated and available land is limited.
   Contact facility owner and trucking associations.

10. **Improve traffic flows, Oxford Valley Road and Cabot Boulevard.**
    Intermodal site access is constrained by turning radii, left turn lane, and road surface.
    Discuss issues with staffs from Bucks County Planning Commission and Falls Township.

11. **Intermodal map, Delaware Valley Region.**
    Major freight facilities are not adequately treated on available maps.
    Pursue funding to prepare regional intermodal map.

July, 1994

V PROJECT AND STUDY ACTION PLAN

This chapter sets out an action plan, comprised of projects and technical studies, to achieve the ambitious intermodal transportation network described in the preceding chapter. While regulatory, institutional, and other initiatives are of extreme importance, the action plan presented here is focused on capital improvements.

Proposed improvements are grouped into the following categories: airport, highway, port, and railroad. Useful technical studies are also identified, as are a set of proposed passenger transportation improvements that should be monitored by the freight community because of their potential impact on intermodal operations.

This plan brings together all known projects to facilitate the movement of goods at regionally significant intermodal sites. There is no attempt to limit the projects to those which would be eligible for a particular set of private or public funds. In fact, various (and possibly new) funding arrangements will be required if the plan is to be realized in its totality.

Many of the following projects have already been programmed on documents such as the DVRPC TIP. Their identification here serves to reinforce their applicability to intermodal facilities and to highlight the opportunity to use them to improve facility access and other characteristics and attributes. Most of the improvements are designed to upgrade and improve existing facilities, with a few special projects more properly regarded as increases in capacity or new construction.

Within the highway category of improvements, some projects are followed by the letters, "MIS." MIS signifies a major investment study and indicates that the precise nature of the improvements have yet to be defined and must be subjected to a thorough technical analysis.

Airport Improvements

1. Philadelphia International Airport, Philadelphia and Delaware Counties. Install new commuter aircraft runway (8-26).

2. Philadelphia International Airport, Philadelphia. Realign Hog Island Road to intersect with Enterprise Avenue and construct a tunnel under the Runway Protection Zone.

3. Philadelphia International Airport, Philadelphia. Provide realigned rail line adjacent to the north side of realigned Hog Island Road.

4. Northeast Philadelphia Airport, Philadelphia. Develop site, and improve airfield lighting and security fencing.

5. New Castle County Airport, New Castle County. Construct taxiway, modify storm drain, and improve lighting.

6. Mercer County Airport, Mercer County. Reconstruct runway.

Highway Improvements

Pennsylvania

7. I-95, Philadelphia and Bucks and Delaware Counties. Reconstruct highway and improve access to significant freight facilities in the corridor. (MIS)

8. I-95/I-276, Bucks County. Construct interchange between I-95 and the Pennsylvania Turnpike.

9. Oxford Valley Road, Bucks County. Install closed loop signal system for Business Route 1 to Big Oak Road.

10. I-95 and Betsy Ross Bridge, Philadelphia. Improve connections of I-95 to Aramingo and Torresdale Avenues.

11. PA 132, Bucks County. Improve traffic flows and intersections.

12. PA 291 (Industrial Highway), Delaware County. Widen to five lanes with a center turn lane from Ridley Creek to Trainer Borough.

13. PA 291, Improve signal and channelization at PA 420.

14. Christopher Columbus Boulevard, Philadelphia. Reconstruct to 6 lanes from Reed to Richmond Streets.

15. Old Delaware Avenue, Philadelphia. Reconstruct and upgrade along north and southbound portions serving port facilities.

16. US 322, Delaware County. Effect corridor and intersection improvements between PA 452 and US 202.

17. Allegheny Avenue, Philadelphia. Improve signals from PA 611 to I-95.

18. PA 611, Philadelphia. Realign interchange at I-76.

19. Walt Whitman Bridge, Philadelphia and Camden Counties. Provide additional ramps to improve access to I-76 and NJ 42.

20. Commodore Barry Bridge, Delaware County. Improve approach from US 322.

21. I-476 and I-676, Philadelphia and Delaware and Montgomery Counties. Install traffic and incident management system.

22. Traffic and Incident Management System, Delaware, Montgomery, and Philadelphia Counties. Install TIMS system to manage traffic operations of the region's interstate highway system.

New Jersey

23. NJ 42, Camden and Gloucester Counties. Add a fourth lane in each direction from NJ 41 to I-295.

24. Computerized Traffic Signal System, South Jersey. Install computer-controlled traffic signal system along various corridors.

25. I-295, Gloucester County. Improve interchanges from exits 14-20.

26. Traffic Operation Center, South Jersey. Implement traffic operation center and other advanced traffic management techniques.

27. US 30 and 130, Camden County. Eliminate traffic circle.

28. US 130 and New Jersey Turnpike, Burlington County. Construct full interchange.

29. New Jersey and Pennsylvania. Develop electronic technology for toll facilities.

Port Improvements

30. Delaware River, Delaware County and Philadelphia. Dredge river to 45 feet as far north as the Walt Whitman Bridge.

31. South Philadelphia. Construct FastShip terminal and improve access and internal circulation as required.

32. South Philadelphia. Provide additional capacity for truck, rail, and ship intermodal activities.

33. Beckett Street Terminal, Camden County. Expand terminal entrance, and move power lines and security gate.

34. Beckett Street Terminal, Camden County. Repair main rail leading into terminal, install rail into J building, and install turn-off from rail for Berth 4 going east/west.

35. Broadway Terminal, Camden County. Repair rail at main ingress at south end.

36. Broadway Terminal, Camden County. Construct new access road and gatehouse.

37. Pier 98 Annex, Philadelphia. Provide rail spur and siding to car staging facility.

38. Tioga Marine Terminals, Philadelphia. Improve internal circulation patterns and access from Delaware Avenue.

39. Columbus and Oregon Avenues, Philadelphia. Improve landside connections between Pier 96 and 98 Annex.

40. Petty's Island, Camden County. Improve truck access, with possible use of 37th Street as primary access route.

Railroad Improvements

41. CSX Rail Line, Philadelphia. Effect clearance and capacity improvements from the Eastside Yard west to Belmont.

42. CSX Rail Line, vicinity of Schuylkill Expressway and Grays Ferry Avenue, Philadelphia. Enhance operating conditions for north-south rail movements.

43. Oxford Valley Road, Bucks County. Improve traffic and truck flows along East Cabot Boulevard and Oxford Valley Road.

44. Regionwide. Improve railroad/highway grade crossings (particularly along major freight routes in Delaware and Montgomery counties) and deteriorated bridges.

Technical Studies

45. Port Richmond, Philadelphia. Investigate means to increase use of rail facilities at the Tioga port facilities.

46. Philadelphia International Airport, Philadelphia. Examine alternatives to improve access from the south and Tinicum Island Road to the east and Hog Island Road.

47. Delaware River. Identify measures to improve drayage operations such as cost equalization and the institution of ferry service.

48. Regionwide. Explore means to attract truck traffic to toll facilities.

49. South Jersey. Study shipper needs and transportation issues.

50. CSX rail line, Delaware County and Philadelphia. Identify measures to establish a double-stack clearance route from port facilities in South Philadelphia to Delaware, Maryland, and the South.

51. South Philadelphia. Examine adequacy of rest facilities for truck drivers and develop proposals for increases as needed.

Proposed Passenger Transportation Initiatives Which May Impact Intermodal Freight Operations

- Chester, Montgomery, and Bucks Counties. Cross county rail service between Downingtown and Trenton.
- Schuylkill Valley Metro, Montgomery County. Restoration of commuter rail service between Norristown and Pottstown.
- Delaware Avenue and Front Street, Philadelphia. Waterfront trolley service to Snyder Avenue.
- Harrisburg to Philadelphia. Leasing of two train sets and provide additional improvements to support inter-city rail passenger service.
- Penn's Landing, Philadelphia. Construct an enclosed ferry terminal for passengers.
- Trenton and Morrisville. Construction of a new rail yard for New Jersey Transit operations.

References

Dahlburg, Ted. "Intermodal Primer: The Case of CMCU 2011400" Delaware Valley Freight Intermodal Study, Delaware Valley Regional Planning Commission. (1994).

Delaware Valley Regional Planning Commission. *Conformity of the Delaware Valley's Direction 2020 Transportation Plan.* (Draft), Philadelphia, PA (July 1995).

Pennsylvania Department of Transportation, Air Quality Task Force. *On-Road Mobile Source Emission VOC Inventory and Forecast.* Garmen Associates. (October 1993).

Delaware Valley Regional Planning Commission. *Drayage Costs in the Ports of the Delaware River.* For the Delaware River Port Authority, Philadelphia, PA (March 1991).

Ports of Philadelphia and Camden: "An Overview of Facilities and Capabilities" Promotional Brochure, (date unknown).

Ports of Philadelphia and Camden. *1994-95 Handbook.* (1994).

Delaware Valley Regional Planning Commission. *Comprehensive VOC Emissions Inventory.* Philadelphia, PA (March 1994).

Pennsylvania Status Report: *Progress in Implementing the Clean Air Act Requirements for Ground Level Ozone.* Bureau of Air Quality Control, Department of Environmental Resources, Commonwealth of Pennsylvania. (November 1992).

DVRPC. *1987 Travel Simulation for the Delaware Valley Region.* Delaware Valley Regional Planning Commission, Philadelphia, PA (May 1988).

B-2: Freight Activity and Emissions Profile: Chicago Region

B-2 Freight Activity and Emissions Profile: Chicago

The following is a summary of findings obtained in the course of a meeting on May 16 with the staff of the Chicago Area Transportation Study (CATS), the MPO for the Chicago, IL region in relation to intercity freight issues, including air quality, freight characteristics, planning capabilities, and strategies under consideration for enhancing freight activity. CATS staff supplying information consisted of David Zavattero, Deputy for Operations and head of air quality and intermodal planning activities for CATS, and Gerald Rawling, Director of Operations Analysis and leader on freight related issues. The objective of the interview was to accomplish the following requirements from Task 2 of the work scope:

Review air quality issues relating to intercity freight in nonattainment areas. Identify the area's overall air quality issues and estimate the relative contribution of rail, drayage for intermodal service, and over the road truck. Identify areas where freight congestion (truck or rail) contributes to secondary air pollution.

From this investigation, the study expects to gain insights into the level of importance currently attached to freight issues in transportation and emissions planning, analytic and data capabilities, estimated share of regional emissions attributable to intercity freight modes, and strategies which have been or are being considered as options for improving freight operations and emissions.

The following questions were posed to elicit this information:

1. What is the Area's Current and Projected Air Quality Status?

CATS encompasses a 6-county region centered on Chicago. The counties include Cook (which contains the City of Chicago), Dupage, Kane, Lake, McHenry and Will. The Lake Michigan region includes three Severe Ozone NonAttainment areas: Chicago/NE Illinois; Milwaukee/ SE Wisconsin; and Gary/NW Indiana. Each of these areas is required to reach attainment by 2007. These same areas are presently in attainment for CO, though McCook in Cook County, Illinois and Lake County, Indiana (Gary, Hammond, East Chicago) are rated as a Moderate nonattainment area for PM-10.

The region's ozone problem is attributed mainly to VOCs; regional officials believe that attainment by 2007 is achievable, though not a certainty.. NOx (as a contributor to ozone) is not considered to be a major problem, and in fact, the Lake Michigan Ozone Study concluded that <u>small</u> reductions in NOx could actually <u>increase</u> ozone levels. Chicago is included in a consortium of northern mid-west states (IL, IN, MI, WI) that have jointly applied for a waiver on NOx under Section 182 of the CAAA based on this finding.

Chicago is also part of the Lake Michigan Ozone Study region (LADCO), a 4-state confab that includes southern Michigan (Detroit area) along with IL-IN-WI which is working together to attack the multi-state nature of the ozone problem through a coordinated action, where each state will identify and implement the control measures that are most effective for it and contribute most meaningfully to the whole.

2. Principal Contributors to Emissions by Source (stationary, mobile, area), Current and Future

The 1990 emissions inventory submitted by Illinois EPA (IEPA) in November 1993 [1] lists the ozone precursor emissions by source, as follows:

1990 Ozone Precursors Emissions Inventory for CATS Region

	VOCs		NOx		CO	
Source	**tpd**	**Pct.**	**tpd**	**Pct.**	**tpd**	**Pct.**
Point	350.1	27.9%	290.7	28.4%	716.8	15.1%
Area	268.0	21.4%	23.8	2.3%	22.5	0.5%
Mobile	491.2	39.2%	540.3	52.9%	2,924.4	61.5%
Off-Road	144.3	11.5%	167.5	16.4%	1,086.6	22.9%
Total	**1,253.6**	**100%**	**1,022.3**	**100%**	**4,750.3**	**100%**

Note: Biogenic sources add another 109.8 tpd of VOCs, or 8.0% of a total 1363.4 tpd
Mobile source emissions include Illinois I/M credit

(Source: 1990 Emissions Inventory, IEPA, November 1993)
[Fig. 2-2/4, p. 33/35]

As may be seen from the above, Mobile sources are the major contributor to VOCs (39.2%), NOx (52.9%), and CO (61.5%). Particulate matter (PM) emissions are not specified.

3. Proportion of Emissions Related to Freight & Perceived Importance in Regional Efforts to Achieve Attainment

The emissions inventory does not break out the contribution of "freight" modes. Freight emissions -- local or intercity -- must be estimated indirectly using surrogate relationships that make assumptions regarding the contributions of particular vehicle classes within the MOBILE model. The MOBILE model incorporates 8 vehicle classes:

LDGV: Light-duty gasoline vehicles

LDDV: Light-duty diesel vehicles

MC: Motorcycle

LDGT1: Light-duty gasoline trucks (under 6000 lb. gvw)

LDGT2: Light-duty gasoline trucks (6000 to 8500 lb. gvw)

HDGV: Heavy-duty gasoline vehicles (over 8500 lb. gvw)

HDDV: Heavy-duty diesel trucks (over 8500 lb. gvw)

The Heavy-Duty vehicle classes in MOBILE -- HDGV and HDDV -- include all vehicles with gross vehicle weight (GVW) ratings above 8,500 lb.. These are the vehicles most commonly associated with freight movement. However, the MOBILE class definitions do not permit a clean break in separating out freight modes. While the heavy duty classes include local delivery operations in the form of trucks that weigh between 8,500 and 14,000 lb. GVW, there can also be freight-hauling activities that are carried out by vehicles in the LDGT and LDDV classes. Therefore, the vehicle classification employed in MOBILE does not yield a direct estimate of freight emissions, and factoring is necessary to construct such an estimate.

Table 1 on the following page shows the contribution of individual MOBILE vehicle classes to each of the ozone precursor pollutants, as reflected in the 1990 IEPA emissions inventory. Using the HDDV and HDGV classes as a first approximation of freight activity, these classes account for 8.4% of Mobile Source VOCs, 8.1% of Mobile Source CO, and 50.3% of Mobile Source NOx.

Freight emissions attributable to railroad locomotives are estimated as Off-Road sources. Off-Road emissions inventories are developed by Illinois EPA, not CATS, and include also aircraft and marine sources; as well as construction and other heavy moving equipment. While rail emissions in Off-Road include passenger rail, it is assumed that freight is the substantial share of the calculated emissions.

Rail emissions were estimated by IEPA using methodologies suggested by the U.S. EPA and reported in the AP-42 guidance document. This methodology estimates emissions on the basis of fuel consumption. 139.4 million gallons of fuel oil were delivered to Illinois in 1989. This was apportioned to individual counties in the CATS region using "% of state track mileage" obtained from the Illinois Department of Revenue (well over 80% of the consumption occurred in Cook County under this allocation). Emissions factors obtained from EPA publication A-42 were then used to obtain emissions volumes from the fuel consumption estimates [1]:

Pollutant	Factor
VOC	94 lb. per 1000 gals.
NOx	370 lb. per 1000 gals.
CO	130 lb. per 1000 gals.

Table 1
1990 Ozone Precursor Emissions for Chicago Region
Mobile Source Contributions by Mode

Source	VOCs tpd	VOCs Pct.	NOx tpd	NOx Pct.	CO tpd	CO Pct.
LDGV	371.9	75.7%	227.4	42.1%	2,247.2	76.8%
LDDV	0.6	0.1%	2.0	0.4%	1.4	0.5%
LDGT1	40.1	8.2%	24.0	4.4%	259.9	8.9%
LDGT2	26.1	5.3%	12.8	2.4%	145.8	5.0%
LDDT	1.4	0.3%	0.8	0.1%	9.6	0.3%
HDGV	16.7	3.4%	9.3	1.7%	134.9	4.6%
HDDV	24.6	5.0%	262.6	48.6%	100.8	3.4%
MC	10.0	2.0%	1.5	0.3%	24.9	0.9%
Total Mobile Sources	**491.2**	**100%**	**540.3**	**100%**	**2,924.4**	**100%**
Heavy Duty (HDGV + HDDV)	41.3	8.4%	271.9	50.3%	235.7	8.1%
Intercity Truck (80.8% of HDDV)	19.9	4.0%	212.2	39.3%	81.4	2.7%
Total All Sources	1,254	100%	1,022	100%	4,750	100%
Intercity Truck (80.8% of HDDV)	19.9	1.6%	212.2	20.8%	81.4	1.7%

Source: 1990 Emissions Inventory, IEPA, November 1993
Tables 5-13/5-15, pp. 183-191

The data in Table 2 suggest that rail is a relatively small share of Off-Road source emissions as a group, and of course, an even smaller share of overall regional emissions. Locomotives (not all of which are in freight operations) account for 4.0% of Off-Road VOC emissions and 0.5% of total regional VOCs. As expected, locomotives contribute more heavily to NOx: 14.0% of Off-Road NOx and 2.3% of total regional NOx. Locomotives' smallest contribution is to CO: they contribute only 0.8% of Off-Road CO and 0.2% of regional CO.

The region has submitted a conformity determination for its FY 94-99 TIP, and a 2010 TSO update. A VOC budget has been established for 1996, but no budget has been established for NOx. Since the region appears to have made its base year conformity determination by a very small margin [2], it is clear that the next conformity issue will be with NOx, unless the requested NOx waiver is received from EPA. If the waiver is not granted, the focus will fall heavily on NOx reductions, and that will of necessity focus on diesel emissions, and also on freight modes since bus-related actions were already utilized in the prior mitigation efforts.

Table 2
Summary of 1990 Off-Road Emissions by Source

Source	VOC (tpd)	VOC (Pct)	NOx (tpd)	NOx (Pct.)	CO (tpd)	CO (Pct.)
Lawn & Garden	61.9	43.0%			503.3	46.3%
Pleasure Craft	23.6	16.4%			59.8	5.5%
Lt. Comm. Equipt.	15.1	10.5%	1.8	1.1%	240.2	22.1%
Construct. Equipt.	12.7	8.8%	81.0	48.2%	78.3	7.2%
Aircraft	8.2	5.7%	14.4	8.6%	40.2	3.7%
Ind. Equip.	8.1	5.6%	17.5	10.4%	113.0	10.4%
RR Locom.	5.8	4.0%	23.5	14.0%	8.7	0.8%
Rec. Vehs.	3.2	2.2%			10.9	1.0%
Others	3.0	2.1%	2.2	1.3%	2.2	0.2%
Agric. Eq.	2.4	1.7%	11.8	7.0%	12.0	1.1%
Airport Op & Comm. Vessels	0.0	0.0%	16.0	9.5%	19.6	1.8%
Total Off-Road	144	100.0%	168	100.0%	1087	100.0%
Total Regional	1253.6		1022.3		4750.3	
RR Locom. % of Regn.	3.2	0.5%	23.5	2.3%	8.7	0.2%

Source: 1990 Emissions Inventory, IEPA, November 1993 (Table 5-21, p. 198)

4. Efforts to Break Out Intercity Component of Freight Emissions

For the purpose of this study, intercity freight refers to commodity movements which have at least one end of the trip outside the region. This would include trip movements from, to, or through the CATS region. Attention is also restricted to highway and rail modes; air and marine freight are excluded, as are pipelines.

This definition is beset by various definitional problems wherein intercity and local freight moves are hard to separate. For example, what is the difference from a pure dray operation and local delivery/distribution? If gravel is delivered by barge to a port, and then is subsequently delivered within the region by heavy truck, is that the continuation of an intercity trip or is it local freight? And, how is a trip classified that is of relatively short length, but has one end outside the region? These distinctions are somewhat important, not only in tailoring and determining the effectiveness of particular strategies, but in avoiding "double-counting" of local freight remedies.

The previous section presented a first-cut estimate of intercity freight emissions. One way to construct an estimate of Intercity Truck emissions is to use the assumption that intercity freight is primarily carried by combination trucks with 3-or-more axles, the great majority of which are diesel powered. Using data compiled from the HPMS and TIUS data bases, it is possible to estimate the portion of HDDV VMT which is generated by combination trucks in a given nonattainment area. Table 4.3 (Chapter 4 of Main Report) suggests that this proportion is 80.8% in the Chicago region. Thus, we multiply the HDDV emissions totals by 80.8% to get an estimate of Intercity Truck emissions.

As seen in Table 1, this calculation suggests that only 4% of Mobile Source VOCs and 2.7% of CO are attributable to Intercity Truck, but 39.9% of NOx emissions are linked to [diesel-powered] Intercity Truck. In relation to ***total*** regional emissions from all sources, Intercity Truck is only 1.6% of regional VOC and 1.7% of regional CO, but still a major contributor to NOx at 20.8%.

Local officials concur that the scope of attention given to freight enhancement or emissions control strategies has been limited by shortcomings in analytic tools and data capable of framing and evaluating solutions.

5. Nature of Regional Freight Operations

Chicago has historically been and continues to be one of the country's major transportation, and particularly rail, centers. Many regard Chicago as the hub of the nation's freight transportation system. Eight of the nine Class I railroads in the United States have lines and terminals in the Chicago region. More than 100 freight trains arrive and depart the area daily. In 1989 Chicago handled 1.2 million containers and trailers on rail, which is more than double any other U.S. city [3].

On the highway side, it is suspected that nearly every major U.S. trucking company has a terminal in Chicago, along with major operations within the region. In 1991, it was estimated that there were more than 180,000 large truck (GVW greater than 28,000 lb..) trips within the 6-county Chicago region, and more than 67,000 large trucks entering and leaving the area each day.

Combining with the highway and rail networks are air freight operations out of O'Hare and Midway airports, seaway and river networks, and a pipeline system. The port/marine mode is not a major freight activity source in Chicago, accounting for only a small fraction of total commodity flows through the region. Attachments 1 through 5 illustrate the location and extensiveness of the region's freight transportation facilities, covering respectively the regional Railyards, the Intermodal Facilities, major Truck Terminals, major Container Depots, and the region's ports and airports. These facilities have all been encoded in a regional GIS network to facilitate their incorporation into the planning process.

Typical commodity movements through Chicago by mode are characterized as:

- Railroad: Grain, coal, steel, petroleum, intermodal/containerized cargo.
- Truck: Beverage and food products, LTL shipments of parcels and packages
- Marine: Primarily low-value bulk commodities, such as gravel/sand and petroleum, shipped by barge.
- Air: Parcels and air express services.

The trend that has characterized the freight environment in Chicago over the last decade has been a pronounced movement toward intermodal and truck terminal operations. This has been a period of major consolidation and restructuring of the trucking industry, into only about 20 major carriers. The amount of freight shipped to/through Chicago via rail intermodal has increased by 14% since 1986, and is continuing to grow in share. This shows itself in the transport of goods to Chicago by truck (or rail) where they are then loaded onto rail for the next stage of their journey. Table 3 indicates the level of activity at some of the area's major intermodal freight facilities.

The volume of freight traffic into and through Chicago has led to studied efforts to address freight congestion issues in order to facilitate both smooth operation and continued growth in traffic. Congestion and its associated time costs have been causing a number of carriers to shift their intermodal operations to another location, such as Indiana or Ohio, to avoid the delays in Chicago.

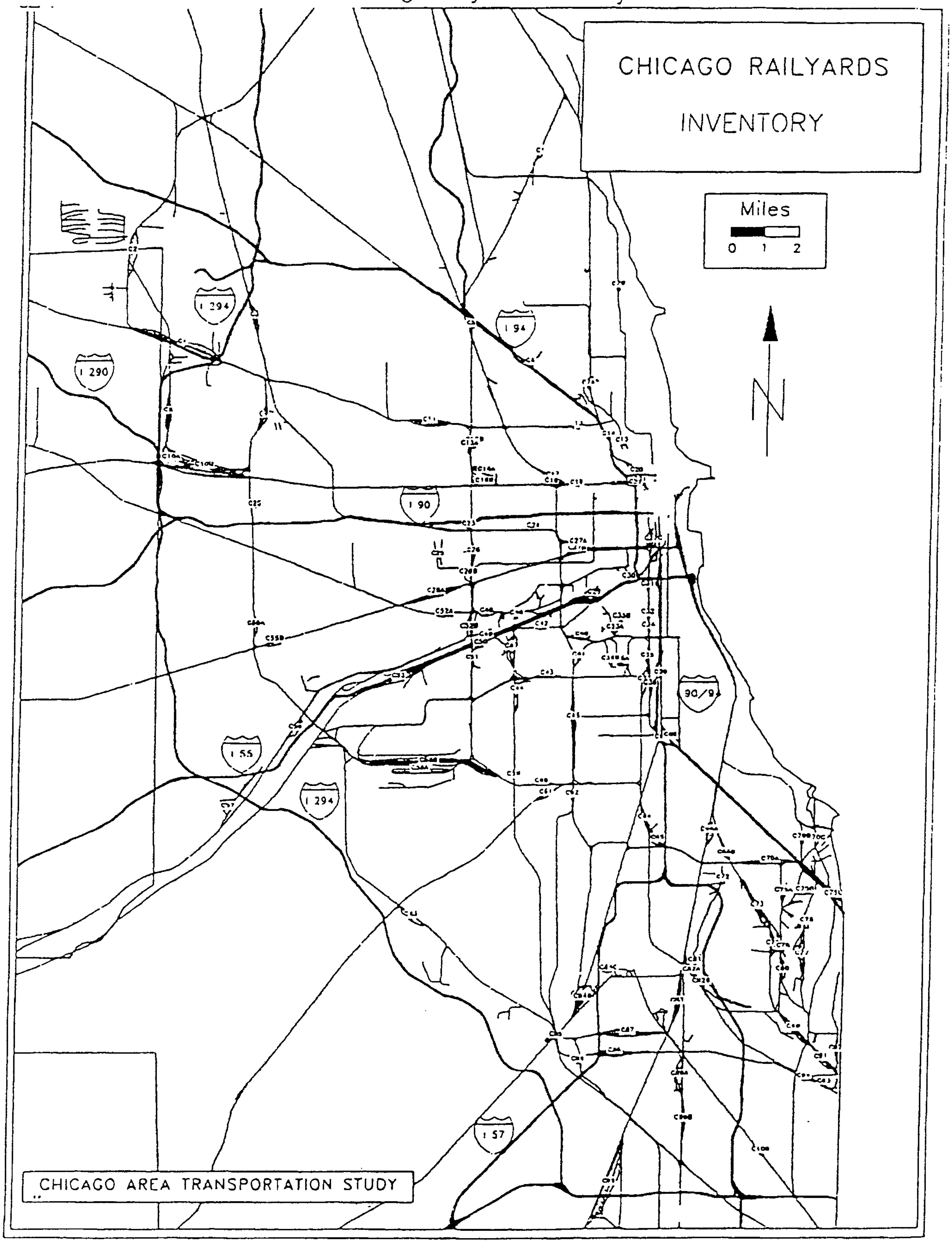
One such effort to address this problem was the Operation Green Light program [4] in 1991, a comprehensive, integrated traffic congestion reduction program for Northeastern Illinois. Recognizing that the success of congestion management strategies would depend at least partially on the response of the freight sector, freight handlers and the trucking industry were drawn into the problem/solution identification process, resulting in some of the following key observations regarding the Chicago freight environment:

Large truck[1] travel accounted for 6.6% of total regional VMT in 1980, and was projected to decrease to 4.9% by 2010 based on higher rates of growth in automobile traffic. *However, as these estimates were obtained from a standard "assignment" on an "unrestricted" network, when those restrictions (e.g., geometry, clearances, restrictions) are considered in the assignment of*

[1] *Large Trucks were defined by Operation Green Light as Multi-Unit Trucks, which would include but not equal the vehicles contained in the HDDV and HDGV class of MOBILE, although these are most likely to be the types of trucks engaged in intercity freight operations.*

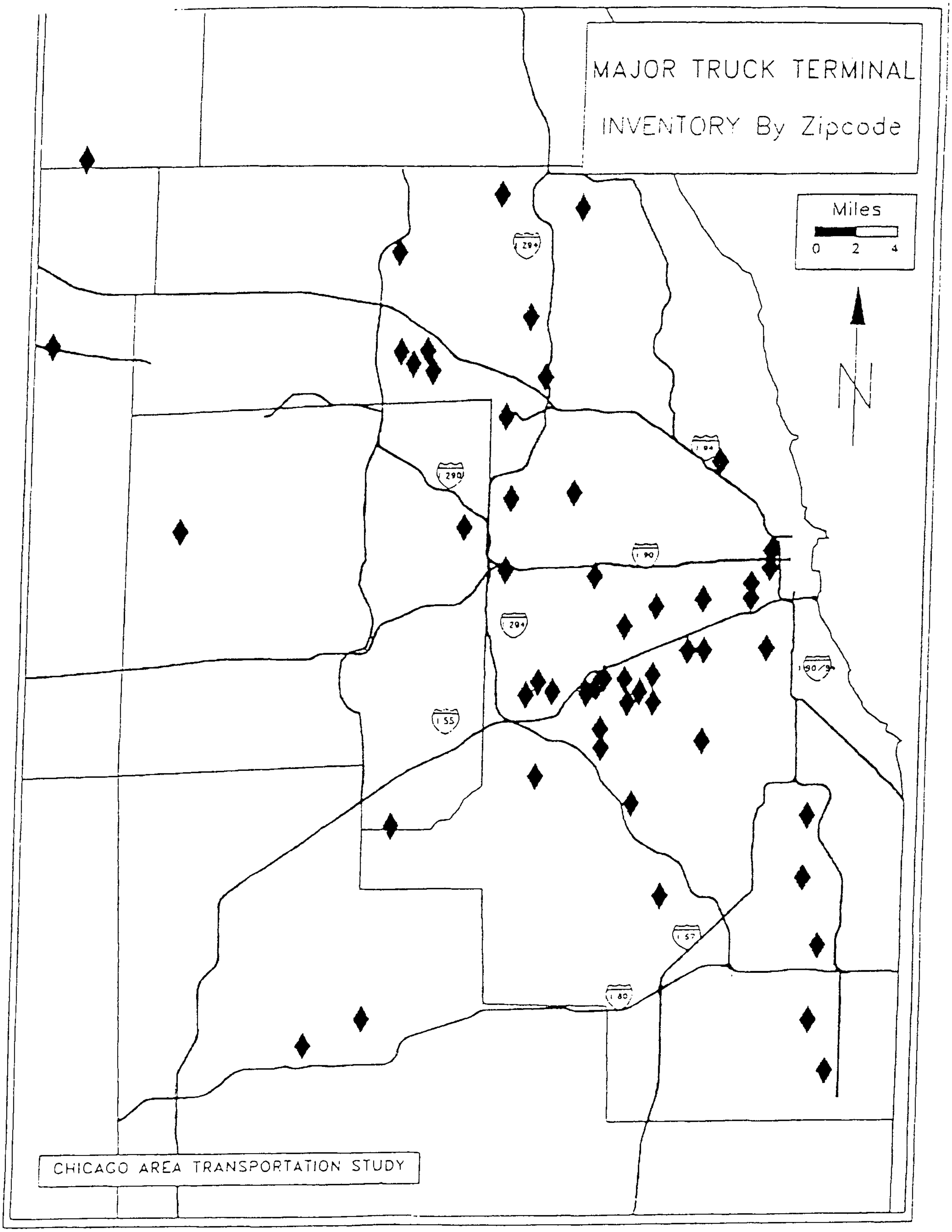
Attachment 1

Chicago Railyards Inventory



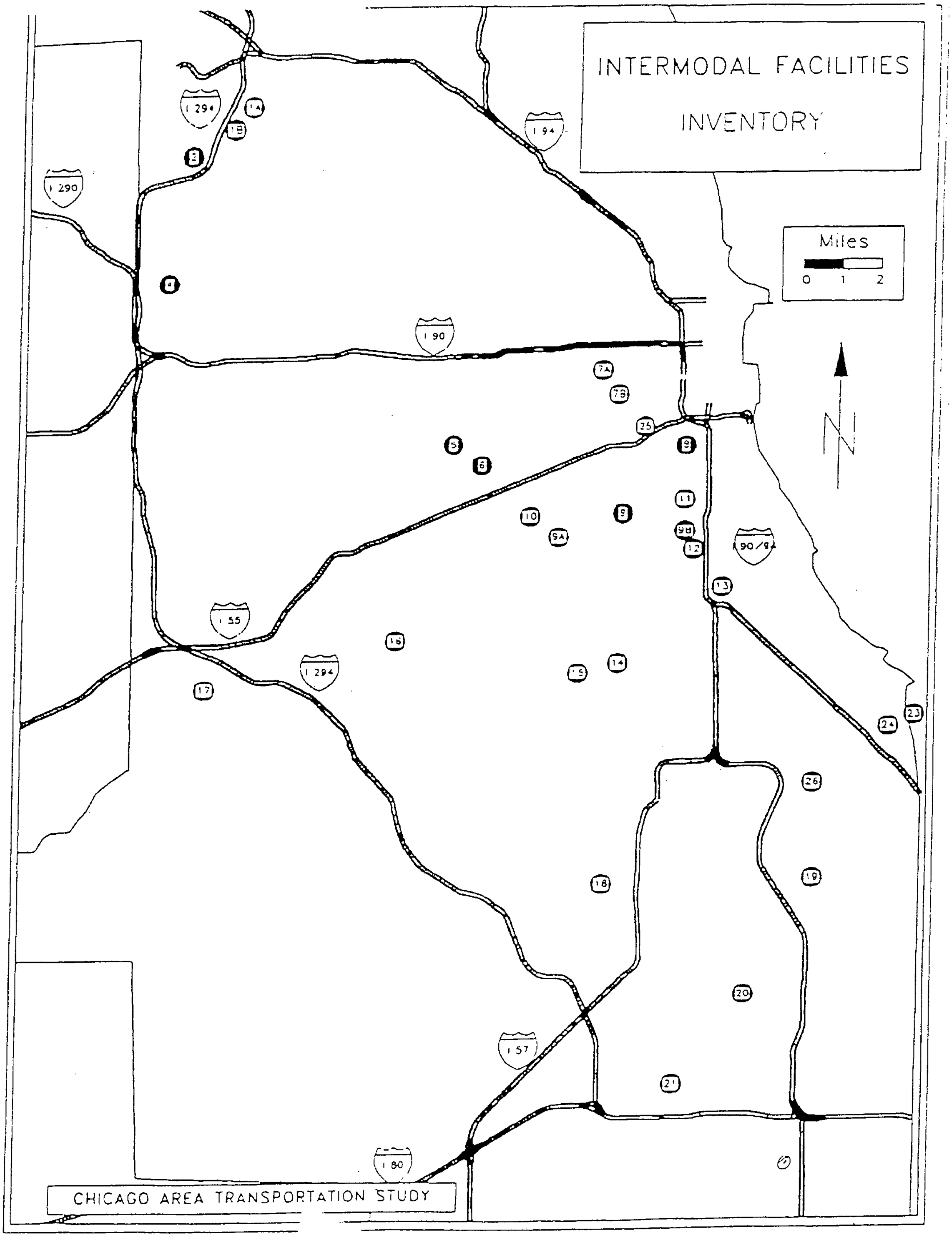
Attachment _

Major Truck Terminal Inventory



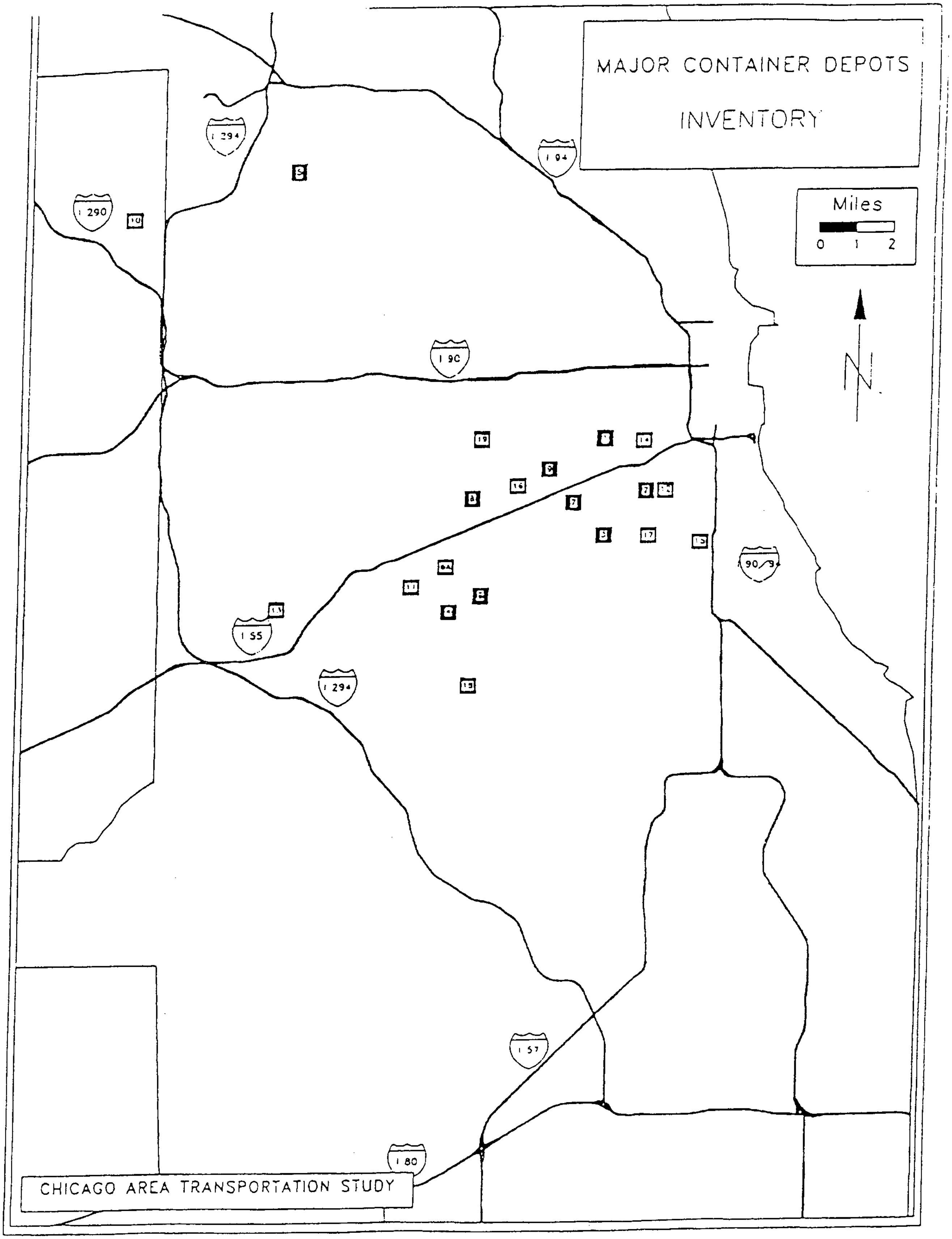
Attachment 3

Intermodal Facilities Inventory



Attachment 4

Major Container Depots Inventory



Attachment 5

Port and Airport Inventory

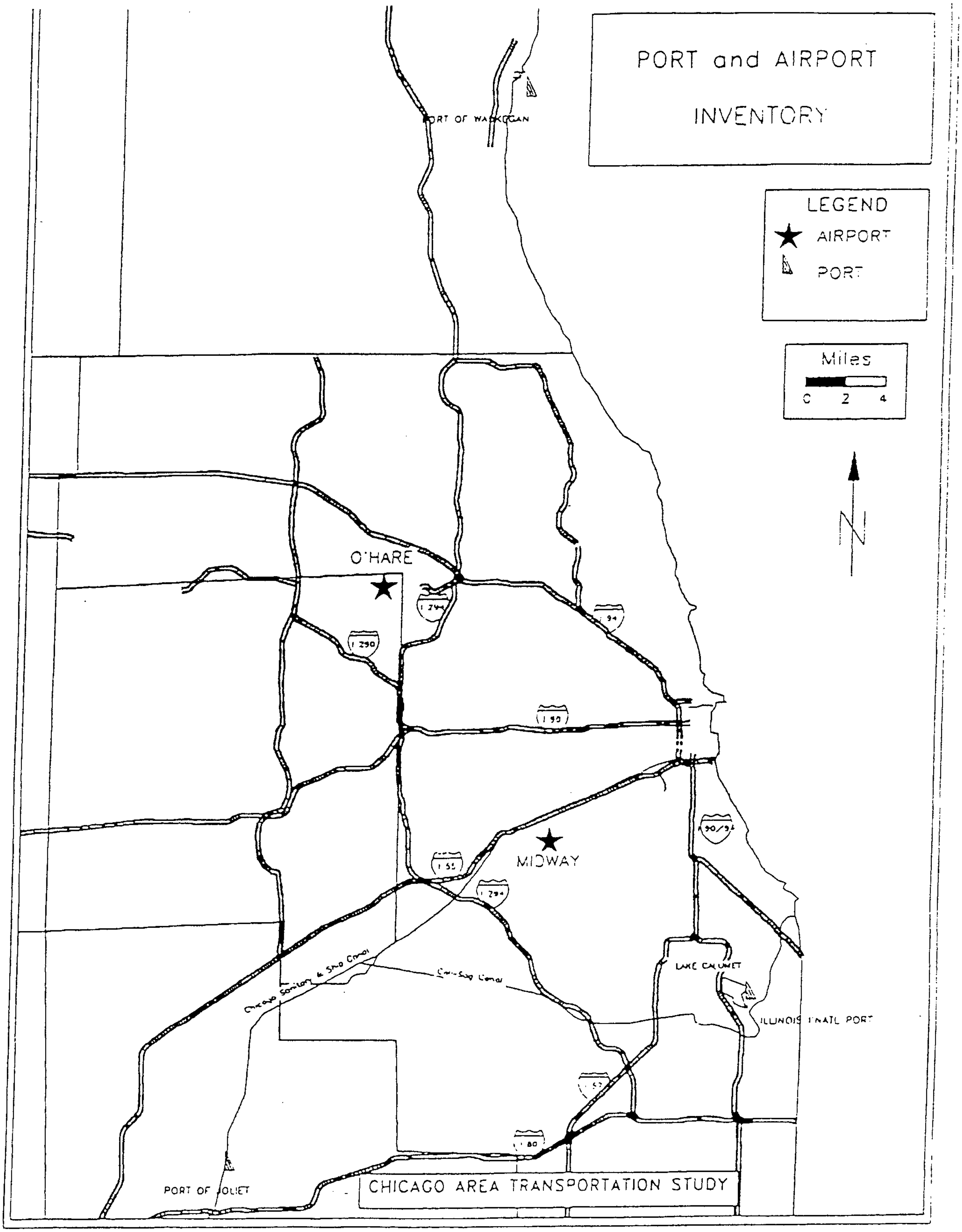


Table 3

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Inventory of Major Intermodal Freight Facilities

Operational Level Data

Inv_imf2.wk3

ID	NAME	OPERATOR	ADDRESS	CITY	FACILITY TYPE	ANNUAL LIFTS	Days Per Week	DAILY TRUCKS 1-WAY* (1)	DAILY TRUCKS ADT (2)	Reported TRUCKS (Daily)	% 20 Foot Units	% 40 Foot Units	TEU (Calculated) (3)
1 A	Schiller Park East	CP Rail System	9665 W. Lawrence	Schiller Park	CN	70,000	5	141	283	-	50%	50%	105,000
1 B	Schiller Park West	CP Rail System	4423 N. 25th St.	Schiller Park	CN	22,000	5	44	89	-	60%	40%	30,800
2	Bensenville	CP Rail System	10800 Franklin	Franklin Park	PB/CN	97,000	7	140	280	-	10%	90%	184,300
4	Global Two	Union Pacific	300 W. Lake St	Northlake	PB	225,000	7	325	649	-	5%	95%	438,750
5 A	Cicero/BN CECO	Burlington Northern/Sante Fe	5601 W. 26Th St	Cicero	CN	430,000	7	620	1240	-	5%	95%	838,500
5 B	Cicero/BN Ogden	Burlington Northern/Sante Fe	5600 W. Ogden	Cicero	PB		7						
6	Cicero/CCP	Chicago Central & Pacific	2601 S. Cicero	Cicero	PB	32,760	6	55	110	35	40%	60%	52,416
7 A	Global One	Union Pacific	1425 S. Western	Chicago	PB/STK	350,000	7	505	1010	1000	0%	100%	700,000
7 B	Western Ave. BN	Burlington Northern/Sante Fe	1551 S. Western	Chicago	PB	60,501	7	87	175	250	60%	40%	84,701
8	26Th St/UP	Union Pacific	436 W. 25Th Pl	Chicago	PB	160,000	7	231	462	250	5%	95%	312,000
9	Railport	Canadian National	2075 W. 43Rd St	Chicago	PB	96,000	7	138	277	100	20%	80%	172,800
9 A	CN Lumber	Canadian National	3500 W. 51st St.	Chicago	Bulk	-	-	-	-	-	-	-	-
9 B	CN Paper	Canadian National	3300 W. 49th St.	Chicago	Bulk	-	-	-	-	-	-	-	-
10	Corwith	Burlington Northern/Sante Fe	3526 W. 43Rd St	Chicago	PB/STK	663,937	7	958	1915	1500	10%	90%	1,261,480
11	47Th St. Yard	Conrail	361 W. 47Th St	Chicago	PB	286,000	7	413	825	250	10%	90%	543,400
13	63Rd St. Yard	Conrail	63rd St & Indiana	Chicago	PB	400,000	7	577	1154	250	10%	90%	760,000
14	Forest Hill	CSXI (Lessor:Southern Pacific)	2252 W. 79Th St	Chicago	CN/STK	48,000	7	69	138	225	5%	95%	93,600
15	Landers	Norfolk Southern	75th & Western	Chicago	PB/CN	264,000	7	381	762	350	5%	95%	514,800
16	Bedford Park	CSX Intermodal	7000 W. 71St St	Bedford Park	PB	600,000	7	865	1731	1500	5%	95%	1,170,000
17	Willow Springs/Hodgkins	Burlington Northern/Sante Fe	7600 Sante Fe Dr.	Hodgkins	PB/CN	250,000	7	361	721	-	0%	100%	500,000
18	Iowa Interstate	Iowa Interstate	2050 Prairie	Blue Island	PB/CN	17,500	5	35	71	35	10%	90%	33,250
20	Yard Center	Union Pacific	Sibley Blvd & Indiana	Dolton	PB/CN	255,500	7	369	737	-	5%	95%	498,225
21	Markham	Illinois Central/Wisc.Central/SP	16800 S. Center	Harvey	PB	103,000	7	149	297	-	5%	95%	200,850
22	Sauk Village	Transdevelopment	Sauk Trail Blvd	Sauk Village	U.C.	-	-	-	-	-	-	-	-
23	Iroquois Landing	Ceres Terminals	9301 S. Kreiter	Chicago	CN/Bulk	-	-	-	-	85	-	-	-
24	Federal Marine	Federal Marine Terminal Inc.	3434 E. 95Th	Chicago	CN/Bulk	-	-	-	-	125	-	-	-
25	IMX	Southern Pacific	3000 S. Damen	Chicago	CN/PB	150,000	7	216	433	100	5%	95%	292,500
26	Triple Crown	Norfolk Southern	2040 W. 103rd St.	Chicago	RR	36,000	7	52	104	-	0%	100%	72,000
27	Auto-Transload	Union Pacific	225 Kress Road	West Chicago	AT	-	-	-	-	-	-	-	-
28	Auto-Transload	Burlington Northern/Sante Fe	Fort Hill Rd.	Naperville	AT	-	-	-	-	-	-	-	-
29	Auto-Transload	Union Pacific	State St.	Chicago Hts.	AT	-	-	-	-	-	-	-	-
WT1	Water Terminal Cluster 1	Calumet River Cluster	-	Chicago	-	-	-	-	-	473	-	-	-
WT2	Water Terminal Cluster 2	Lake Calumet Cluster	-	Chicago	-	-	-	-	-	683	-	-	-
WT3	Water Terminal Cluster 3	KCBX Cluster	-	Chicago	-	-	-	-	-	252	-	-	-
	REGIONAL TOTALS					4,617,198	-	6,730	13,461	7,463	-	-	8,859,373

* = EACH WAY (IN/OUT)

KEY	
ADT	Average Daily Traffic
AT	Auto Transloader
CN	Containers
PB	Piggyback Trailers
STK	Stacktrain
RR	RoadRailers
TEU	Twenty Foot Equivalent Unit
U.C.	Under Construction

Major Sources

- CHICAGO DEPARTMENT OF TRANSPORTATION
- CHICAGO RAMP PROFILE
- INDIVIDUAL FACILITY OPERATOR INPUT
- INTERMODAL ASSOCIATION OF NORTH AMERICA
- PIGGYBACK ASSOCIATION

Sample Calculations

(1) 1 WAY DAILY TRUCKS = [ANNUAL LIFTS/(52 Weeks * Days Per Week)] * 1.05 Bobtail Factor
(2) DAILY TRUCKS ADT = (1 WAY DAILY TRUCKS) * 2
(3) TEU (Calculated) = (ANNUAL LIFTS * % 20 Foot Units) + (2 * ANNUAL LIFTS * % 40 Foot Units)

trucks, the result is elongated, more circuitous trips, and more VMT, namely a heavy truck share of 10.0% in 1980 and 7.6% by 2010

- Large truck VMT is greatest on expressways and is less on lower functional classes of highway (6.9% on expressways to 6.1% on arterials). Also, trucks were found to be in smaller proportions on "congested" facilities than uncongested (6.6% on congested expressways. to 5.5% on congested arterials).
- On some regional facilities, large truck share exceeded 20% of total ADT.
- Problems identified as influencing the pattern and efficiency of highway freight traffic included:

  Shipper demands for goods delivery relative to traffic cycles, greatest during peak hours

  Widespread limitations in access, facility geometry, and signal timing

  Inadequate information signing

  Numerous vertical clearance problems at viaducts
- Specific issues related to intermodal traffic

  Connection between rail yards is a major intermodal impediment

  Only about 10% of such cargoes currently exchange by rail

  Rest is by truck on highway; rail potential is ~ 35-50%

  Automatic 6-hour delay to make an intermodal transfer

  If rail interconnection, can cost shipper a whole day

  11-12 cars is now the break-even threshold for rail

  Big issue is connection between east and west rail movements

  It is estimated that improved connections between Conrail and ATSF's Corwith Yard alone would remove 8,000 street moves per month.

6. Characteristics of Regional Environment that Affect Freight Operations

Many of the major freight facilities of regional and national importance are located in the older, more densely developed areas of the region, with the resultant bottlenecks caused by clearance, grade crossings, highway design geometrics, etc., which need to be identified and improved on a priority basis

Key characteristics of that environment, summarized from above, include:

- Both rail and truck are the major modes, heavily vested in Chicago region because of the national hub locational geography.
- There is an intense rail network based on Chicago's historical importance as a rail center; however, connections just do not exist for effective intermodal service transfers, pushing about 90% of the transfers onto the highway system.
- Most of the freight facilities -- terminals, distribution centers, rail yards -- are located in the City (over 80% of regional rail ton miles in Cook County), primarily on the south

and Southwest side. However, over time the locus of freight generating activity has been shifting out to the suburbs. Thus, a lot of freight gets shipped into town for connection/transfer and distribution. It generates considerable local traffic, and is impeded by constraints and bottlenecks, such as low clearances (< 13' - 6"), turning radii, and facility or area access prohibitions.

- Chicago is both a major start/end point for shipments and a national transfer site. Its central location makes it the highest volume intermodal center in the U.S.
- While Chicago is on Lake Michigan, it's port activities are not a major feature of its freight operations. Air freight is a growing segment, but this too is specialized and small in relation to the rail/truck operations.
- There are numerous expressways/intestates that serve as the major thoroughfares for motor freight conveyance through the region (I-80 is the major through artery, which runs south of, i.e., not near, the city). However, because of restrictions and access impediments, a good portion of truck traffic is pushed onto arterials and/or forced into circuitous patterns to reach destinations.

7. Strategies Considered to Improve Freight Operations or Reduce Emissions

- An Intermodal Advisory Task Force was convened by CATS in October 1994 [5]. The task force will develop and make recommendations to the CATS Work Program and Policy Committees. The membership includes approximately 15 members of the freight industry and 6 public agency representatives. While this committee with public and private membership was strongly motivated by ISTEA, it is only the most recent of several generations of freight-oriented committees at CATS has historically sought to involve the freight industry in its planning activities. The IATF has the purpose of bringing a focus on freight and intermodal issues, needs and opportunities to the planning process, and taking both a long-term and near-term perspective. The objectives of the task force include:
    - Prepare/maintain an inventory of intermodal facilities
    - Identify operational constraints
    - Conduct studies to evaluate problems and identify solutions
    - Develop projects for consideration, facilitate implementation
    - Identify potential transportation control measures or other beneficial air quality projects for intermodal facilities.
- Operation Green Light was a comprehensive study of traffic congestion problems in the region and identification of strategies that could alleviate those problems; the freight industry was formally involved in this process, and the recommendations for strategies that would improve operations and have a beneficial effect on congestion (and air quality) include:
    - Recognizing that shippers/receivers of goods desire maximum service chiefly at the beginning and end of the day -- coinciding with peak traffic periods -- it was recommended that incentives be offered to shippers to shift all possible demand to off peak periods (industry

believed it would be injurious to outright ban/limit peak operations).

- Viaduct clearance restrictions were seen as a major factor in reduced access, circuity and congestion, particularly in relation to accessing intermodal yards. 17 viaducts were identified on Class II Truck Highways that were below design standards for tractor-semitrailers.
- Limitations on truck size and weight were cited (by the industry) as factors fueling traffic levels.

- Numerous difficulties with roadway geometry and operations were cited that impede truck flow and contribute to circuity and congestion; these include traffic signal timing, limited turning radii, and inadequate signing.

- Access prohibitions for trucks were cited as contributing to circuity and congestion; an example was given of the access problems in reaching the 63rd St. Conrail Yard (one of most active intermodal facilities) that requires a series of wasted movements to cope with physical limitations and area bans on truck traffic.

- Major problems associated with increased intermodal transfer by rail include old tracks with insufficient clearances for double-stack trains, problems with shortage and accounting for rail chassis in yards, equipment shortages, and yards operating at capacity. Recommendations focused on expanded "hubs" where select east-west railroads would be joined. The concept of linking all or a majority of the roads into one super-hub was seen as unrealistic because of the lack of sufficient rights of way; however, strategic link-ups were seen as practical and beneficial in four locations:

  1. Clearing Yard
  2. Willow Springs, Tri-State/DesPlaines River
  3. Kankee/Jouliet
  4. Conrail/CWI near the Dan Ryan

- In 1972, a study done by the Piggyback Association of Chicago, consideration was given to a Belt Railway to connect the major east-west routes between 39th and 51st streets, thought the payback was not seen to be sufficient. In 1990, however, new operating and consist agreements gave the association greater flexibility in dealing with other railroads, causing the Belt Railway to suggest that it could move a substantial portion of intra-regional intermodal traffic at below the standard truck rate.

- Along with the intermodal facilities, it was suggested that all large truck generators, industrial parks and terminals be evaluated by a public/private team to suggest improvements.

- The Federal Railroad Administration sponsored a study in 1973/74 of a rubber-tire intermodal roadway.
- A Strategic Regional Arterial System has been considered to accommodate long distance, large truck traffic that is not well or completely served by the expressway system, including provision for key access connections. An example is providing for improved access to the ATSF Corwith Yard (busiest intermodal yard in the U.S.); getting traffic off of Kedzie street and onto an SRA facility would greatly reduce traffic on local streets.
- A CMAQ-funded project is underway involving a variety of access improvements to the Canadian-Pacific intermodal yard, including elimination of a large number of grade crossings.
- Chicago is a participant in a tri-state assessment of an ITS Priority Corridor, running from Milwaukee through Chicago to Gary, IN. An early deployment plan has been developed. While freight is not the dominant issue, it is certainly an important consideration. It is expected that ITS would impact the operational efficiency of truck movements within the region by decreasing congestion at weigh stations, improve route management and load identification, decrease congestion, allow automated safety inspections, and introduce other opportunities to decrease congestion and enhance fleet management.
- Under its Unified Work Program, CATS is having discussions with several private firms that want to do a freight operations study in relation to minimizing delays at the regional rail yards. There is considerable congestion and delay to traffic in the yards attributable to sub-optimal scheduling and information exchange. CATS is considering a small initial operations study to assess the potential benefit of a rail operations center. Should this prove favorable, a larger scale implementation project may be considered.
- ATSF's Willow Springs yard arranged to get special access ramps built as part of an arrangement where the railroad owned and ceded over the property for the improvements; the arrangement included safeguards and improved access given to local interests. Santa Fe, UPS, ISTHA, IDOT, and two municipalities collaborated on the arrangement.
- Various transportation departments in the region have taken actions which acknowledge highway freight problems; In the Cicero Corridor, over half of the projects over the past 10 years have had at least partial motivation through freight issues.
- During the reconstruction of the Dan Ryan Expressway in 1987/90, as part of a traffic management plan, trucks were asked to stay within a defined "construction zone", and in consideration, regular traffic was re-routed. This strategy was later copied during similar repairs on the JFK and AS Expressways
- An Intermodal Center Platform was constructed at the Port of Chicago at a cost of $15 mil., as a strategy to enhance intermodal connections with marine freight, but the ultimate facility turned out to be undersized for its intended application, and as a result, has been underutilized.

8. Freight Contributions to Congestion and Secondary Pollution

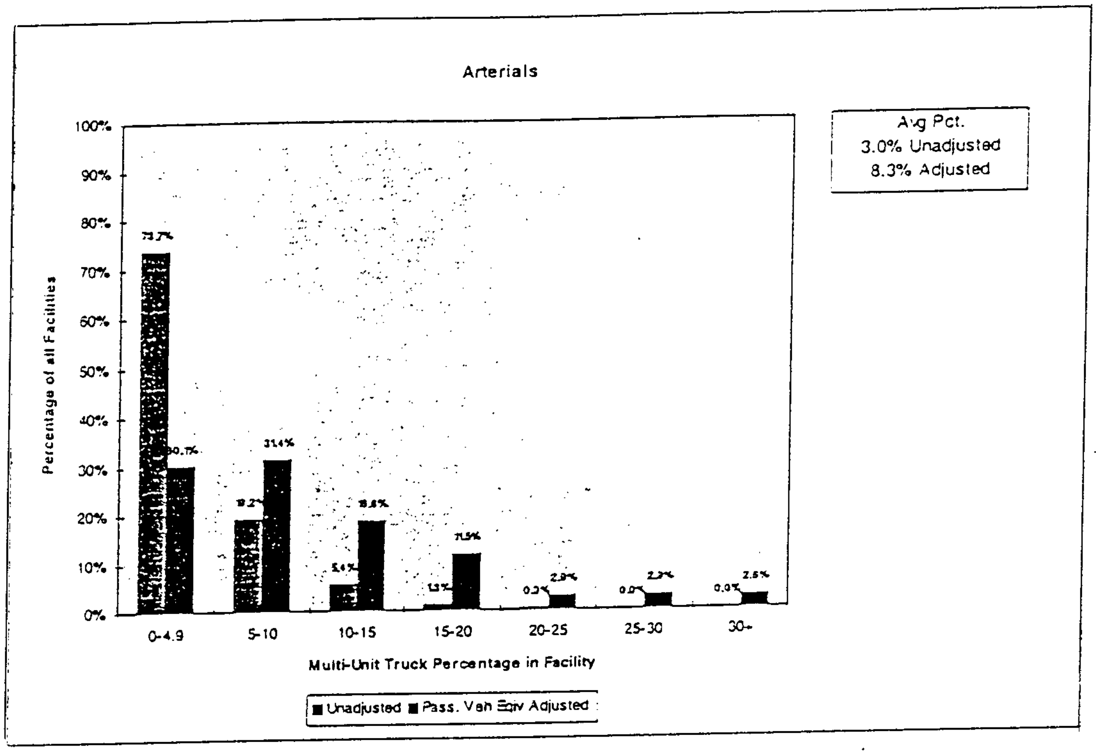
It is generally acknowledged that large trucks do add to highway congestion in the region. It was estimated that there were 180,000 large truck trips each day in the region, with 67,000 large trucks (> 28,000 lb. gvw) entering or leaving the region each day. Travel forecasting models projected large truck travel to account for 6.6% of regional VMT in 1980, declining to 4.9%[2] as a share by 2010 -- due not to an absolute decrease in freight traffic, but to a higher rate of growth in other (chiefly auto) traffic. Because of restrictions, the levels of large truck VMT would actually be higher -- 10% and 7.6%, respectively -- owing to circuity from what would be the shortest-distance path [6].

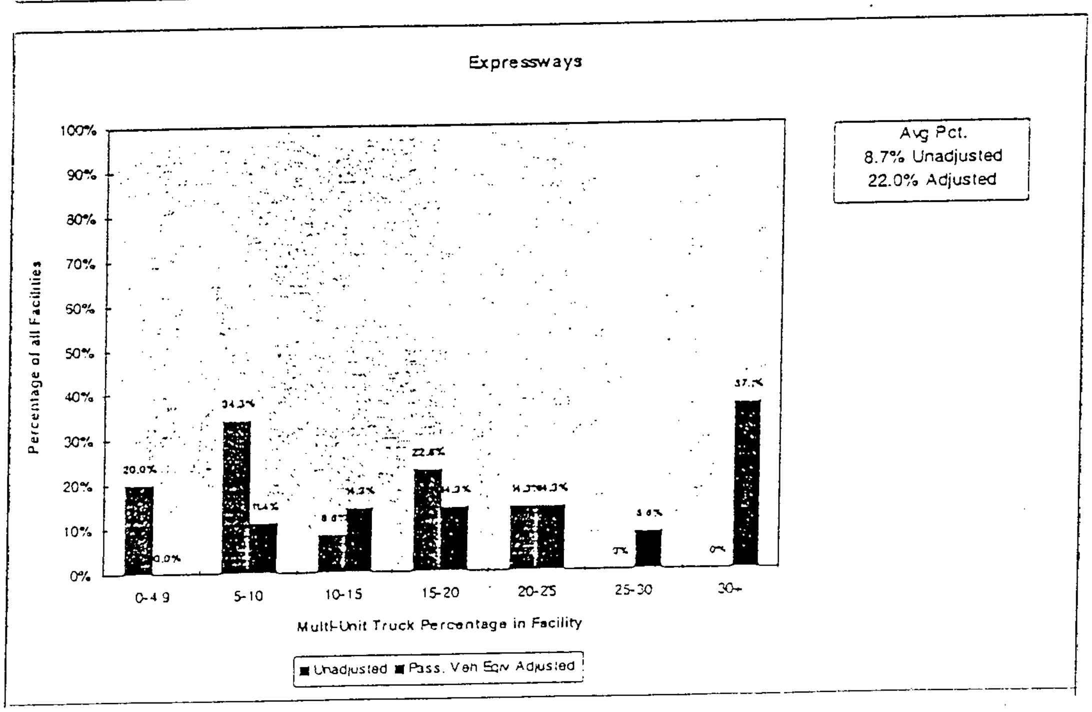
Attachment 6 illustrates the relative proportions of heavy, multi-unit trucks on the Chicago region's highways, specifically expressways and arterials, for 1988. The first graphic details the truck percentage on arterials, while the second graph details expressways. The graphs indicate the percentage of all arterials or expressways, respectively with the indicated percentages of multi-unit truck traffic. Each graphic shows two distributions: the first (unadjusted) is the straight percentage that trucks comprise of all vehicles; the second distribution has been "adjusted" to convert the large trucks to a Passenger Vehicle Equivalent, or VEQ, an attempt by CATS to account for the greater impact of large trucks on the capacity of the roadway system. Note that before adjustment, 73.7% of all arterials were carrying less than 5% multi-unit truck share and less than 1% were carrying 15% or more, whereas after adjustment for size, only 30.1% of arterials were found to be carrying less than 5%, and 19.6% of arterials were carrying 15% or greater share of multi-unit trucks. Expressways carry an even greater percentage of multi-unit trucks: even before adjustment, 37.1% of expressways were carrying multi-unit truck shares of 15% or greater; after VEQ adjustment, this percentage grows to 74.3%. On average,. multi-unit trucks make up 8.3% of total traffic on arterials (3% without adjustment) and 22% on expressways (8.7% without adjustment).

[2] This validity of this estimate has recently been subjected to some concern.

Attachment 6

Share of Multi-Unit Trucks on Chicago Region Highways, 1988





Source: *Operation Green Light*, CATS, 1991 [4]

The table below presents similar information in a somewhat different format. It shows the percent of vehicles on the respective highway types -- Urban Interstate, Urban Other, and Rural -- which are passenger vehicles, single-unit trucks, and multi-unit trucks. The distributions are shown both in straight per-vehicle percentages and VEQ-adjusted percentages.

Annual VMT by Vehicle Type by Type of Roadway

Vehicle Type	Urban Interstate	Other Urban	Rural	All Facilities
	Unadjusted/ (VEQ-Adjusted)	Unadjusted/ (VEQ-Adjusted)	Unadjusted/ (VEQ-Adjusted)	Unadjusted/ (VEQ-Adjusted)
Passenger Vehicles	75.1% (61.7%)	76.1% (66.4%)	64.6% (50.3%)	71.3% (8.9%)
Single-Unit Trucks	18.8% (23.4%)	22.1% (29.0%)	28.2% (32.9%)	24.2% (30.0%)
Multi-Unit Trucks	6.0% (14.8%)	1.7% (4.5%)	7.1% (16.7%)	4.5% (11.1%)

The data in the table confirm that multi-unit trucks are at their highest share on urban interstates (6%) and rural roads (7.1%), whereas single-unit trucks are greatest on rural roads (28.2%) and other urban (22.1%). Total truck share accounts for 24.8% of traffic on urban interstates, 23.8% on other urban roads, and 35.3% on rural. When the VEQ factor is applied to trucks to reflect their size-effect on actual capacity required, the "effective" share of multi-unit trucks translates to 14.8% on urban interstates, 4.5% on other urban, and 16.7% on rural roads. The totals for all heavy trucks when adjusted amount to 38.2% on urban interstates, 33.5% on other urban, and 49.6% on rural roads. **These truck percentages, particularly when VEQ adjusted, are significant, and undoubtedly have an effect on overall traffic flow.**

Temporal data suggest that large truck shares drop during the periods of greatest traffic congestion, although the difference is modest: CATS figures suggest a 6.1% large truck share on arterials over the entire day, dropping to 5.5% during peak periods. On expressways, the share drops from an average of 6.9% over the entire day to 6.6% during congested periods. These shares would appear to be sufficient, particularly on arterials with signalized stop-and-go cycles, to cause truck freight to contribute to general congestion. These relationships suggest that the freight haulers, and the shippers/receivers, feel the impacts of congestion and respond to the extent possible to modify shipment schedules to avoid travel under congested conditions.

Major actions considered to try to affect the traffic congestion impacts contributed by heavy trucks have included consideration of a cross-town expressway exclusively for trucks (essentially north/south connector), and peak period truck bans (as were considered in Los Angeles) considered as a Transportation Control Measure. The expressway idea was killed as a result of community opposition, while the TCM action was never fully assessed.

9. Analytic Tools/Data to Evaluate Enhancement Strategies

The regional travel modeling process developed and applied by CATS for the Chicago region explicitly includes commercial vehicles as a mode. Since the late 1960s, CATS has maintained a policy of seeking separate data on commercial vehicles for regional planning and forecasting, and has been regularly involved in national forums on urban goods transportation [8].

CATS conducted an extensive commercial vehicle survey in 1970, which indicated activity patterns that were quite different from automobiles, arguing strongly against a practice of factoring auto trips to account for truck. This original survey featured extensive field interviews of owners and operators, charting vehicle movements and commodity by weight data. These data were used to develop and calibrate the first commercial vehicle model component within the CATS planning process [6, 7]. By 1986, CATS had recalibrated many of the components of its travel model process and performed a new commercial vehicle survey to attempt to update its information on truck activity. The 1986 survey sampled approximately 8800 truckers in the CATS region, from a vehicles population base of about 355,000 regionally-registered vehicles., and used license plate/registration information to select the sample. A mailback survey form was used to obtain a log of commercial trips over 1 mile in length. This survey sampled from trucks of all size classes, <u>including</u> so-called "B-Plate" vehicles which made up about 67% of the identified sample population of 355,000 trucks. Vehicles owned and used by governments were <u>excluded</u> from the survey, as were taxicabs, commuter vans, ambulances, tow trucks, and **vehicles registered outside the region**[3]. In 1984, CATS also surveyed trucks entering the region in 1984 according to weight category and stated destination, resulting in a matrix of origin-destination trips by point of entry vs. destination within the region; exiting trucks were not surveyed, but assumed to be the *transpose* of those entering. The same survey also showed a high percentage of heavy trucks, particularly on interstates such as I-80 and I-94, which were only passing through the region (these were given entry and exit point O-D coordinates).

A summary of the findings from the 1986 Truck Survey is shown in the table below:

[3] *It should be noted that trucks which are not registered in the state but that pass through the region contribute to regional emissions but those contributions are often not estimated well. The MOBILE model is believed to have a subroutine that estimates "out-of-state" emissions separately from those of base-plated trucks.*

Vehicle Weight Group	Weight Intervals	1986 Registrations	1986 Working Population	Average Daily Trips	Average Trip Length[4]	Principal Land Use Attraction
B	< 8,000 lb..	240,600	129,398	6.9	11.1	Retail
Light	8,001 to 28,000 lb..	48,182	28,277	7.9	9.6	Retail
Medium	28,001 to 64,000 lb..	21,800	12,240	9.3	10.5	Retail
Heavy	64,001 to 80,000 lb..	48,801	12,584	5.9	24.9	Transp /Warehousing
Total		359,383	182,769			

The process by which this truck survey data is then used in the CATS travel forecasting process is illustrated schematically in Attachment 7 and described briefly in the steps below:

- The truck survey data was geocoded to the CATS zonal system of 1542 zones.
- The vehicle registration data was then associated with 1980 zone-level socioeconomic data, in particular land use and employment density (believed to be a better measure for truck activity than households as used in person travel analysis). Trucks are segmented into 10 working categories:
  - "B-Plate" (commercial) vehicles under 8,000 lb. (the 21% of these used primarily for personal travel taken out).
  - Light weight trucks (8,001 to 28,000 lb..)
  - Medium weight trucks (28,001 lb. to 64,000 lb.)
  - Heavy weight trucks (64,001 to 80,000 lb.)
  - Light, Medium and Heavy trucks bearing IRP plates
  - Light, Medium and Heavy trucks of the of the US Postal Service

attachment 7 here

[4] *Average trip length reflects only regional O-D movements*

- Trips are then distributed (formed into origin-destination trip flow matrices) based on employment density information, with the exception of the USPS vehicles that also need to track household characteristics because of the nature of mail distribution. A separate O/D matrix is obtained for each (10) weight class.

- These individual truck matrices are then converted in to passenger vehicle equivalents; VEQ factors of 2 for Medium trucks and 3 for Heavy trucks are used (the VEQ-weighted estimate of truck travel suggested a daily truck VMT contribution of 12.5%, compared to roughly 3 to 6% levels typically used by other MPOs who do not perform such weighting).

- These VEQ weighted matrices are then combined into one truck matrix and added to the auto O/D matrix, which are then assigned to the CATS regional highway network. This network consists of about 28,000 links. About 600 of these links (mostly in Chicago) have truck restrictions, and the assignment is made to reflect this. The assignment results were compared with actual classification counts compiled by IDOT.

- When performing forecasts, truck registrations and working populations are estimated using forecast employment density (also household info for USPS) data. This process is assisted with a regression equation. The results of the forecasts have met with some controversy with the freight community (represented by CATS' Motor Carrier Advisory Committee) because of their suggestions regarding complex market trends by type of carriage. (CATS has accepted these reservations, but not yet explicitly altered the process).

- The types of outputs which can be obtained from the CATS modeling process relating truck activity include:

    - 24-hour volumes for Heavy, Medium and Light duty trucks, separate or combined.

    - Volumes for each of the above <u>with VEQ weights applied</u>.

    - Volumes of truck by weight type as a percentage of all vehicles on a facility.

    - As above, with VEQ weighting

    - Ratio of peak volumes to hourly capacity (V/C ratio) on particular facilities.

CATS believes that an important purpose of creating separate trip tables for truck is in being able to demonstrate that a limited proportion of the principal highway network is "truck-heavy", or in other words, which part of the network is mainly responsible for (and affected by) truck movements. Mapping is used to illustrate the impact of truck volumes on either the existing or future regional highway network and subsystems

The overall CATS travel modeling process is perhaps one of the more advanced among MPO planning capabilities, including the accounting for freight. It appears that reasonable assessments can be made of traffic network and congestion impacts through the trip generation, distribution and assignment capabilities available for freight. What is difficult for the CATS model, and 4-step models in general, however, is looking at the complex impacts that would result from specific strategies, in particular intermodal strategies, where several modes are involved in the completion of a shipment -- including rail, and not just highway submodes.

CATS prepares emissions estimates using MOBILE5a, just as does all other MPOs, and in so doing realizes the same shortcomings due to simplifications regarding emissions rates, speed variations, mix by facility, etc.

10. Suggestions for Most Effective Strategies

In addition to the strategies described above in Section 7, strategies suggested by the CATS staff which they thought would be effective in addressing intercity-freight related issues (and consequently emissions) included:

- Earmarking a specific budget, say $50 million per year, exclusively for intermodal projects, and then establishing and applying the analytic methods and data systems to ascertain which projects are of greatest merit and qualify for the funding. Currently, freight is rarely considered as an issue when planning or programming transportation projects.
- There would seem to be great potential for application of ITS type technology innovations for collecting data and managing system operations, particularly in informing about and offering remedies in regard to delay.
- The location, capacity and access to intermodal terminals is a major element in any intercity freight management approach. The terminals are the focal point for intermodal activity, and present some of the most complex and challenging logistical problems. Measures which the region is investigating include:
    - Access to/from the terminals, both over-the-road and rail-to-rail
    - Identifying connectors to the National Highway System (NHS)
    - Identifying bottlenecks and constraints and developing improvement proposals
    - Prioritizing capital and operating improvements to achieve enhanced access,
- Some uniform decisions on truck size and weight would be useful; as truck size creeps up, it adversely affects highway geometry, traffic merging and wear rates of infrastructure. This frequently requires trucks to take longer and less direct routes.

References

1. Illinois Environmental Protection Agency. *1990 Ozone Precursors Emissions Inventory for the Chicago Area.* Illinois Ozone State Implementation Plan, Springfield, IL (November 1993).

2. Chicago Area Transportation Study. *2010 Transportation System Development Plan and Transportation Improvement Program for Northeast Illinois (Revised),* Conformity Supplement, Chicago, IL (June 1994).

3. Chicago Area Transportation Study. *Chicago Area Transportation System Development Plan Update for Northeastern Illinois,* Chicago, IL (March 1994).

4. *Operation Green Light: Freight Movements and Urban Congestion in the Chicago Area,* Chicago Area Transportation Study, Chicago, IL (March 1991).

5. Memorandum: "Intermodal Advisory Task Force Mission Statement", Chicago Area Transportation Study, Chicago, IL (November 22, 1994).

6. Rawling, F. Gerald and Eugene Ryan. "The Role of a Commercial Vehicle Survey in Transportation Planning for Northeast Illinois", Research News, Vol. 26, No. 1. Chicago Area Transportation Study, Chicago, IL (February 1987).).

7. Rawling, F. Gerald and John Reilly. "CATS Commercial Vehicle Survey of 1986: A Discussion of Project Management Issues", Research News, Vol. 26, No. 1. Chicago Area Transportation Study, Chicago, IL (February 1987).

8. Gerald Rawling and Robert DuBoe. "Application of Discrete Commercial Vehicle Data to CATS' Planning and Modeling Procedures", CATS Research News, Spring 1991, Chicago Area Transportation Study, Chicago, IL (1991).

9. Rice, Daniel, et al. "Using Geographic Information Systems for Intermodal Planning: NHS Connectors and Intermodal Inventory Development". Chicago Area Transportation Study. (1995)

B-3: Freight Activity and Emissions Profile: Los Angeles/South Coast Air Basin

■ B-3 Freight Activity and Emissions Profile: Los Angeles/ South Coast Air Basin

1. What is the Area's Current and Projected Air Quality Status?

The South Coast Air Basin (SCAB), which comprises all of Los Angeles and Orange Counties and portions of Riverside and San Bernardino Counties, has long been recognized as having the worst air quality in the country. It is the only extreme ozone nonattainment area in the country; as such, it is required by the Clean Air Act (CAA) to demonstrate attainment by 2010. The state implementation plan (SIP) for ozone, which was submitted last November, projects attainment by the 2010 deadline, but that is predicated on the implementation of very aggressive, technology-forcing control measures.

The next major issue facing the area is the submittal of an attainment plan for the current PM_{10} standard. Even as this is ongoing EPA is considering a change in the national ambient air quality standards (NAAQS) for particulate matter which is generally thought to include a new limit for finer particles such as a $PM_{2.5}$ or PM_1. Because much of the particulate matter in Southern California is secondary sulfate and nitrate, formed from direct emissions of SO_2 and NOx, the attainment of the PM_{10} standard will require further controls on these gaseous precursors. (This will be especially true if there is increased emphasis on $PM_{2.5}$ or PM_1.) Since heavy-duty Diesel engines used in trucks, locomotives, and off-road equipment are such a large source of NOx, this need for additional NOx reductions to achieve the PM_{10} standards may focus further attention on these engines which are the dominant prime mover for land-based freight.

In addition to ozone and PM_{10} nonattainment, SCAB is out of compliance with the federal carbon monoxide (CO) standard. However, since Diesel engines emit a relatively low amount of CO, it is doubtful that any control strategies would be aimed at CO reductions from heavy-duty Diesel engines.

In the past 15 years, considerable progress has been made in reducing the number of violations of the federal ozone standard in the SCAB, which is shown in Figure 1. However, it is questionable whether or not the area will comply with the federal requirements by the 2010 attainment date. Ambient PM_{10} concentrations are shown in Figure 2, which also shows steady progress toward attainment. Finally, the trends in violations of the federal CO standard are illustrated in Figure 3. That figure indicates a fairly significant decline in the number of violation days and violation periods* over the last 15 years. This trend can be attributed primarily to controls on gasoline-fueled motor vehicles.

*Violation periods are the number of eight-hour periods when the eight-hour CO standard is exceeded. Violation days are the number of days on which one or more violations occurs.

Figure 1

Hours of Violation of Federal 1-Hour Ozone Standard South Coast Air Basin, 1978-1993

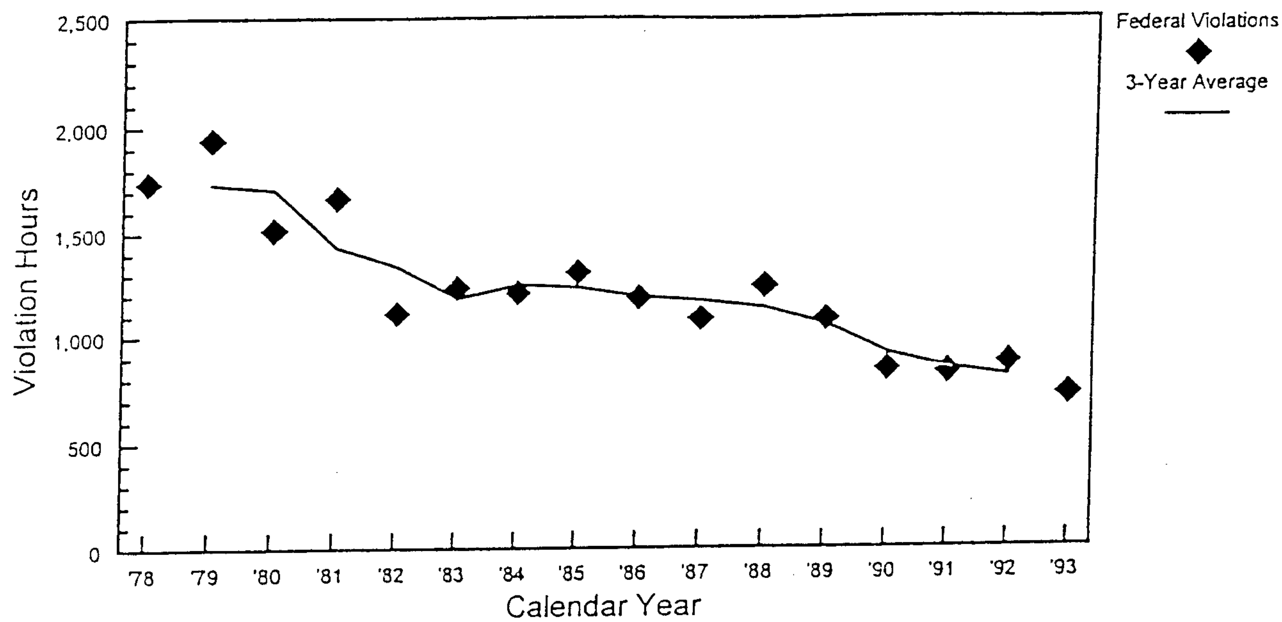


Figure 2

Maximum Annual Arithmetic Mean PM10 South Coast Air Basin 1985-1993

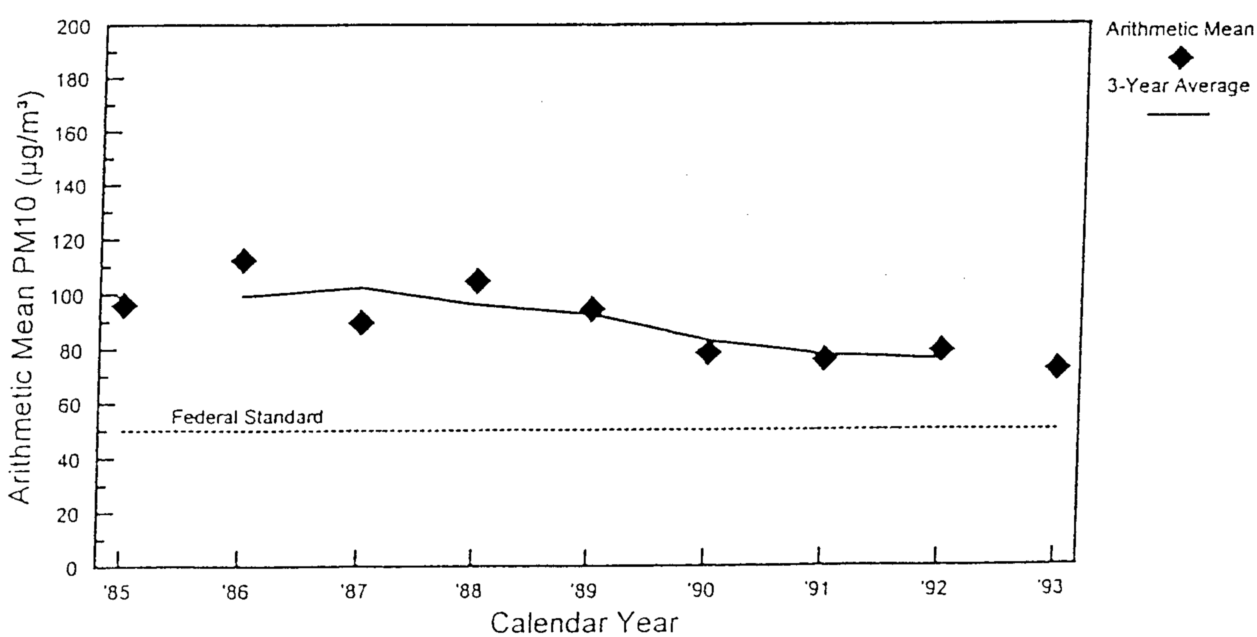
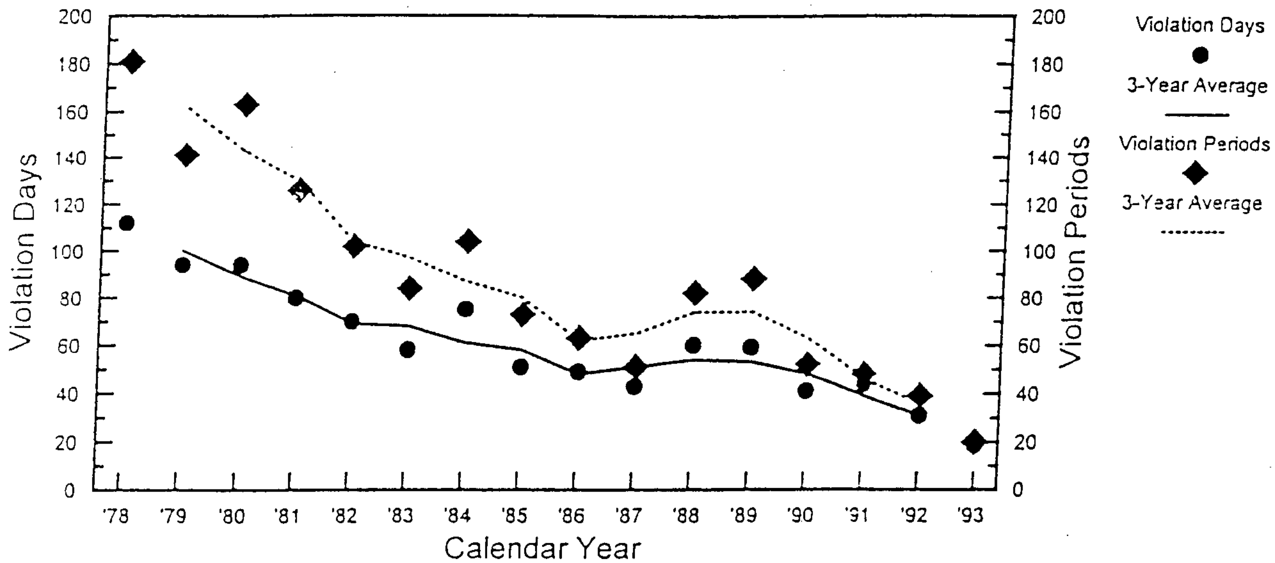


Figure 3

Violations of the Federal 8-Hour Carbon Monoxide Standard South Coast Air Basin, 1978-1993



Prior to 1982, the violations are based on the National Standard (9 ppm).

2. Principal Contributors to Emissions by Source (Stationary, Mobile, Area), Current and Future.

Table 1, which was developed from information presented in the South Coast Air Management District's (SCAQMD'S) 1994 Air Quality Management Plan, provides a summary of the VOC and NOx emissions by source category for the South Coast Air Basin in 1990 and 1996. The table also includes the emissions budget and reductions needed for attainment of the federal ozone standard. The inventory data in Table 1 show that on-highway mobile sources are responsible for roughly half of the ozone precursors (VOC and NOx) in 1990, but by 1996, the relative contribution of on-highway mobile sources to the VOC inventory drops to 36% (while the NOx contribution remains essentially unchanged).

As seen in Table 1, considerable progress in reducing emissions from point & area sources and on-highway mobile sources is being projected between 1990 and 1996. The on-highway mobile source reductions are primarily the result of new emission standards being phased-in and the implementation of reformulated gasoline regulations. These are significant reductions, especially considering that vehicle miles traveled in the Basin are expected to increase by 14% during the 1990 to 1996 time frame. The decrease in off-highway NOx emissions is unexpected; the California Air Resources Board's (CARB's) standards for new heavy-duty Diesel off-highway engines are not effective until the 1996 model year. However, this category does not have a significant impact on total emissions.

Table 1

VOC and NOx Emissions by Source Category for the South Coast Air Basin (Summer Planning Inventory - Tons Per Day)

Source	1990		1996		1990-96 Change	
	VOC	NOx	VOC	NOx	VOC	NOx
Point & Area	666 (43.9%)	235 (17.3%)	585 (51.1%)	163 (14.7%)	-81 (-12.1%)	-72 (-30.6%)
On-Highway	701 (46.2%)	746 (54.8%)	410 (35.8%)	578 (52.2%)	-291 (-41.5%)	-168 (-22.5%)
Off-Highway	150 (9.9%)	380 (27.9%)	149 (13.0%)	367 (33.1%)	-1 (-0.7%)	-13 (-3.4%)
Total	1,517	1,361	1,144	1,108	-373 (-24.6%)	-253 (-18.6%)
Emissions Budget			313	274		
Needed Reduction for Attainment						
On-Highway Sources			831 345	834 470		
Other Sources			(42%) 486 (58%)	(56%) 364 (44%)		

Although progress in reducing emissions from all source categories continues, the emission reductions needed to achieve the federal ozone standard are staggering. The SCAQMD has estimated that an additional 73% reduction in VOC emissions and a 75% reduction in NOx emissions from 1996 levels will be needed to meet the ozone standard. It is clear that squeezing this magnitude of emission reductions from sources that have already been controlled for nearly 30 years will be a significant challenge, and all sources will be subject to great scrutiny.

3. Proportion of Emissions Related to Freight & Perceived Importance in Regional Efforts to Achieve Attainment.

The agencies responsible for preparing emission inventories for the SCAB (i.e., SCAQMD and CARB) do not break out the specific contributions of freight modes to the regional emission inventory. However, those contributions can be inferred by examining specific subcategories within the on-highway and off-highway categories. The heavy-duty vehicle classes contained in the on-highway inventory can be used as a surrogate for on-highway freight movements, while rail, marine, and aircraft emissions are contained in the off-highway inventory.

CARB is responsible for preparing on-highway mobile source emission estimates for all air basins in California. During the past 20 years, CARB has developed its own set of emission factor models to prepare those estimates. The latest version of the models, EMFAC7F/BURDEN7F, was used in the preparation of the inventories for the 1994 AQMP. The EMFAC7F/BURDEN7F models report emission estimates for the following classes of on-highway vehicles:

·PC: Light-Duty Passenger Cars

·LDT: Light-Duty Trucks (under 6,000 lbs. GVW)

·MDT: Medium-Duty Trucks (6,000 to 8,500 lbs. GVW)

·HDGT: Heavy-Duty Gasoline Trucks (over 8,500 lbs. GVW)

·HDDT: Heavy-Duty Diesel Trucks (over 8,500 lbs. GVW)

·UB: Urban Buses

·MC: Motorcycles

The passenger cars and light-duty trucks are also segregated into non-catalyst, catalyst, and Diesel categories; and the medium-duty trucks are segregated into non-catalyst and catalyst categories. Table 2 presents a breakdown of the 1990 on-road motor vehicle ozone (i.e., summer) inventory for the SCAB according to the above vehicle classifications, while Table 3 has the same information for 2010.

Several interesting points can be made in reference to Tables 2 and 3. First, the 1990 inventory presented in Table 2 indicates that passenger cars were the largest contributor to on-highway emissions, while the predominant freight carriers (i.e., HDGT and HDDT) contributed 9.9% to the VOC inventory, 41.1% to the NOx inventory, and 14.2% to the CO inventory. However, by 2010, there is a significant increase in the contribution of HDGTs and HDDTs to the on-highway inventory. By that time, HDGTs and HDDTs are estimated to account for 25.9% of the VOC inventory, 60.4% of the NOx inventory, and 18.6% of the CO inventory.[5] Given this large contribution to the NOx inventory, heavy-duty vehicles are a logical target for emission reductions. CARB's November 1994 SIP submittal includes a proposed 2.0 gram per brake-horsepower-hour (g/bhp-hr) NOx standard for California heavy-duty Diesel engines in 2002, and a national 2.0 g/bhp-hr standard in 2004. However, a recently announced agreement between CARB, EPA and engine manufacturers will eliminate the 2002 state standard and set a national standard of 2.5 g/bhp-hr for HC + NOx in 2004.[6]

[5] Note that the EMFAC7F model does not account for the federal 4.0 gram per brake-horsepower-hour heavy-duty Diesel NOx standard that is to become effective with the 1998 model year. That standard will likely reduce HDDT NOx emissions by roughly 15% by 2010. However, even when accounting for the standard change, 57% of the on-highway NOx emissions would be attributed to the HDGT and HDDT categories.

[6] Emission results do not exist for the new 2004 truck standard. The effect of the cited new standard will be reflected in emissions projections, along with locomotive emission standards that are not yet in final regulatory form.

Table 2

1990 Ozone Precursor Emissions for the South Coast Air Basin
Mobile Source Contribution by Vehicle Class
(Summer Planning Inventory - Tons Per Day)

Source	VOC		NOx		CO	
	TPD	Pct.	TPD	Pct.	TPD	Pct.
PC	482.2	68.9	319.0	42.8	3112	65.2
LDT	99.8	14.3	71.8	9.6	701	14.7
MDT	40.9	5.8	36.3	4.9	253	5.3
HDGT	32.9	4.7	66.9	9.0	549	11.5
HDDT	36.3	5.2	239.4	32.1	128	2.7
UB	1.7	0.2	10.4	1.4	7	0.1
MC	6.3	0.9	1.3	0.2	21	0.4
Total	700.1	100	745.1	100	4,771	100

Table 3

2010 Ozone Precursor Emissions for the South Coast Air Basin
Mobile Source Contribution by Vehicle Class
(Summer Planning Inventory - Tons Per Day)

Source	VOC		NOx		CO	
	TPD	Pct.	TPD	Pct.	TPD	Pct.
PC	105.1	53.3	119.1	22.7	876	55.4
LDT	21.0	10.6	38.5	7.3	257	16.2
MDT	12.6	6.4	38.6	7.3	119	7.5
HDGT	8.3	4.2	45.0	8.6	97	6.1
HDDT	42.9	21.7	271.9	51.8	198	12.5
UB	2.0	1.0	10.3	2.0	9	0.6
MC	5.4	2.7	1.9	0.4	26	1.6
Total	197.3	100	525.3	100	1,582	100

The impact of other freight transport modes on the SCAB inventory can be estimated by investigating the rail and marine emission inventories, which are summarized in Table 4. This was accomplished by reviewing two reports prepared by Booz·Allen & Hamilton (BAH) for CARB.[1,2*] For rail emissions, BAH segregated emissions according to the following train types: mixed freight, intermodal freight, local trains, yard operations, and passenger trains. The estimates presented in Table 4 represent emissions from all of those train types except passenger trains. In estimating emissions from marine vessels, BAH considered three vessel categories: ocean-going commercial vessels (e.g., container carriers, tankers/bulk carriers, general cargo carriers, and passenger vessels), fishing vessels, and harbor vessels. Only emissions from ocean-going marine vessels are considered in Table 4, which include "at-sea" as well as "in-port" emissions. Although emissions from passenger vessels are included in those estimates, the contribution of that subcategory is very small relative to the freight vessels.

Table 4

1987 Ozone Precursor Emissions for the South Coast Air Basin Attributed to Rail and Marine Freight Movements (Tons Per Day)

Source	VOC	NOx	CO
Locomotives	1.5	29.9	4.6
Marine Vessels	6.0	48.2	6.2

The estimates contained in Table 4 indicate that locomotives and marine vessels have a very small contribution to the South Coast VOC and CO inventory. However, NOx emissions associated with those sources are not insignificant. For example, locomotive NOx emissions are roughly 13% of those generated by HDDTs , while marine vessels NOx emissions are about 20% of the HDDT level.

Finally, it should also be noted that the BAH study was an initial attempt at developing a detailed marine emission inventory for California. As such, it has been the subject of some debate. As a result, SCAQMD has funded a project to re-evaluate the marine inventory for the South Coast Air Basin. The contract for that study was recently awarded, and results are not likely to be available for at least a year.

4. Effort to Break Out Intercity Component of Freight Emissions.

Because the emission inventories have been structured to account for specific categories of pollutant sources, no effort has been made to specifically segregate emissions from freight movements. Thus, it reasons that no effort has been placed on separating out the "intercity" component of freight emissions by local air quality planners or the state. Nonetheless, those estimates can be made by evaluating specific components of the emission inventory and making assumptions regarding the fraction of emissions that are attributable to intercity freight movements.

* Superscript numbers denote references listed in section 11.

For example, one can assume that emissions attributed to rail (minus the passenger train component) is nearly all related to intercity freight movements. In addition, that portion of the marine inventory attributed to ocean-going vessels (and emissions from air freight carriers) can be assumed to be related to intercity freight transport (more correctly, a portion of this might be categorized as intracounty freight transport).

The real difficulty in determining the intercity component of a source category lies with on-highway vehicles, i.e. trucks. On first inspection, one might be tempted to simply use the HDDT category of the on-highway inventory to represent intercity freight emissions. Although this approach is probably valid for some metropolitan areas and provides an upper limit on intercity freight transport by on-highway vehicles, that is not the case for Southern California. As discussed below, there is considerable truck traffic from the ports of Los Angeles and Long Beach to areas within the SCAB as well as out of the Basin[⊗].

One way to construct an estimate of Intercity Truck emissions is to use the assumption that intercity freight is primarily carried by combination trucks with 3-or-more axles, the great majority of which are diesel powered. Using data compiled from the HPMS and TIUS data bases, it is possible to estimate the portion of HDDV VMT which is generated by combination trucks in a given nonattainment area. Table 4.3 (Chapter 4 of Main Report) suggests that this proportion is 60.2% in the Los Angeles/SCAB region. Thus we multiply the HDDV emissions totals by 60.2% to get an estimate of Intercity Truck emissions.

Applying this assumption of the data in Tables 2 and 3 suggests that only 3.1% of 1990's Mobile Source VOCs and 1.6% of CO were attributable to Intercity Truck, while 19.3% of NOx emissions could be attributed to Intercity Truck. However, given the projected increase in truck activity, by 2010, Intercity Truck may be contributing 13.1% of the region's Mobile Source VOC and 7.5% of its CO, while the NOx contribution would rise to 31.2%, all of which are important considerations in future air quality attainment efforts.

5. Nature of Regional Freight Operations.

The major focus of freight activities in the SCAB are the ports of Los Angeles and Long Beach. This is the largest import port in the U.S. and significant growth is expected in the next several years. Although this project is directed at intercity freight, the Southern California Association of Governments (SCAG) sees local deliveries as a major problem.

[⊗] Given the large geographic size, population, and economy of the SCAB, it is likely that a significant fraction of the HDDT VMT is attributed to intracity freight movements. A survey of heavy-duty truck operators performed for SCAQMD[3] supports the position that a significant fraction of the HDDT travel in the SCAB is related to intracity freight transport. The survey indicated that 71% of the freight carriers operating in the Basin are intrastate carriers, while 29% are interstate carriers. For intrastate carriers, the average daily fraction of trucks entering or exiting the Basin is 34%, while the value is 75% for interstate carriers. Based on these statistics, it appears that the intrastate carriers are likely to make a significant number of local deliveries. One somewhat surprising result of the survey is that 74% of the interstate carriers' California VMT was in the basin, while only 37% of the intrastate carriers' California VMT was in the basin (indicating that most of the miles logged by intrastate carriers are outside of the SCAB).

Sixty percent of the containers received at the port are bound for local destinations. In addition, all intercity freight has some local component.

A map showing container traffic in U.S. illustrates the immense flow of freight containers that starts in Southern California and works its way across the rest of the country. More than half the container traffic entering the U.S. comes through the ports of Los Angeles and Long Beach. Plans call for a doubling of this amount by 2010. Currently there are 29 trains per day into and out of the ports. This is expected to increase to 90 trains per day by 2020.

The port is a major economic force in the region. Encouraging recovery of the local economy will be a key issue in the formulation of any air quality plan. Because the port is such an important element of the local economy, the maintenance and expansion of port activities will be a key factor in any air quality planning activities. During the period between 1972 and 1992, the total merchandise imports through the Los Angeles Customs District increased from $4.3 billion to $72.4 billion. During the same time period exports increased from $1.9 billion to $49.4 billion.[4]

The region is served by several interstate routes. The main North-South route is Interstate-5. The major routes to the East are Interstate-10 with branches to Interstate-15 and Interstate-40. The major airports with freight operations are Los Angeles International, John Wayne, Burbank, Long Beach, and Ontario.

The area is served by three Class I railroads: Santa Fe, Southern Pacific and Union Pacific. All three railroads have an approach to the SCAB that crosses the San Bernardino mountains. The energy required for climbing grades as the trains leave the SCAB accounts for a significant fraction of rail fuel use in the SCAB.

The Santa Fe main line into California crosses the state border from northern Arizona, proceeds to the Santa Fe yard at Barstow, where trains are routed either to northern California or to Southern California. The Union Pacific line to the SCAB passes through Las Vegas and enters the state at the Nevada border. Southern Pacific has three approaches to the SCAB: (1) from the south, via Yuma, Arizona; (2) from northern California along the Pacific coast; and (3) from northern California through the San Joaquin Valley. The amount of traffic carried by each railroad, in the SCAB, was measured in the 1987 Booz·Allen study of rail emissions.[2] The results of that study are shown in Table 5. Although the train activity is reported in gross ton miles, which includes the weight of the empty cars and the locomotives, an approximate rule of thumb is that the actual freight (net or revenue) ton-miles are half of the gross ton-miles.

Table 5 South Coast Air Basin Class I Freight Rail Activity in 1987[2]		
Railroad	Activity (million gross ton miles)	Fuel Used (thousand gallons)
Santa Fe	2,836	12,237
Southern Pacific	6,800	25,581
Union Pacific	1,887	6,003
TOTAL CLASS I	11,523	44,980

Currently, there are a number of projects underway to better characterize freight movements into and out of the Basin. Probably the most detailed is a study being performed by the Mercer Management Group for SCAG. That study is looking at goods movement into and out of the Basin by the four major transport modes: air, rail, marine vessel, and on-highway truck. In addition to characterizing the current mix of freight transport modes, the study is investigating the effect that cost structure might have on that mix. The data from this study will be incorporated in the final report for this project

6. Characteristics of Regional Environment that Affect Freight Operations.

As noted above, the major element in the freight system of the region is the combination of the Ports of Los Angeles and Long Beach. These serve as both a source of imports and exports. The ocean boundary to the West sets the basic pattern for land-based freight modes in the other three compass directions. The mountains surrounding the region limit both rail and truck routes to the existing mountain passes.

The large population and industrial base in the Southern California area requires a significant amount of freight to provide the normal requirements of the population for personal, commercial, and industrial products. Local industries produce products that are transported out of the region. In addition, the port is the origin for through freight which is shipped to other parts of the U.S., or even through Europe from East Coast ports.

The dispersed nature of the region creates long distances for local deliveries. This makes the vehicle miles (and emissions) from local deliveries more important than those from intercity freight.

7. Strategies Considered to Improve Freight Operations or Reduce Emissions.

The current SIP has a single transportation control measure (TCM). That is the entire regional transportation improvement plan (RTIP). The major freight item in the RTIP is the Alameda corridor, a consolidation of rail routes and elimination of grade crossings between the ports and rail yards. The Alameda corridor is a key element in the port expansion. Without the corridor, it will not be possible to provide the number of trains necessary to handle all the proposed expansion in port traffic. The Alameda Corridor is still in its early design stages and $1 billion of an estimated $1.8 billion dollars in funding has been obtained. Construction is expected to begin in April 1996; the target date for completion of the corridor is 2001.

Previous strategies are rail electrification and time-of-day controls on truck usage. Although SCAG is planning to go forward with consideration of rail electrification, this measure is very costly and is opposed by the railroads. Consideration of time-of-day limitations on truck use is restrictive of necessary truck operations and is opposed by local industry. This strategy is now in abeyance.

A strategy proposed by EPA as part of its now-defunct FIP was for fleet averaging for locomotives in the South Coast, relying on post-2000 locomotives. The railroads proposed the fleet average as a way to met the special needs of this region, the only extreme ozone nonattainment area in the country, while maintaining a single set of locomotive emissions standards. The railroads, however, were very concerned about the standards formally becoming part of the FIP, since the CAAA allows other states to adopt the California standards. Such a development would be strongly opposed by the railroads; whereas they were willing to adjust their operations to make greater use of their newer locomotives in the South Coast shifting operations to achieve higher standards elsewhere in the U.S. would severely tax their fleet and scheduling capabilities. Thus, while the strategy may ultimately be adopted in the South Coast, the railroads would likely oppose its implementation in other areas.

The U.S. Maritime Administration is currently funding a study to examine the concept of an inland port. In this concept, containers would be quickly moved to an inland location, outside the Basin, where they would be sorted. This would relieve the local sorting emissions at the ports.

The largest source of "freight" emissions is local activity (intracity freight), not intercity freight. Any measures that would reduce both local deliveries and intracity freight would be most beneficial to the region.

8. Freight Contributions to Congestion and Secondary Pollution

There are no quantitative tools to evaluate this effect. As noted in section nine, a model has been developed for predicting the distribution of trucks on freeways, but this has not been extended to forecasting congestion emissions.

The construction of the Alameda Corridor, with the elimination of rail crossings, is expected to provide significant reductions in congestion due to freight movements.

9. Analytic Tools/Data to Evaluate Enhancement Strategies

SCAG relies on emissions data from the South Coast Air Quality Management District (SCAQMD) and the California Air Resources Board (CARB). As noted earlier, the mobile source emissions are determined by a series of computer programs, CALIMFAC, EMFAC and BURDEN, which have been developed by CARB for use in California. CALIMFAC computes the basic tailpipe emission rates from passenger cars and light-duty gasoline trucks, considering the distribution of model years (with different emission standards) and the effects of vehicle (I/M) inspection and maintenance programs. EMFAC computes other emissions (evaporative emissions from all vehicles and all emissions from vehicles other than light duty) and provides speed and temperature correction factors. BURDEN uses distributions of vehicle speeds to convert the vehicle emission rates from EMFAC into ton-per-day emission numbers for a particular region. There are no specific tools for estimating emissions from freight use.

SCAG has a model for predicting the distribution of trucks on local freeways. This can be a significant effect. Trucks can account for 25% of the traffic and 50% of the incidents (accidents, spills, etc.) on freeways.

There are no good models for freight traffic. Caltrans is beginning to develop such a model. They have studies looking at freight on two main interstate corridors (I-15 and I-40) to estimate future truck traffic, but they are just getting started. Their consultant on this project is Reebie Associates, a Connecticut firm.

SCAG has a major study of interregional freight that is being conducted by Mercer and DRI. This study is due for completion in September or October. This should provide a basic policy analysis tool for freight. One of the key concerns to be addressed in the study is diversion of freight from one mode to another and from one area to another.

10. Suggestions for Most Effective Strategies.

A major thrust in SCAG's air quality planning is to rely as much as possible on technology and market incentives to encourage improved efficiency. Although there are no specific recommendations, some ideas include applications of intelligent vehicle and highway systems (IVHS) and global positioning sensors to maximize efficiency. SCAG is establishing a goods movement advisory council with both public and private sector representation. This has two goals:

1. Have the council help establish a basic agenda on what the role of local government can or should be. What are the problems in the goods movement area and what should the role of local government be in trying to resolve the problems?
2. The council would provide feedback to SCAG on proposed strategies and become involved in various studies on an ongoing basis.

SCAG plans to try to use performance standards rather than absolute requirements. With regard to the goods movement sector, the plan contains a two-tier program for emissions from goods movement. The first tier uses available technology to the maximum extent possible. The second tier requires all the modes to deal collectively with resultant emissions. This would be done by negotiation among modes to attain further reductions.

There are some problems that are specific to the Los Angeles area. These include the role of interstate trucks, the growing use of the open border with Mexico, and the lack of air freight capability in San Diego (due to runway size). There is a large amount of air freight that is trucked from San Diego to LAX. Another problem is the local geography. There are a limited number of access routes into [illegible] out of the region.

SCAG staff believes that almost every idea has some merit to it. There are many aspects to managing goods movement and SCAG will have to use all the ideas for some portion of the management strategy. It will also be important to look at the interplay between the strategies.

11. References.

1. "Inventory of Air Pollutant Emissions from Marine Vessels," Prepared by Booz-Allen & Hamilton for the California Air Resources Board, March 1991.

2. "Locomotive Emissions Study," Prepared by Booz-Allen & Hamilton for the California Air Resources Board, 1991.

3. "Truck Operations Survey Results," Prepared by Lockheed IMS for the South Coast Air Quality Management District, March 1993.

4. Southern California Association of Governments, "Draft Regional Comprehensive Plan," December 1993.

Appendix C: Advisory Panel

C-1: Purpose and Composition of Panel

C-2: Discussion Agenda from June 6, 1996 Meeting

C-3: Minutes of June 6, 1996 Meeting

C-1: Purpose and Composition of Panel

■ C.1 Initial Advisory Panel Findings

A project Advisory Panel was formed to serve as a resource to the project to help understand working characteristics and problems of the freight industry, to help identify potential strategies and their economic and institutional implications, and act as a review body to assess the usefulness and realism of the ultimate guidance tools that are produced by the study. The panel consists of about 12 members, hand-selected because of their involvement, interest in and experience with emissions-related freight issues. They include representatives from MPOs, states, air quality agencies, and the truck and rail freight industries. Members of the panel and their affiliation are listed below:

Jack Broadbent, South Coast Air Quality Management District, Los Angeles

Jim Cunningham, Penn Truck Lines, Conshohocken, PA

Ted Dahlberg, Delaware Valley Regional Planning Commission, Philadelphia

Steve Eisenach, Norfolk Southern Corp., Norfolk, VA

David Friedman, Association of American Railroads, Washington, DC

Aubrey Holmes, United Parcel Service, Washington, DC

Gordon Proctor, Ohio Department of Transportation, Columbus, OH

Allen Shaeffer, American Trucking Association, Washington, DC

Keith Sherman, Illinois Department of Transportation, Springfield, IL

Mark Stehly, Atchison, Topeka & Santa Fe Railway Co, Schaumberg, IL

David Stein, Southern California Association of Governments, Los Angeles

David Zavattero, Chicago Area Transportation Study, Chicago

An all-day meeting of this group was held in Washington D.C. on June 6, 1995. Each of the above listed members participated, with the exception of Gordon Proctor, Jim Cunningham, and Aubrey Holmes, who realized last-minute schedule conflicts. Also in attendance were the project sponsors, the principal consulting team, and interested staff from DOT. This initial meeting was designed to elicit input from the experts on problems, needs and strategies, and get initial reactions to the proposed methodology. This group was subsequently used to review the projects' methodology and products

The topics addressed at the June 6 meeting were :

- Current activities, needs and concerns
- Major issues underlying freight operations, enhancement measures, and emissions determinations
- Potential strategies which should be considered
- Analytic needs and demands to be placed on the proposed methodology.

The following is a summary of the key points that were derived from the meeting. The discussion Agenda for the June 6 meeting is presented in C-2. A more detailed, point-by-point summary of comments and ideas from participants at the meeting is provided in C-3

Summary of Problems Currently Being Faced, Activities Engaged In

MPOs

- Challenge of meeting long-term air quality attainment goals, specifically with regard to NOx and PM.
- Having capability (models, data) to realistically look at freight as part of planning and emissions activities.
- Attention being devoted to freight raised to a higher level by ISTEA, especially the Intermodal requirements; most major areas now have active freight task forces with public and private members to address freight issues.
- Too many needs and too little funds to address regional transportation problems, freight not always given proper attention
- Getting different agencies to think and act intermodally
- Types of projects:
  - Alleviating bottlenecks that affect freight and other traffic
  - Improved access to intermodal facilities, connection to the NHS
  - Port enhancement, data collection to better understand patterns

States

- Freight has transportation, economic, and emissions concerns for states
- Intercity freight is often overlooked in regard to its potential impacts and reduction potentials, since urban travel and passenger travel command the greatest Air Quality attention. (e.g., Pennsylvania's double-stack project did not have air quality considerations.)
- Big concern is figuring out how best to work with freight industry, especially on issues like emissions where primary benefits are to public sector

Air Quality Agencies

- Ensuring attainment with federal and state air quality standards the primary concern
- Freight is known to be an important issue, particularly with regard to NOx and PM-10

- In past have looked at modes individually, developed "technical standards"; now convinced must take a more systematic approach to goods movement, but don't see the models or data to get into it
- Market mechanisms are gaining much more attention (at least in California -- scrappage)

Railroads

- Intermodal is a big interest and growth market for railroads; however, profit margins are slim, and capacity and efficiency improvements are needed
- Specific areas needing attention are the intermodal connectors, especially linkages to the National Highway System
- There are good opportunities for industry and the public sector to work together on jointly beneficial projects; CMAQ has been an important vehicle
- Education of folks outside the industry as to industry practices and needs is a big need
- Emissions are just one consideration to the railroads, and probably not one of the high priority considerations; for emissions control strategies to be effective and be supported, they must recognize, conform to and be of benefit to the business and operating characteristics of the industry -- ultimately, it's serving the market in the most economical way that drives decisionmaking
- Widely varying strategies or rules from region to region can play havoc with railroad operational systems, e.g., having to switch equipment at state lines
- Strong feeling that there needs to be a stronger link between ISTEA and air quality planning; doesn't appear that MPOs/public agencies effectively coordinate these activities
- Concerned about comparing rail vs. truck on emissions in terms of comparability of methods and modes themselves.

Trucking Industry

- Intermodalism is also a big interest to trucking industry; many are involved in it -- has major growth implications
- Basic lack of information on truck movements, and this is an impediment when start dealing with public agencies on projects and regulations
- Concerned about lots of assumptions and uncertainties in models being used for emissions.
- Anecdotal evidence (now being studied formally) that drayage vehicles are oldest and most polluting vehicles in fleets; support market-based measures such as California's scrappage program

Desires and Expectations of Project Sponsors:

Federal Railroad Administration

- Concern that freight is at the bottom of the transportation planning list
- Freight may have an important impact on congestion and emissions, but it is foreign and complex to many who are charged with affecting it (public agencies)
- Good opportunities exist for public/private partnerships if can better identify effective strategies and their impacts

Federal Highway Administration

- Major goal is to bring forth better methods and procedures to improve the capabilities of states and MPOs to deal with freight-related emissions issues
- CMAQ funding and Conformity requirements have important needs for better planning/emissions methods for freight
- CMAQ concern is deciding where to best apply limited funds, which projects have highest impact
- Conformity concern is whether freight improvements can positively affect outcome of a highway investment decision

Environmental Protection Agency

- Expectations and requirements issued from EPA, or decisions made on emissions credits, must start with accurate information on impacts, so need to be able to better quantify effects of these actions
- Also, need to identify which are the most effective types of strategies

Summary of Issues and Concerns Related to Identifying/Quantifying Emissions Reduction Strategies for Intercity Freight

Integrating Freight Concerns into the Public Planning Process

- MPOs generally focus on commuter travel issues, and very little on freight.
- Know that freight is an important part of the transportation system, and factor in emissions, but haven't had ability to determine what certain strategies can do
- How to make up for lack of hard data on goods movement
- Intermodal focus is strong push on states and MPOs under ISTEA
- Hard getting different public agencies to think/act intermodally

- Too many needs and too few funds for planning agencies and transportation programs; means that problems like freight don't get properly studied, and project decisions involving freight are not made on objective/quantitative grounds
- How to integrate the perspectives of the freight industry into the public planning process; how to educate public sector on the needs and workings of the industry
- How to identify and implement solutions from the public side which emphasize "eliminating barriers" and not advocating use of one mode or the other
- How to get industry to support initiatives (like air quality) that have primarily public benefits
- How to develop strategies that have air quality benefit but don't disrupt the operations and economics of the industry, or prices/service to shippers/customers
- Need stronger, more visible link between ISTEA and air quality planning/programs
- Public agencies tend to have a view of problem or solution as concerns their mode or geopolitical constituency; industry tends to take view of their market and service operation
- Things change so fast in the industry (e.g., mergers, technology) that some strategies may be obsolete by time get to implementation
- MPOs must plan and execute improvements, but may not have full buy-in from industry or other jurisdictions or agencies; places anticipated benefits in doubt (i.e., for CMAQ projects)
- Should we be looking only at intercity freight, how do you separate it out from local
- Is intercity freight an activity that can be affected by MPOs, or do some strategies require a view that is larger than a region and demand a broader authority or coalition
- What kinds of strategies or actions can states or MPOs actually affect, and should that be factored into the types of guidance/methods which are offered? Can MPOs or states affect emissions rates
- Extent to which "national" solutions/requirements be factored in

Credibility of Planning Techniques and Data

- How to evaluate intermodal strategies
- How to get at drayage movements
- How to define <u>intercity</u> freight, as distinct from local
- How to draw out freight contributions to regional emissions from SIP Inventories
- How to make sure don't double count effects of emissions reductions of intercity vs. local
- Truck and rail determined by different agencies using different procedures and data:
    - MPOs do truck freight through planning process as mobile source

- State environmental agency does rail, marine, air, etc. as off-road sources (mate fuel consumption for region with emissions factor for the mode)

- Lots of concern about the level of detail and assumptions made by Mobile model:
  - Truck load is important factor in emissions, but currently all trucks of same class carry same emissions rate
  - Speed, grade and operating condition are very important to emissions rate, but not dealt with by Mobile
  - How to account for different trip lengths
- For either mode, effect of changes in technology on emissions rates due to incentives or over time
- Are there freight planning models in existence, are they relevant, and can we rely on them
- Type of strategy to be considered and size of impact have much to say about the usefulness and accuracy of various models/analytic techniques.

Kinds of Problems/Concerns Linked to Freight

- PM-10 is a looming problem, may even drop to PM-2.5 (harder test)
- NOx is a problem pollutant linked to freight (diesel engines)
- How aggressively to attack NOx emissions, given its interrelationship with VOCs in creating ozone. When NOx and VOCs are in "critical" proportions, reductions in NOx levels beyond those necessary to balance VOCs may actually contribute to ozone formation.
- Intermodalism is a growth area for the entire freight industry, but margins are slim and there are numerous impediments with capacity and access
- Drayage is a major feature of intermodal freight operations; it may involve unproductive idling time at yards, local travel under congested or erratic-flow conditions, and empty backhauls, It has also been suggested by the ATA that drayage trucks may be representative of the older trucks in the fleet.

Strategies

Types of Strategies

- Incident management: 50% of freeway delay in areas over 1 million due to accidents/incidents, and 50% of those have trucks involved
- Intermodal connectors: especially to the NHS

- Improved access to terminals, in general (eliminate barriers, obstructions)
- Technology and fuels
- Strategies to improve drayage operations
- Terminal-to-terminal connections (rail-to-rail, etc.)
- ITS
- Loading zones for freight in congested areas
- Economic incentives, such as for technology upgrades, fuel switching, etc.

Scope

- What type of project should take on for illustrative (case study) analysis: Major project like Alameda Corridor, or smaller, more typical types
- Should focus on strategies that are win-win for everyone -- all modes, and both economic efficiency as well emissions benefits
- If terminal connectors, what is public role, private role? How to make sure that industry is in agreement, will use,. support, even help finance the improvements
- How to define and treat ITS type measures
- Are loading zones an intercity or a local freight strategy
- Extent to which national and local strategies are considered, worked into methods
- Whether to look at strategies that are within the power of MPOs or states to accomplish or affect; where to draw the line between industry prerogatives and decisionmaking and public policy or action
- Whether to look at strategies that extend beyond the purview or area of expected emissions credit of a single MPO or state

Analytic Needs and Concerns

Desired Analytic Aids/Capabilities

- Sufficient information to enable intelligent decisionmaking on CMAQ projects
- Assistance in performing Conformity analysis, including freight activity/strategies in the assessment
- Data to perform freight analysis, and/or techniques to make best use of available resources; for example, the upcoming FHWA/CSI freight planning manual's methods for developing freight trip tables, or instructions on how to use HPMS (especially for small MPOs)
- Ability to plan for intermodal connectors to NHS, as required under ISTEA

- Ideas/concepts for enhancing current models or databases to make them better able to address freight issues
- Improving the accuracy and comparability of the emissions estimating procedures themselves (rail vs. truck, plus accounting for major sensitivity variables)
- Ability to handle the drayage aspects of intermodal service; can it be done through current trip tables or should be done on a site basis using sketch-planning methods
- Ability to group strategies into packages
- Guidelines on how to handle ITS
- Ability to address modal shifts, operational improvements, and changes in fuels or technology
- Guidelines/methods for calculating costs/economic implications

Issues and Concerns

Listed below is a summary of the principal issues and concerns that came out of the June 6th meeting, coupled with an initial response as to how these concerns will be addressed in the proposed methodology

Issue 1:. Should truck and freight modes be placed on a more even basis for comparison of emissions impacts, in terms of emissions factor methods and basic inputs, i.e., VMT is used for truck while ton-miles are used for rail?

Response: We will endeavor to place both modes on an equivalent ton-mile basis.

Issue 2: Can methods allow for the different levels of detail necessary for CMAQ vs. Conformity analysis?

Response: As will be noted in the presentation of the proposed methodology in Chapter 4, we are recommending a "flexible" methodology that allows the user to scale the level of the analysis to the level of precision/detail desired in the answer, which depends on what type of question the analysis is to address, and issues of data and modeling capability. In general, the type of analysis and precision contemplated by this study's methods will be such as to support project-level, rather than system/network level assessments. In other words, CMAQ-type project assessments should be quite manageable with the techniques, while conformity is more difficult. Without giving specific guidance on how to perform a conformity analysis, the methods are expected to provide some guidance on network level analyses, which could then be related to the types of analyses suggested by conformity. Also, it has been suggested that EPA may be in the process of questioning and revising its conformity rules to focus more on a project-level demonstration of consistency with air quality plans.

Issue 3: How will the acknowledged gaps in freight data be accommodated by the methodology?

Response: The flexible methodology will allow for a range of analyses methods linked to data availability. First, General guidance will be given on identification of currently-available sources (national, local, private) and how to best use them. The methodology will then be scaled into "levels" which will be roughly defined by the type of data available. "Naive" estimates will be enabled through simple analytic relationships and maximum use of existing data, probably involving factoring methods. These types of analyses may be quite appropriate for early screening. For more precise answers, users will then be guided in how to compile specific data locally, through targeted data collections, discussions with freight operators, or more complex manipulations of existing databases. The guidance will also allow for new data, such as the CFS, becoming available in the near future.

Issue 4: Questions were raised about the most appropriate "scale" of area for which methods will be developed and applied; current case study sites (3 "very large" metropolitan areas) may not be the most typical encountered in relation to intercity freight issues, which may be more like medium to large urbanized areas.

Response: It is not possible to add a new case study site at this time, given budget parameters. One of the prime considerations in selecting the current sites was that "air quality" problems were an important issue, and indeed that is primarily what the methods are to address. This being the case, the types of sites considered most likely to be looking for freight emissions analysis assistance would be the larger metropolitan areas. This fact notwithstanding, it is acknowledged that the methods may well be important and relevant to smaller areas. Our general response is that many of the types of strategies which will be considered will probably be approached in a similar manner regardless of area size. The specific way that we will recognize and address this concern is twofold: (1) When developing the general methodology and guidance, we will attempt to identify steps or procedures that would be different in areas of another size class; and (2) when performing the case studies, we will point out where the approach to or results expected from a tested strategy might differ if done in a different size/type area.

Issue 5: Methods and guidance must be able anticipate wide variety of backgrounds, experience and capabilities, especially on freight issues; also must be capable of communicating information to non-technical types (public officials); important purpose is education.

Response: Absolutely, and in fact that is why the flexible, staged methodology has been devised. Also, the first portion of the final manual (preceding the methodology) will serve as a primer on freight issues.

Issue 6: Is the audience only MPOs and states, or is it also the freight industry?

Response: Our primary objective is to improve the capabilities of public agencies to deal better with these complex and often overlooked issues. MPOs are the primary audience, followed by states and other public agencies. The freight industry may benefit from these methods, but probably more as a result of being called into a more enlightened public planning process.

Issue 7: How will the methods and guidance deal with the disparities in emissions calculation methods

Response: It will be a direct objective of the research to ferret out and address the disparities and attempt to clarify and resolve them. To the extent of remaining differences, "average" vs. "range" estimates may be provided and their use recommended.

Issue 8: The methodology should not get in position of recommending strategies, but only giving the guidelines on how to evaluate.

Response: This is entirely consistent with the planned approach, to give methodological guidance. Clearly, it would be a difficult [and likely misleading] task to suggest that some strategies are better or worse than others, independent of context.

Issue 9: To what extent will/should the methodology get into detailed assessment of cost and other impacts?

Response: The primary emphasis in the methodology will be in quantifying the travel/activity impacts and the emissions changes which result. Although economic, safety, social and other environmental impacts are of concern, they will be treated in a more qualitative way. Users will be directed with guidelines in which of these to consider, how important they may be in relation to particular strategies/environments, and what factors should be involved in their estimation. Portrayal of strategies in terms of comparative cost-effectiveness is not contemplated in this guidance.

C-2: Agenda and Discussion Topics for June 6, 1995 Meeting

Air Quality Issues in Intercity Freight Transportation
June 6, 1995 Advisory Panel Meeting

MEETING AGENDA

1:00 to 1:30 pm	**Background and Introductions**	
		Intro of project, team, sponsors Intro of Advisory Panel Objectives for meeting
1:30 to 1:45 pm	**Project Overview**	
		Goals and objectives Task plan and approach Schedule and status report
1:45 to 2:30 pm	**Discussion Topic 1: Current Methods for Handling Freight/Emissions**	
		See Attachment
2:30 to 2:45 pm	**Break**	
2:45 to 3:45 pm	**Discussion Topic 2: Identification of Strategies**	
		See Attachment
3:45 to 4:00 pm	**Break**	
4:00 to 4:45 pm	**Discussion Topic 3: Analytic Needs**	
		See Attachment
4:45 to 5:00 pm	**Final Discussion and Wrap Up**	
5:00 pm	**Adjourn**	

Discussion Topics and Questions

Topic 1: How Freight and Emissions Issues Currently Handled

1. What are MPOs and state DOTs doing now in planning for freight?

   How is freight considered/dealt with in the transportation planning process?

   - How does the modeling and data compare to passenger modes?
   - How important are freight concerns when developing regional/state transportation plans and projects?
   - How are "intercity" freight movements taken into account?

   What level of visibility/concern does intercity freight get in your area, and in what context is most of its attention directed (e.g., port operations, intermodal transfers, truck/highway congestion/safety)?

   How is freight considered in emissions estimates, and to what extent have actions been directed to reduction of freight emissions?

   Have approaches or priorities changed under ISTEA and the Clean Air Act Amendments?

   How would characterize current [planning] capabilities and resources available to deal with freight issues, and how does that affect ability to frame issues or develop solutions?

2. How do Air Quality agencies deal with freight?

   Are specific policies or actions directed at freight, and intercity freight in particular?

   What considerations go into framing these actions? Specifically, how are transportation planning and industry operations considerations worked in? What coordination is there between agencies (transportation and AQ)? Among modes (rail, highway, marine, etc.)?

3. What do industry people think about the state/MPO planning process as regards consideration of freight?

   How well are trends and needs of the industry reflected in public planning processes and projects?

   How well do public approaches understand industry needs and operations?

   What has changed in terms of public sector impact on or interest in your industry as a result of ISTEA and the Clean Air Act? (things being asked to do, opportunities given, restrictions imposed, actions taken, etc.)

Topic 2: Strategies

1. What kinds of strategies might be effective in reducing emissions due to freight, and intercity freight in particular?

   Which are the strategies that are most likely to have both industry appeal (time/cost savings) <u>and</u> emissions benefits? Which are likely to emphasize one over the other?

   Which are likely to happen as a natural course of events, and which will need proactive effort to either enable or to accelerate implementation?

   Which require primary responsibility by the public sector, which by industry, and which would benefit most from cooperative action?

2. What is the most appropriate geographic and institutional "envelope" to define intercity freight actions?

   What actions are within the direct control of MPOs? How do they rank in terms of potential impact (what portion of the problem do they encompass)?

   What actions require authority at a state or larger level?

   If emissions benefits result in a corridor or territory outside the initiating MPO or state, should there be a means to claim credit? Would this affect the type of strategies that MPOs or states would be willing to pursue, or the level of interest applied?

3. What actions have MPOs and states taken to date which affect Intercity Freight operations/emissions?

   What types of actions have been taken by MPOs or states, and what need or problem were they designed to address? Was emissions reduction a consideration or a product?

   Which of these actions were taken "by choice" and which were "forced" on the area?

   Same questions as applied to states.

   What kinds of strategies are the easiest to deal with and fall within the domain of the MPO/state or its component jurisdictions?

   Which kinds of strategies are not pursued by MPOs/states and why?

Topic 3: Future Planning and Analysis Needs

1. For MPOs and states, what types of freight planning or evaluation functions do you expect to be faced with in the future?

    What types of planning functions or strategies that involve freight do you think you will have to perform or evaluate?

    Are there others that you would like to be in a position to perform or evaluate?

    What specific role do you expect that air quality will play in actions you will be addressing related to freight.

    What kinds of analytic impediments would you face in addressing these needs?

    What kinds of tools and information would be of greatest use to you?

        Basic primer on freight vs. detailed planning techniques?

        Near term (our study) vs. longer term?

        Planning/transportation vs. emissions or other impacts?

2. For air quality agencies, what future needs do you see for tools and information?

    What role or importance do you see being placed on freight?

    What type of information would you need in order to make effective decisions?

    Do you see any change in your need for information from planning agencies or industry?

3. For industry representatives, what types of analytic capabilities would you like to see propagated?

    What types of strategies would you like to see advanced, by what level of geographic/institutional scope, and what factors do you wish were included in any strategy assessment?

    What ways do you see in which the industry and the planning and air quality organizations can work most effectively together?

C-3: Minutes from June 6, 1995 Advisory Panel Meeting

■ Appendix C-3: Summary of Advisory Panel Meeting Comments

1. Profile of Participants:

MPOs:

David Stein, SCAG (Los Angeles) -- Principal Planner, in charge of freight issues

- Freight is a big issue in Los Angeles: region has worst air quality in country, and freight movement is major part of transportation scene -- major port for nation, plus significant intra-regional distribution
- Initiated the Alameda Corridor freight project 14 years ago, still not funded/built
- ISTEA has pushed region into major freight planning mode.
- Biggest problem re. freight: How to make up for lack of hard data on local goods movement, including pure internal traffic as well as that which is transhipped though region
- Are involved in some major studies to make up for gaps: CA statewide goods movement study by SANDAG and CALTRANS; ISTEA Intermodal Management System study (looking at flows throughout CA)
- Have 1997 PM-10 air quality plan on horizon, focuses these concerns

David Zavattero, CATS (Chicago) -- Director of Air Quality and Intermodal Planning

- Freight also a very big issue in Chicago, basically a rail and manufacturing hub(nation's largest rail-to-rail transfer hub)
- ISTEA also pushing renewed interest in freight, and also air quality (severe ozone area); has focused need to get freight and intermodal issues more integrated into the planning process
- Biggest issue is in coordinating these rail/rail or rail/truck transfers through intermodal strategies; Many initiatives studied over years
    - crosstown expressway to serve truck movements, many of which involve local hauls from/to railyards
    - with FRA, looked at rubber tire connector between ~dozen railyards
    - have established Intermodal Advisory Committee to address these issues

- now engaged in identifying bottlenecks and intermodal connectors to the national highway system as part of ISTEA IMS development

- Some bottlenecks relate to trying to ensure connection to NHS, others just due to fact that facilities in region are old and clearances, geometrics are inadequate.
- Biggest problems faced:
  - Marrying the voiced needs of the industry with the decisionmaking process and priorities of the MPO
  - Too many needs and too few funds
  - Getting the different agencies to think/act intermodally

Ted Dahlburg, DVRPC (Philadelphia) -- Manager of Urban Goods Program

- Freight interest centers around being largest freshwater port in country, 2 states, and service by 3 Class I Railroads
- Area's interest fueled by ISTEA and CAAA (severe Ozone non-attainment)
- Pennsylvania and New Jersey both have been active in intermodal/freight initiatives:
  - PA is now completing doublestack container route through state
  - Lots of attention by both states on freight and ports -- developed port facilities
- Key concepts/guide words:
  - Inclusivity -- ensure freight concerns properly represented in overall planning process
  - Advocacy -- see the basic benefits from freight, i.e., jobs, economic development
  - Information -- freely share information and educate each other
- See main task as "removing barriers" -- not dictating modal preferences or "right answer" -- like to know how MPOs can do that best.

States

Keith Sherman, Illinois DOT -- Intermodal Coordinator

- Chicago and St. Louis are the state's 2 major intermodal centers, but Chicago is 80-90% of action
- At state level, interested in how can best work with freight industry, especially on an issue like air quality where primary benefits are public

Air Quality Agencies

Jack Broadbent, South Coast Air Quality Mgt. District, Los Angeles -- Director of Planning

- Sole function is to achieve national air quality standards for South Coast Basin
- In past, have looked at the individual modes in establishing technological based standards
  - e.g., gram/mile standards for RR or trucks or ships
  - Slowly have become convinced that must take a systematic approach to goods movement
  - Studies mentioned by David Stein should be of assistance
- Just finished major planning effort -- were facing a FIP, so updated 1994 SIP as attempt to respond to/avert the FIP
  - While discussion in process was centered on national standards and freight movement, still technological-based standards remained in SIP and the FIP was rescinded (by Congressional Act)
- Still have 1997 PM-10 demonstration coming up; big issue will be NOx control, and stationary sources are on path of reducing NOx by 85%. Thus, think that freight is a significant concern because of its contribution. Need to come to table able to look at potentially effective strategies and types of tools that are needed.(thinks we are severely limited now)

  David Stein adds that PM-10 may be replaced by PM 2.5, which will be much harder to attain. Also indicates that freight industry was asked to indicate what they were capable of doing individually (by mode) in cleaning up their sources, then would take the remaining and deal with it in the fairest possible manner so as to not penalize any one group. Haven't figured out how to do that [identify effective strategies] yet, but proposal is on the table.
- Market incentives are being looked at with great interest in California, especially the scrappage program that Calif. Trucking Association pushed to get in the SIP (are working with CTA to develop a model of how might work). May mark a point of departure with the kinds of approaches have been pursuing, to pursue same end goal [economically] while backing away from technology

Railroads

Steve Eisenach, Norfolk Southern RR (Norfolk, VA) -- Director, Strategic Planning

- Operations cover eastern US, extending to Chicago, Kansas City, New Orleans
- Been very active in intermodal issues:

- ISTEA project in Cincinnati to construct 3rd mainline to alleviate congestion/bottleneck problems -- big intermodal corridor

- N/S was threatened by congestion and some intermodal traffic was going back to the highway

- worked cooperatively with feds, state, region to design a successful project -- tapped CMAQ funds for project

- See lots of opportunities for those types of projects

- Has been very vocal nationally that intermodal connectors should be a part of the national highway system
- Intermodalism is big growth market for railroads, but:
  - margins are slim
  - lots of things need to be done to expand/improve capacity
- Education is a big need/barrier -- people in decisionmaking positions really don't know much about freight rails

Mark Stehly, Santa Fe RR, Shaumburg, IL -- V.P. of Environment and Hazardous Materials

- Seventh largest RR in US, run from Chicago to Los Angeles; try to provide the best possible and most cost-effective service in that market
- We fashion emission control strategies that are cost-effective and address a wide range of issues, not just air quality in 1 or 2 regions -- it's a network view
  - Locomotives are "free-floating", so makes it difficult to endorse policies that would require switching locomotives at borders
  - Interested therefore in seeing regulations fashioned that don't cause one mode's short-term gain, but that consider the total transportation system so that shippers get best marketplace has to offer (and not result in higher prices for goods)
- Would like to see strategies that are technology-based, cost-effective, reasonable, and considering a range of issues beyond the air quality in just a small number of locations in the US

David Friedman, AAR -- Senior Economist and Environmental Policy

- Represent Class I railroads
- Share the industry-wide point of view that intermodal factors are high on list of policy concerns in terms of passage of national highway system bill

- Feel strongly that needs to be connection between ISTEA and air quality planning -- hasn't always been the case; sit on another committee looking at barriers between freight policy and environmental regulations. Consensus is that MPOs and other public agencies have not incorporated emissions work, emissions comparisons, or looked at freight issues concurrently with air quality issues -- so any attempt to combine these would be welcome

- AAR has particular interest in emissions comparisons -- apples vs. oranges with how calculated for, say, rail vs. truck

Trucking Industry

Allen Schaeffer, American Trucking Association -- Vice President, Environmental Affairs

- Representing both air quality and freight policy interests of organization (today)

- Reason want to be involved is that there is very basic lack of information on truck, and this is notable when start dealing with MPOs or air quality agencies on strategies. Think this would be great opportunity to start developing tools and information.

- Review of work in field suggests lots of assumptions and uncertainties in EPA's and California's models.

- Membership is into intermodal "big time"; spells a lot of growth for trucking as well.

- Also, market based types of programs like California's scrappage program very important strategies -- believe [anecdotal data] that drayage vehicles are among the oldest and most polluting in service. They are studying this internally.

Sponsors

Mickey Klein, FRA -- Office of Policy

- Hopeful that this study will develop information about freight issues helpful to planners.

- Freight does have an important impact on congestion and emissions but it is complex for people to focus on, and public planners may not know exactly how to change current arrangements.

- There are good examples of public and private interests working together. If emissions and economic implications of various strategies could be determined, there might be more public-private cooperative efforts to achieve mutually-beneficial results.

Dane Ismart, FHWA -- Office of Intermodal Planning

- Major goal for project is better methods and procedures so can begin to put some numbers on these strategies.

- Two main thrusts/needs: CMAQ funding and Conformity analysis.

- CMAQ: Where should we spend funds? MPOs have little idea right now of relative benefit of freight projects, so gets handled politically.
- Conformity Analysis: Certain projects that are looking to move ahead and have freight interests involved might stand better chance of implementation if can demonstrate emissions reductions.

Will Schroeer, EPA -- Office of Policy Planning and Evaluation

- We need to start with accurate information, and you've all indicated that it doesn't exist.
- Therefore, primarily interested in the quantification of these types of actions.
- However, also interested in what policies make most sense to the actors involved, so important that we talk about which policies are rationally examined and what information is necessary to support their analysis.

Issues and Concerns

- Knowing that freight is an important part of the transportation system and emissions, how to get a handle on what types of strategies could be effective in getting reductions out of freight.
- How to make up for lack of hard data on goods movement. (Stein)
- PM-10 will be an upcoming problem
- Intermodal issues are at high level of interest, need to better integrate into the planning process. What are intermodal strategies and how to evaluate them. (Zavattero)
- Bottlenecks are a big problem, owing to physical barriers (clearances, insufficient access) or operations that affect flow (signalization, restrictions, etc.) (Zavatterro).
- Problem with getting the different public agencies to think and act "intermodally"
- Too many needs and too few funds.
- Integrating the perspectives of the freight industry into the public planning and decisionmaking process.
- Trick is to stay on side of "removing barriers" rather than dictating particular modal preferences.
- How can <u>states</u> best work with freight industry to address a problem like air quality where the benefits are primarily public.
- How to educate decisionmakers [industry view] to a higher level of understanding about freight issues and needs.
- Intermodalism has lots of growth potential, but margins are slim and need important improvements to infrastructure and capacity.

- Industry is concerned about air quality, but strategies must also pass tests of cost-effectiveness, reasonability, and not variable across the various [small number of] air quality non-attainment areas.
- There are practical operational and economic factors that must be taken into account when considering emissions control strategies, e.g., strategies that would require using equipment in unorthodox ways.
- Should be a stronger link between ISTEA and air quality planning -- hasn't always been the case; freight issues and air quality issues not often combined.
- Must take systematic approach, can't focus on individual modes.
- NOx control is a big upcoming issue in future attainment demonstrations, both directly and as input to PM-10; also, PM-10 may be replaced by PM-2.5, which will be a tougher standard to meet.
- Whether or how to attack NOx is a mysterious issue: concern is that "small" reductions in NOx will not help ozone, and may actually worsen it.
- Drayage vehicles may be among the oldest and most polluting of all vehicles in fleet.
- How to define and separate out the emissions contributions of intercity freight
- Truck and rail emissions are calculated by different agencies, using different processes with different emission factor assumptions.
- Broad concerns about how much detail goes into or can be captured from the Mobile model and the SIP inventories.
- Rail emissions are calculated through EPA directive that mates emission factor with gross regional fuel use; factor incorporates important assumptions as to traffic mix, operational patterns, efficiency, etc., and this is a fairly coarse approximation.(e.g.,. Chicago is a rail hub with lots of through traffic, but emissions estimate is based on regional fuel consumed.)
- When doing an analysis of a freight strategy, consider the impact on efficiency and the emissions rate, and not just mode shifts (Dane).
- Truck load (loaded weight) has important impact on emissions rate, though current emissions models treat a truck as a truck (same emissions loaded or unloaded)
- Speed and grade are also important components to emissions rate. Trucks operating off-peak and traveling above 55 mph are generating much greater NOx emissions.
- How to account for fact that emissions vary with speed, and speed varies on different links, but Mobile model deals with average speed.
- How to account also for different trip lengths, and should we consider a trip-based over a link-based approach? (Chicago has tables which show VMT by speed level for each link, and Mobile is applied link-by-link however, the links have fairly similar speed characteristics)

- How to make sure impact of strategies is seen from effect on overall system, and not just efficiency or emissions gain to one mode or type of movement (e.g., better terminal locations as opposed to truck-only express highways through a region).
- Make sure that emissions rates reflect improvements in technology over time (this may be biggest source of most emissions savings)
- Different levels of understanding at different levels of government, differences in capability among big and small MPOs, different systems to maximize for public officials (geo-political issues) vs. industry (their "system")
- Things are changing so fast in the freight industry, re. intermodalism, corporate mergers, etc., that there is nagging uncertainty that if you decided to do something today (build a new terminal) that it would still be used 5 years from now (Sherman).
- MPOs are charged with providing for intermodal connectors to the NHS, need to be able to communicate criteria placed on them by FHWA/ISTEA, need cooperation from freight industry but the level of communication/understanding of each others position not great.
- Size of the impact of strategies, in terms of whether can pick up within the accuracy range of the estimating tool or data (Stein/Ismart).
- Why are we looking only at intercity? How do we define intercity? What happens when Yellow Freight downloads a shipment for local distribution using a city delivery truck? (MS, DZ) By definition, that's a local delivery segment. Need to get a good definition is to avoid double counting of emissions savings for freight.
  - Cohen: focus should be on what aspect of freight is of most interest to people; rather than attempt a hard definition, why not focus on the freight-related issues that people deal with?
  - Klein: Cautious about including local freight -- think our interest is on what are the inefficiencies and opportunities that exist for intercity freight. Discourage getting bogged down in totality of freight.
  - Plea is to be clean enough with methodology to cut down concern about counting twice.(DS, DZ)
  - Ismart: let's keep our scope to intercity; freight planning handbook can carry this off somewhat, but separate from this project
- To what extent can MPOs or states affect emissions rates for different modes, and is that something that we should be providing guidance on? [HC]
- Raises question of what are things MPOs can do by themselves, and what are things that might involve the DOT or a coalition of MPOs -- LA would rather stick with broader, national solutions than deal with it locally (DS)
- Issue of types of strategies MPOs or states can get into, re. authority: For example, access to and use of terminals are a key part of the puzzle, but what role or authority

should the public sector exert? Should each sector basically take care of their infrastructure and leave the usage decisions to the market? Are their certain boundaries beyond which the MPO or state should not pass, e.g., connecting rail terminals with rail. Is the only appropriate way of fostering the desired use pattern through incentives (Sherman)? Klein: If the related problems were serious enough, probably would want to address it: see if it's a result of congestion that's being fueled by drayage; are long-distance moves being made by truck that could be made by rail; is terminal in a different location than the major customers.

- In the end, the shippers are the ones who have to buy into a concept, in terms of the change in service that it conveys
- MPOs don't look at freight very seriously, generally a commuter focus. Also they deal with local more than intercity freight because its difficult to frame and maybe harder to see a way to affect.

Strategies

- In our case studies, do we take on a significant project like the Alameda Corridor, or smaller and more versatile, broader-application strategies?
- One type of important strategy -- 50% of incident delay in Southern California is caused by truck accidents (Stein), and incident delay is 50% of all delay on freeways in areas with populations over 1 million. (Dane - national statistic). [consult research mentioned by MK done by ATA and Oregon Incident Management Team 2 years ago]
- Intermodal connectors (to National Highway System, or more general)
- Recommend focusing in on strategies that are win-win for both modes; everybody benefits some and turf fighting is less likely. (Stehly)
- Lots of concern about the comparability of the emissions methods for truck vs. rail, and the reasonableness of AP42 on rail emissions -- based on fuel burn rate and some average type of operating efficiency -- may reflect Chicago, but certainly not Flagstaff.
- Technology and fuels strategies -- most of emissions reductions have come from this; e.g., Santa Fe is testing LNG for switching; might use alternative fuels for dray trucks (MK) maybe can demo?
- Strategies that affect drayage operations.
- Access to terminals:
- Terminal connections: rail-to-rail, rail-dray-to-rail, etc. -- problem is that if analyze as a strategy, does it make sense to the industry (Sherman)? (Eisenach): Terminal connections are important, Railroads definitely take an interest in this, suggest it would be important to put a focus on transportation enhancements to ease the egress movements from terminals that would make the rail line or truck line willing to invest in the project. To do this, should focus on access/egress to the terminals, and not necessarily whether its rail-to-rail, etc.. (Ismart): OK, know it needs to make economic sense to the industry, but question is, if a project is framed and you don't have full

cooperation/support promised, are other MPOs likely to want to take on such a project?

- How to handle ITS (it's being done as an across-the-board capacity increase)
- Loading zones (avoid double parking, circling) (Dane). Would make shippers happy -- spend lots in traffic tickets (DS, but question is, it that "intercity"?
- National vs. local strategies -- probably need both, since local ones simply can't be handled because of the politics. Are there things that MPOs should stay out of because there is a more effective national approach that isn't being currently contemplated.(DS); **[think national strategies here is referring more to emissions standards, though these may already be built into Mobile]** would like if report indicated whether the strategy is a national or local strategy (Dane). Study should be very careful about appearing to advocate some type of strategy because it's going to be a "national rule"(MK). This seems like more of a conformity concern as opposed to changing roadblocks -- finding ways to implement new solutions; certainly every MPO should take full advantage of national strategies in conformity findings (MS). But where would that be? thought one of products of this study was to at least outline a method by which could take advantage of national strategies (DZ). Issue focus is that the standards may change by some horizon year, and not have been captured yet in Mobile -- will always be some uncertainty here (LC)
- Do we want to look at strategies that may not appear at the outset to be desirable or sensible
- Things MPOs and states can do (Ismart): can do bridge reconstruction; can relieve physical limitations; can do street improvements; can do grade crossings; maybe relocations. What they can't get into is industry practices or decisionmaking, e.g., 2 railroads merging. (Shaeffer): Probably need to look at process as a series of ***concentric circles*** -- innermost circle provides greatest benefits to both modes (I think he means physically the circle around a terminal, and not metaphorically the circles of desirability of actions) and is a good place to base decisionmaking and reach agreements; can't in any way be in position of dictating market share or modal shift; instead, focus on terminals and how intermodalism really works, that will have the natural effect of supporting growth in the practice -- without saying mode shift. Then if you want to do loading zones for trucks, do them within the circle, because that supports intermodal -- why do it on the shipper end (this is the truck guy!!) (Eisenach) We have good precedent, e.g., Cincinnati 3rd Main, for working with the government without needing to go to the government for help -- if the benefit is there, the industry will jump in and finance the improvement. Now, though, there are public benefits in these projects, like emissions and safety, where cost sharing might be appropriate.
- In general (Ismart), should focus on strategies that are within the MPO/state's typical mainstream, and shouldn't get involved in issues/strategies that have a policy orientations, such as taxes, and weight limitations. Concentrate on strategies that are going on in everyday situations.
- Participants think should broaden our circle of thinking, even if can't affect as an MPO/state; one way in which can affect is through incentives, say for railroads to purchase enough equipment to facilitate a direct connection through

Analytic Needs and Desires

- How to get enough information from planning process to make best possible decisions on awarding CMAQ funds among competing applications; in particular, how to make sure that freight projects get a fair shake.(Dane)

- CMAQ is a real need, but it's "project-level" analysis. For MPOs who are dealing with these issues and using a variety of tools, a "look-it-up" approach [like Dane mentioned out of TDM case studies] would be very useful -- i.e., to be able to look at specific projects, compare them with other projects and help in selecting the most effective.

- Conformity is a different and bigger issue (Chicago mentions). Need to be able to address the actions at a regional, system-wide level. How will project-level be integrated into the system level? Should these tools be able to help areas address conformity? (*Sponsors are cautious about whether the proposed tools can be extended to conformity analysis; Dane suggests that Harry's freight planning manual will help in providing truck trip tables to facilitate such an analysis, and that's why the two projects are being closely coordinated)*

- Because some analyses may be done by MPOs with computer models, would it be superior to get the freight activity specified into VMT terms instead of the more standard "grams per ton mile" metric (Caretto)? Issue comes back again to the project vs. regional level of analysis needs, and what this set of methods will serve. Problem is that for many of these freight strategies, effect will be so small or so unique that won't/can't be picked up by the network (Dane). So the methods may depend greatly on the types of strategies being analyzed, and vice versa. And the methodology will have to lean toward handling these specialized impacts.

- Survey of MPOs in 8-30 showed that there was very little data available, and that people who have to work on freight-related projects -- particularly in small MPOs -- do not have a freight background. Therefore, should we be gearing our materials to people who do not know a lot about freight? (Harry C,)

- Don't think that the Philadelphia-Chicago-Los Angeles group is typical of what freight industry runs into (Eisenach).

- You must be able to talk to all kinds of planners; the big MPOs are obviously much more sophisticated, but all have needs. (Sherman) Also, need to be able to run the concepts up the public agency [bureaucrat] chain, e.g., states are different than . Have to be able to integrate the geopolitical/modal concerns of public agencies with the system/market orientations of the freight industry.

- Ismart -- reality and resources will cause us to focus on the large and medium MPOs for now.

- Cohen -- will try to lay out information so that anticipates different levels of background and need.

- Planning for intermodal connectors to the National Highway System, and what criteria or guidelines can expect from FHWA.,

- Would like to have ideas/concepts for enhancements to existing models; CATS is going through a major modeling development/enhancement process, but not really dealing with freight issues, trip tables or emissions.
- Who is the audience? MPOs and states mainly, but also the freight industry must be an audience, at least in terms of identifying strategies and building the partnerships. to support the projects. It must fly with the industry.
- Having confidence that the emissions which are calculated for each mode are reasonable. Big concerns about rail vs. truck (Stehly) -- who will do this and where will get the information? The two modes approach subject very differently. Railroads keep careful track of their operations because of the traffic density on road and equipment wear. So, railroads can produce fairly decent estimate of emissions from their traffic statistics and fuel burn rate -- within 10 to 20%. But how can possibly get this type of accuracy on the truck side, considering the accuracy of planning models, data, and all the things that get factored in. How can the two be compared? Maybe in this first stage (Zavattero), at least come up with something that's defensible (doing same thing or using similar kind of data). But EPA has given us the method (Stehly). But EPA hasn't really worked with the industry in developing the guidance procedure, so we would benefit from a technique that we could work with them on. We probably can work with EPA and change the procedure if we can prove it is deficient (Klein).
- Question about accuracy vs. data collection costs. What kinds of decisions are you going to make? If just getting "directionality" of the effect, then simple data, but if for baseline purposes where going to cap emissions, then extremely important and want to get best data.
- What kind of data can the railroads provide to support this analysis (Eisenach), without causing a lot of new work! Maybe we have a section that says who you should contact (Harry).
- Small MPOs probably don't have truck data; would have to use HPMS, so give guidance on how to use.
- How to handle the drayage issue -- could be regional model if have a truck trip table and drayage is included in the table. Or, could look at an given site and say "we have this much drayage"(DZ).
- If start to look at operational strategies, that involve changes in industry practice -- like terminal changes, will probably need different kinds of analytic techniques than with removing a clearance restriction (DZ)
- Should be a way to be able to group strategies into programs with the proposed methodology, where the combined effect is appreciable when the individual strategies don't provide much (Klein).
- How to handle ITS
- Education is a big need (DZ) -- public agencies may not front-line certain strategies, but could greatly benefit from having their knowledge and perceptions broadened; sometimes we think too narrowly, and should allow ourselves to get ideas from a broader arena -- see different solutions, approaches; may still have to accept can't

affect, but reshapes your thinking. (Sponsors support the concept of education and broader thinking on strategies, but advocate focusing on the things that are currently realistic and not abstract for the methodology)

- The methodology should not get into the position of recommending strategies (HC); we provide analytic methods that allow user to estimate and compare the emissions reductions of X vs. Y. (Stehly): yes, with this strategy, this is the kind of analytic work we need to do to evaluate it -- with this, the MPO doesn't have to start from scratch, here's a reasonable approach.

- Economic implications -- we will look at economic implications as part of the analysis (Klein)? (Broadbent) How far can you go with this? Lots of things would have to consider that get into industry and market impacts that are hard to get at. (HC) Our emphasis will be on air quality, and beyond that whatever guidance we can give them on other impacts. (ISMART) Agree, don't have the resources to get deeply into sophisticated economic analyses. (Sherman) Agree -- Identify the issues. (HC) We may identify the "types" of impacts that may result from a strategy, but our method will not produce estimates of them.. (Klein) Yes, but should get into it a little more -- explain why the types of impacts would be as they are.

- (Ismart) Remember that air quality is just one aspect of the decision, there may be other consequences of the strategy that this helps illuminate. An AQ idea may prove undesirable because of other adverse impacts it brings up.