Assessment of the Effects of Proposed Locomotive Regulations on Goods Transport Modes and Locomotive Emissions

Contract Number 92-930

Final Report

February 1996

Submitted to:
California Air Resources Board
Mobile Source Division
9528 Telstar Avenue
El Monte, California 91731

Submitted by:
Jack Faucett Associates, Inc.

In cooperation with:
Abacus Technology Corporation
Bowers & Associates, Inc.
Judith Lamare, Ph.D.

JACK FAUCETT ASSOCIATES

4550 MONTGOMERY AVENUE • SUITE 300 NORTH

BETHESDA, MARYLAND 20814

(301) 961-8800

Bethesda • Maryland Walnut Creek • California

Assessment of the Effects of Proposed Locomotive Regulations on Goods Transport Modes and Locomotive Emissions

Contract Number 92-930

Final Report

February 1995

Submitted to:
California Air Resources Board
Mobile Source Division
9528 Telstar Avenue
El Monte, California 91731

Submitted by:
Jack Faucett Associates, Inc.

In cooperation with:
Abacus Technology Corporation
Bowers & Associates, Inc.
Judith Lamare, Ph.D.

Table of Contents

List of Exhibits

Executive Summary

The California Air Resources Board (ARB) has determined that locomotives contribute significantly to the air quality problems across the state. In 1987, locomotives accounted for 155 tons per day of oxides of nitrogen emissions (NO_x). This contribution accounts for approximately 5 percent of the state's total NO_x emissions inventory. Currently, locomotives operating in California are not subject to any type of emissions mitigation program, except for some locally adopted opacity limits. Locomotives comprise one of the largest classes of uncontrolled NO_x and oxides of sulfur (SO_x) sources. Consequently, the ARB has determined that substantial NO_x emissions reductions can be achieved by formulating and promulgating control strategies that target this source.

Overview of Study Objectives and Approach

Little is known about the indirect economic impacts of strategies to mitigate emissions from locomotives. For instance, the railroad industry argues that rail, as a low-cost provider of freight transport, is integral to the distribution of goods and services in California. They further argue that emissions regulations that focus on locomotives will increase the cost of providing service and will increase the rates that the railroads charge to their customers. Given the alternative modes that exist to transport freight, increases in rail rates may cause significant shifts from rail to other modes, especially from rail to truck. Mode shifts that result from locomotive emissions regulations may, in turn, be counter-productive to solving the air quality problems attributable to freight transportation, since trucks emit more pollutants per ton of freight moved than does the rail mode. The purpose of this study is to assess the effects of proposed locomotive emissions regulation strategies on mode choice and locomotive emissions and to formulate the framework for an active market for locomotive emissions reduction credits.

The approach employed in this study includes the following five tasks, each of which addresses various study objectives.

- *1) Estimate Commodity Flows by Mode* — Surprisingly, prior to this study little was known about the modal share of freight transport in California. As a result, a major focus of this effort is to estimate modal splits, particularly between rail and rail-competitive trucks.

- *2) Calculate the Contribution of Emissions by Goods Transport Mode* — The air quality planning processes employed by states and metropolitan planning organizations across the country do not focus specifically on emissions from freight transport activities. The relative contribution of freight modes to emissions in a region is seldom reported in State Implementation Plans or regional Air Quality Management Plans. Therefore, one objective of this study is to isolate freight-related emissions by mode and to ascertain changes in modal emissions resulting solely from economic and/or demographic growth.

- *3) Perform a Comprehensive Review and Evaluation of Mode Choice Models* — To ensure that the ARB is fully cognizant of the factors that determine mode choice or mode shifts, and to ensure that the best possible forecasting tools are used in this study, a comprehensive review and evaluation of previously conducted mode shift analyses needs to be performed.

- *4) Assess the Direction and Magnitude of Mode Shifts Attributable to Locomotive Emissions Regulations* — Using the best possible mode shift model, the central objective of this study is to determine the mode choice impacts of various locomotive emissions control strategies and to determine the consequent emissions repercussions.

- *5) Develop the Framework for an Active Locomotive Emissions Market* — The final objective of this study is to determine the best possible framework for an active market in locomotive emissions reduction credits.

Base Year and Forecast Emissions (No-Control Scenario)

The relative NO_x emissions from the four competing freight transport modes are compared in Exhibit E-1. In 1987, this study's base year, railroad locomotives contributed approximately 20 percent of California's NO_x emissions attributable to the four modes representing the freight transportation sector. They also contribute about 6 percent of California's mobile source NO_x emissions and about 4 percent of California's total NO_x emissions.

Marine vessels operating in California waters contribute slightly greater estimated NO_x emissions than locomotives and are therefore good candidates for control measures. Ships offer more flexibility for accommodating the weight and volume of emissions control hardware than trucks and locomotives. On the other hand, enforcing emissions limits on ships is probably more difficult than for any other mode. Nonetheless, such efforts are underway. The potential for diversion of freight from rail to ships, however, is judged in this study to be small. Consequently, this study does not address the potential of modal diversion from rail to commercial marine vessels.

Overall, civil aircraft contribute only about 3 percent of the NO_x emissions from the four modes, and the majority of those emissions are from passenger operations. Air freight operations are therefore not a significant source of NO_x emissions in California. Furthermore, because cargos that are typically shipped by rail are very unlikely to be diverted to air freight, aircraft were not considered in the diversion analysis.

Of the four competing freight shipping modes, heavy-heavy-duty diesel trucks (i.e., diesel trucks weighing over 33,000 pounds GVW) contribute the greatest percentage of NO_x emissions; nearly 52 percent of NO_x emissions attributable to the four freight shipping modes and almost 12 percent of all NO_x emissions in the state. Truck lines are also the primary competitor with railroads for freight revenues. Therefore, the modal diversion analysis only considers the

Exhibit E-1

NO_x Emissions Contributions by Freight Mode (1987)

Freight Mode	NO_x (Tons/Day)	Percent of Total	ROG (Tons/Day)	Percent of Total
Rail	155	20%	7	6%
Truck*	402	52%	68	60%
Water	186	24%	12	11%
Air	27	3%	26	23%
Total	771		112	

* Only includes diesel trucks weighing over 33,000 lbs. GVW (i.e., those trucks that compete with rail for shipments).

possibility of diversions between these two modes.

Exhibit E-2 presents truck and rail NO_x emissions on a ton-mile basis. In 1987, heavy-heavy-duty diesel trucks emitted almost twice the amount of NO_x per ton-mile than rail. Truck movements emit, on average, 0.009 pounds per ton-mile of freight moved, while rail movements emit 0.005 pounds per ton-mile of freight moved in California. This result has important ramifications when developing emissions control strategies for freight transport in the state. Regulations must be developed that approach emissions control at the system level by accounting for the relative contribution of each mode at the margin. Furthermore, strategies that result in large diversion shifts from rail to truck may be counter productive from the perspective of total freight emissions.

The forecast California locomotive NO_x emissions in 2010, under a no-control scenario, is 57,583 tons (or almost 158 tons/day). The 2010 emissions forecast represents an increase of less than one percent over the 1987 base year emissions estimate. It suggests that technical and operational improvements (aerodynamics, dispatching, etc.) will combine with the decreased activity expected in the local and yard sectors to offset increases in emissions from the anticipated increase in linehaul activity, particularly in relatively pollution-intensive intermodal operations. These factors also account for the reduction in locomotive emissions per ton-mile of freight moved. Rail is expected to account for 36,541 million ton-miles of freight by 2010 under a no-control scenario. Consequently, rail is expected to emit 0.003 pounds of NO_x per ton-mile in 2010, a decrease of 40 percent from the 1987 baseline of 0.005 pounds of NO_x per ton-mile.

As shown in Exhibit E-2, NO_x emissions from trucks operating in California during 1987 contributed 0.009 pounds/ton-mile of freight moved. This contribution reflects a fleet average NO_x emissions rate of 7.83 grams/Bhp-hr, as estimated by EMFAC7, and the prevailing NO_x standard during that year of 6 grams/Bhp-hr. In 1991, the NO_x standard was reduced by the ARB to 5 grams/Bhp-hr, and EMFAC estimates the 2010 fleet average NO_x emissions rate to be 4.6 grams/Bhp-hr—not including the proposed drop in the standard to 4 grams/Bhp-hr in 1998. Furthermore, by 2010 many technologies may be incorporated that affect truck emissions rates during a given trip. For example, aerodynamic improvements that are implemented to reduce fuel consumption may have emissions reduction consequences on a grams/Bhp-hr basis. Improvements in fuel management may also result with decreases in emissions rates. These technologies, as well as others that are deployed to comply with more stringent standards, will penetrate the fleet slowly since the operational life of a heavy-heavy-duty diesel truck often exceeds 10 to 15 years. Consequently, this analysis assumes that, on average, heavy-heavy duty diesel trucks will emit NO_x at a rate of 5 grams/Bhp-hr (i.e., the prevailing standard).

Assuming that the percentage change in average emissions from 7.83 to 5 grams/Bhp-hr holds on a ton-mile basis, trucks are expected to emit 0.006 pounds/ton-mile of freight moved in 2010 under the no-further-control scenario. Using this study's forecast for heavy-heavy-duty diesel truck ton-mileage in 2010 of 52,148 million, it is estimated that these vehicles will contribute roughly 410 tons/day of NO_x emissions during that year.

Exhibit E-2

Rail and Truck NO_x Emissions per Ton-Mile of Freight Moved 1987 and 2010 (No-Control)

	1987		2010 (No-Control)	
	Rail	Truck*	Rail	Truck
Ton-Miles (millions)	24,592	32,717	36,541	52,148
NO_x Emissions (tons/day)**	155	402	158	410
NO_x Emissions (lbs/ton-mile)	0.005	0.009	0.003	0.006

* According to EMFAC7, the 1987 heavy-duty diesel truck fleet average NO_x emissions rate was 7.83 g/Bhp-hr. The truck emissions estimates shown above reflect this fleet average.

** Numbers may not add up exactly because of rounding.

CALFED and Changes in Rail Cost Advantage by Regulatory Scenario

After reviewing the available modal diversion models that reported parameters which could be used for the current effort, the CALFED modal diversion algorithm was selected as the most useful modal diversion analysis tool for the present study.

CALFED disaggregates freight flows in California by 16 commodity/activity categories, five sub-state regions, and six origin-destination (O-D) regions. Modal diversion is determined as a function of the relative cost of rail and trucking. Diversion is calculated for each commodity and each O-D region. A parameter that measures the sensitivity to service cost (i.e., rail costs as compared to truck costs) has been calculated for each commodity and this is applied to the change in the rail cost advantage per ton-mile for transport of each commodity to or from each O-D region. This parameter is a measure of how much the rail share (expressed in terms of ton-miles) of the shipments of a given commodity will change for every dollar change in the rail cost advantage per ton-mile as compared to truck costs. An adjustment is made which takes into account the current mode split for each commodity shipped between each O-D pair. Thus, flows which have a relatively even mode split are assumed to be very competitive and the sensitivity to each mode's cost of service is the major determinant of mode shift when the relative costs of rail and trucking change. Whereas, flows which are dominated by one mode or the other are less competitive and experience less relative diversion in response to a change in rail or trucking costs. Aside from this adjustment (which implicitly takes into account the importance of non-cost variables on the historic mode split for a given commodity shipped between a given origin and destination), the CALFED modal diversion algorithm only considers explicitly the impacts of changes in the relative costs of rail and trucking and does not consider the impacts of changes in other service variables, such as time delays that might be associated with changing locomotives to comply with California locomotive emissions regulations.

There are several obvious advantages of the CALFED model. These are listed below:

- it is based on actual California shipment data;
- mode cost sensitivities are developed by commodity group and thus reflect the unique commodity characteristics which would favor one mode over another irrespective of mode cost (e.g., commodity value, use rate, shelf life, etc.);
- modal diversion is calculated for O-D pairs which reflects the actual production and consumption patterns of California economic regions and their trade relationships with the rest of the nation;
- it uses aggregate shipment data which are the only data readily available without additional survey work;
- it implicitly considers the impact of length of haul on mode choice through the procedure used to calculate the model parameters; and

- it includes a variable which takes into account the current competitive position of rail versus truck for each commodity group which helps offset some of the bias in other model parameters which are estimated with 1977 data.

In this study, CALFED was employed to estimate the diversion and resulting NO_x emissions impacts under six regulatory strategy scenarios. Since the focus of this study is on the impacts of locomotive emissions, the first four scenarios isolate the effects of the following locomotive NO_x emissions control technologies:

Technology	Description
Dual-Fuel (DF)	Natural gas fuel is mixed with engine intake air; ignition in the cylinder is accomplished by injecting a small amount of diesel fuel near top-dead-center of the piston stroke, as in a conventional diesel engine.
Liquid Natural Gas with Spark-Ignited Engine (LNG-SI)	A spark-ignited (Otto cycle) engine is fueled by natural gas.
Selective Catalytic Reduction (SCR)	A chemical reductant (ammonia or urea) is mixed with the engine exhaust gas; this mixture undergoes a catalyst-promoted reaction, reducing NO_x to harmless N_2 and water (and CO_2 if urea is used as the reductant).
Dual Fuel plus Selective Catalytic Reduction (DF+SCR)	A dual-fuel locomotive is equipped with selective catalytic reduction.

The last two scenarios have been designed to capture the range of possible mode shift given combined locomotive and truck control strategies. Scenario 5 assumes that locomotives operating in California will be powered by dual-fuel engines, while heavy-heavy-duty diesel trucks will be powered by LNG/lean-burn spark-ignition engines. Dual-Fuel is the least expensive strategy for locomotives investigated in this study. LNG/Lean-Burn SI is the most expensive strategy for trucks investigated in this study. Consequently, this scenario has been designed to represent the high-end of diversion from truck to rail. Likewise, Scenario 6 has been designed to represent the high-end of diversion from rail to truck, since it includes the most expensive locomotive regulation (SCR) and the least expensive truck regulation (CNG/Lean-Burn SI). The six scenarios are summarized below.

- *Scenario 1* — assumes that locomotives operating in California in 2010 will be powered by engines that use either natural gas or diesel (i.e., dual-fuel), while heavy-heavy-duty diesel trucks will experience no further control beyond that of the current NO_x standard of 5 grams/Bhp-hr.

- *Scenario 2* — assumes that locomotives operating in California in 2010 will be powered by LNG-SI engines, while heavy-heavy-duty diesel trucks will experience no further control beyond that of the current NO_x standard of 5 grams/Bhp-hr.

- *Scenario 3* — assumes that locomotives operating in California in 2010 will be powered by Dual-Fuel engines with SCR devices, while heavy-heavy-duty diesel trucks will experience no further control beyond that of the current NO_x standard of 5 grams/Bhp-hr.

- *Scenario 4* — assumes that locomotives operating in California in 2010 will be powered by engines with SCR devices, while heavy-heavy-duty diesel trucks will experience no further control beyond that of the current NO_x standard of 5 grams/Bhp-hr.

- *Scenario 5* — assumes that locomotives operating in California in 2010 will be powered by engines that use either natural gas or diesel (i.e., dual-fuel), while heavy-heavy-duty diesel trucks will be powered by LNG/lean-burn SI engines, reducing NO_x from 5 grams/Bhp-hr to 2.0 grams/Bhp-hr in 2010.

- *Scenario 6* — assumes that locomotives operating in California in 2010 will be powered by engines with SCR devices, while heavy-heavy-duty diesel trucks will be powered by CNG/lean-burn SI engines, reducing NO_x from 5 grams/Bhp-hr to 2.0 grams/Bhp-hr in 2010.

As reported in Exhibit E-3, the change in the cost advantage of rail ranges from -0.08 to -0.31 cents (1977 dollars) for those scenarios that isolate the impacts of locomotive regulations (i.e., Scenario 1 to 4). The change in the cost advantage of rail for Scenario 5 is 0.34, signaling a shift from truck to rail. While that for Scenario 6 is -0.11, signaling a shift from rail to truck. These changes in the cost advantage of rail are employed to calculate mode shifts using CALFED's mode choice sensitivity parameters.

Modal Diversion and Emissions Impacts by Scenario

Exhibit E-4 presents the results of the diversion analysis for each of the six regulatory scenarios. Scenario 1, *Dual-Fuel for Rail and No Further Control for Trucks*, is expected to reduce rail ton-miles by 406 million in 2010, or by 1.1 percent. Consequently, in 2010 heavy-heavy-duty diesel truck ton-miles are expected to increase to 52,554 million from 52,148 million. The estimated diversion impact of Scenario 2, *LNG-SI for Rail and No Further Control for Trucks*, is a decrease in rail ton-miles and a corresponding increase in truck ton-miles of 762 million, representing a drop in rail ton-miles of 2.1 percent. Likewise, Scenario 3, *DF+SCR for Rail and No Further Control for Trucks*, is expected to reduce rail ton-miles by 1,168 million, or by 3.2 percent, while Scenario 4, *SCR for Rail and No Further Control for Trucks*, is expected to reduce rail ton-miles by 1,625 million in 2010, or by 4.4 percent. The diversion impact of

Exhibit E-3

Regulatory Scenarios for Diversion and NO_x Emissions Analysis

	New Rail Freight Rate (in Cents/ Ton-Mile, 1987$)	New Truck Freight Rate (in Cents/ Ton-Mile, 1987$)	Change in the Cost Advantage of Rail (in Cents/ Ton-Mile, 1987$)	Change in the Cost Advantage of Rail (in Cents/ Ton-Mile, 1977$)
Scenario 1 - Dual-Fuel for Rail no Further Control for Trucks	2.82	22.48	-0.09	-0.08
Scenario 2 - LNG-SI for Rail no Further Control for Trucks	2.90	22.48	-0.17	-0.15
Scenario 3 - DF+SCR for Rail no Further Control For Trucks	3.00	22.48	-0.27	-0.23
Scenario 4 - SCR for Rail no Further Control for Trucks	3.13	22.48	-0.38	-0.31
Scenario 5 - Dual-Fuel for Rail LNG/Lean-Burn SI for Trucks	2.82	22.97	0.41	0.34
Scenario 6 - SCR for Rail CNG/Lean-Burn SI for Trucks	3.13	22.72	-0.13	-0.11

Exhibit E-4

Modal Diversion by Regulatory Scenario (2010)

Scenario	Δ in Rail Ton-Miles (Millions)	% Δ in Rail Ton-Miles	New Rail Ton-Miles (Millions)	New Truck Ton-Miles (Millions)
No Control 2010 Baseline	--	--	36,541	52,148
Scenario 1 - Dual-Fuel for Rail no Further Control for Trucks	-406	-1.1%	36,135	52,554
Scenario 2 - LNG-SI for Rail no Further Control for Trucks	-762	-2.1%	35,780	52,910
Scenario 3 - DF+SCR for Rail no Further Control For Trucks	-1,168	-3.2%	35,373	53,316
Scenario 4 - SCR for Rail no Further Control for Trucks	-1,625	-4.4%	34,916	53,774
Scenario 5 - Dual-Fuel for Rail LNG/Lean-Burn SI for Trucks	+1,727	+4.7%	38,269	50,421
Scenario 6 - SCR for Rail CNG/Lean-Burn SI for Trucks	-610	-1.7%	35,932	52,758

Note: Numbers may not add up exactly because of rounding.

Scenario 5, *SCR for Rail and CNG/Lean-Burn SI for Trucks*, is estimated to be an increase in rail ton-miles of 1,727 million, since the rail cost advantage increases for this scenario. In contrast, Scenario 6, *Dual-Fuel for Rail and LNG/Lean-Burn SI for Trucks*, is expected to decrease rail ton-miles by 610 million.

This analysis shows the importance of developing emissions control strategies that account for the full economic impacts of regulation. Diversion can result in increases in the activity of higher polluting sources that may negate some of the expected emissions benefits of the regulatory initiative. A system-wide approach is necessary to fully account for the indirect economic and emissions impacts. Depending on the mix of regulations promulgated for each source, or mode, the diversion impact may either increase or decrease the activity of a given source. For example, Scenario 5 resulted in increased rail activity relative to truck, while Scenario 6 resulted in decreased rail activity relative to truck. As a result, regulations that impact competition between modes must be analyzed in conjunction to one another to ensure that the net emissions consequences are accounted for in the promulgation process.

Exhibit E-5 presents the corresponding NO_x emissions impacts of each scenario that result from changes in the NO_x emissions factors of locomotives and trucks and of modal diversion. For each scenario, combined truck and rail 2010 NO_x emissions are significantly lower when compared to the 2010 no-control scenario. Scenarios 5 and 6 provide the largest combined truck and rail NO_x emissions reductions. This is because under Scenarios 1 to 4 no further emissions controls from those currently prevalent are assumed for heavy-heavy-duty diesel vehicles. Consequently, increases in truck activity, resulting mostly from economic and demographic growth, offset benefits accrued from locomotive emissions control strategies.

The results presented in Exhibits E-4 and E-5 highlight the relative importance of diversion versus changes in emissions factors resulting from the regulatory strategies examined in this study. In Scenarios 1 to 4, emissions reductions are mostly driven by changes in the emissions rate of locomotives—since significant emissions reductions are achieved from the 2010 no-control baseline even though only small reductions in rail activity occur as a result of decreases in the rail cost advantage (see Exhibit E-4). For example, 2010 locomotive NO_x emissions under the no control scenario are 158 tons/day. Rail NO_x emissions under Scenario 3 are estimated to be 21 tons/day in 2010, a decrease of 87 percent from the 2010 no control level. However, rail ton-miles under Scenario 3 only decrease by 3.2 percent. Consequently, most of the emissions reductions are associated with the effectiveness of control strategies rather than with modal diversion.

The emissions consequences of the regulatory scenarios investigated in this study are encouraging. Diversion by itself is not expected to have a major impact on emissions by mode. Rather, emissions reductions are mostly driven by changes in the emissions rates of locomotives and heavy-heavy-duty diesel trucks that result from technology deployment.

Exhibit E-5

Resulting NO_x Emissions Impacts by Regulatory Scenario (2010, in Tons/Day)

Scenario	Truck NO_x	Rail NO_x	Total NO_x	Difference From 2010 No-Control
No Control 2010 Baseline	410	158	568	--
Scenario 1 - Dual-Fuel for Rail no Further Control for Trucks	413	39	452	-116
Scenario 2 - LNG-SI for Rail no Further Control for Trucks	416	23	439	-129
Scenario 3 - DF+SCR for Rail no Further Control For Trucks	419	21	440	-128
Scenario 4 - SCR for Rail no Further Control for Trucks	423	41	464	-104
Scenario 5 - Dual-Fuel for Rail LNG/Lean-Burn SI for Trucks	159	41	200	-368
Scenario 6 - SCR for Rail CNG/Lean-Burn SI for Trucks	166	42	208	-360

Note: Results may not add up exactly because of rounding.

Markets for Locomotive Emissions — Recommended Market Design

Three market designs were evaluated in this study: emissions allocation trading, emissions reduction credit (ERC) trading, and emissions averaging.

- *Emissions Allocation Trading* — emissions allocations are distributed to emissions sources within a jurisdiction and the allocations may then be bought and sold in an emissions market. The source (e.g., a railroad) must keep its total emissions in the jurisdiction beneath the level set by its emissions allocation. The jurisdiction may be the state or an air pollution control district.

- *ERC Trading* — emissions reductions are certified prior to the issuance of ERCs by pollution control officials. The ERCs may then be traded. A source creating ERCs must keep its emissions below the new limit approved by officials in granting the ERCs. A source purchasing ERCs may increase its emissions by the amount of the ERC.

- *Emissions Averaging* — no specific limit is placed on a source's total emissions. Rather, a limit is placed on the emissions rate of each piece of equipment. If the emissions rate of a given piece of equipment is lowered below its limit, then the rate for another piece of equipment may be increased. The allowable increase in the emissions rate is determined using a weighting system in which the expected rates of utilization for each piece of equipment are used as the weights. Emissions averaging may be conducted at the state or local level. In the case of locomotives, averaged emissions may reflect one railroad or several railroads.

In this study, the following assumptions govern the evaluation and development of candidate market designs: 1) that declining statewide caps are placed on locomotive emissions; 2) that a simplified approach for emissions calculations is developed by the U.S. EPA in its proposed national locomotive rule, or that alternative approaches based on current methodologies developed by the ARB (e.g., methodologies developed by Booz•Allen or EF&EE) are employed; and 3) that air quality goals are developed in terms of either a SIP for a nonattainment area or an air quality maintenance plan for a "prevention of significant deterioration" area (i.e., emissions limits for locomotives and other sources are developed with respect to local environmental conditions).

Of the three market designs investigated in this study, emissions allocation trading is the best suited strategy when combined with a rigid, declining, statewide cap on locomotive emissions. ERC trading adds a costly step that inhibits market participation (i.e., certifying a proposed ERC increases transaction costs). Emissions averaging does not result with significant economic benefits nor does it ensure adherence to the statewide emissions cap.

Under emissions allocation trading, the statewide cap will be used to determine yearly emissions allocations for each railroad operating in the state's air pollution control district or air quality management district. Allocations should be based on the relative, historical contributions of specific polluters (e.g., railroads, power plants, trucking firms, etc.) to emissions in a given air pollution control district. Once allocations have been prescribed to each polluter participating in the recommended emissions allocation scheme, emissions trading will be possible internally within railroads, between railroads, or between railroads and other emissions sources located in a particular district. The suggested unit of trade is tons of emissions per year. Annual emissions limits could be translated to daily limits to accommodate air quality modeling. The duties of a pollution control agency under the recommended market design include the following: assignment of emissions allocations, recording of trades of emissions allocations, monitoring of emissions, and enforcement of emissions limits. Information on the contribution of emissions by source (i.e., stationary sources, rail operations, trucking, etc.) available from SIPs and air quality management plans can serve as the basis from which rigid caps and emissions allocation strategies can be developed.

Under the recommended emissions allocation trading scheme, the state would collect and certify locomotive emissions from railroad operations in each district and disseminate these data to each air quality district. There are a number of methods for accomplishing this state function. This analysis, however, assumes that a simplified approach for estimating the contribution of locomotives to emissions in each district based on methodologies developed by the U.S. EPA in its proposed national locomotive rule, or that an alternative approach based on methodologies previously developed for the ARB, will be employed by California. If measures taken by a given railroad increase the railroad's contribution to emissions in a given district to levels that exceed the prescribed allocation, the railroad must either 1) reduce emissions from the other sources that it operates within the district, 2) obtain additional allocations from another railroad operating in the given district, or 3) obtain emissions allocations from another source (e.g., a stationary source located in the district). Conversely, if a railroad institutes measures that decrease its contribution to emissions in a particular district to levels below its prescribed allocation, the railroad would be able to trade surplus allocations to other railroads or sources.

The following attributes of emissions allocation trading exemplify its inherent advantages over ERC trading and emissions averaging.

- Emissions allocation trading affords the greatest economic benefit since it provides the largest trading universe (i.e., it provides the greatest opportunity to reduce costs associated with NO_x emissions control).

- Emissions allocation trading preserves the emissions cap, thereby maintaining the desired level of environmental protection.

- Emissions allocation trading results in the lowest transactions costs, thereby maximizing the level of market participation.

- Emissions allocation trading will provide railroads with the easiest method for reducing cost burdens associated with the implementation of rigid, declining statewide emissions caps.

However, to maximize the potential benefits of emissions allocation trading, it is necessary to establish emissions trading systems in all jurisdictions of the state where there is likely to be a demand for emissions allocations, and to ensure that, at least with respect to railroads, emissions allocation programs across jurisdictions operate in a uniform manner. Implementing a trading scheme that maximizes the opportunity for trades provides significant economic benefits to market participants. However, even when comprehensive and uniform schemes are developed there will still be the added burden of identifying trading partners in each jurisdiction. State and local emissions clearing houses will ease this burden.

1. Introduction

The California Air Resources Board (ARB) has determined that locomotives contribute significantly to air quality problems across the state. In 1987, locomotives accounted for 155 tons per day of oxides of nitrogen emissions (NO_x). This contribution accounts for approximately 5 percent of the state's total NO_x emissions inventory. Currently, locomotives operating in California are not subject to any type of emissions mitigation program, except for some locally adopted opacity limits. Along with commercial marine vessels, locomotives comprise one of the largest classes of uncontrolled NO_x and oxides of sulfur (SO_x) sources. Consequently, the ARB has determined that substantial NO_x emissions reductions can be achieved by formulating and promulgating control strategies that target this source.

In order to achieve state and Federal standards for ambient ozone concentrations, the South Coast Air Quality Management District, for example, estimates that NO_x emissions in 2010 must be reduced by 69 percent from the 1987 level. In response to this need, the ARB recently completed a study that investigates possible regulatory strategies for mitigating locomotive NO_x emissions.[1] The study concluded that various feasible and cost-effective strategies for controlling locomotive emissions exist for potential promulgation by the ARB. These include, among others investigated, selective catalytic reduction (SCR), use of liquified natural gas (LNG) fuel with low-emissions dual-fuel or spark-ignition (SI) natural gas engines, and LNG combined with SCR.

However, little is known about the indirect economic impacts of these strategies, particularly as they related to the efficient transport of goods and services in California. For instance, the railroad industry argues that rail, as a low-cost provider of freight transport, is integral to the distribution of goods and services in California. They further argue that emissions regulations that focus on locomotives will increase the cost of providing service and will increase the rates that the railroads charge their customers. Given the alternative modes that exist to transport freight, increases in rail rates may cause significant shifts from rail to other modes, especially from rail to truck. Mode shifts that result from locomotive emissions regulations may, in turn, be counter-productive to solving the air quality problems attributable to freight transportation since trucks (according to the railroads) emit more pollutants per ton of freight moved than does the rail mode.

Therefore, in order to develop a policy that most cost-effectively minimizes NO_x emissions in California, it is essential that the ARB have a complete understanding of the relative contributions of each mode to freight transport and emissions in the state, and of the effects of various strategies to control locomotive NO_x emissions on relative freight rates and mode choice. The purpose of this study is to assess the effects of proposed locomotive emissions regulation strategies on mode choice and locomotive emissions and to formulate the framework for an

[1]The study was conducted by a contractor. Engine, Fuel, and Emissions Engineering, Inc., *Controlling Locomotive Emissions in California: Technology, Cost-Effectiveness and Regulatory Strategy*, ARB Contract Nos. A032-169 and 92-917, March 29, 1995.

active market for locomotive emissions reduction credits.

Appendix A presents the general methodology that is employed in this study to achieve the following study objectives.

- *Estimate Commodity Flows by Mode* — Surprisingly, prior to this study little was known about the modal share of freight transport in California. As a result, a major focus of this effort is to estimate modal splits, particularly between rail and rail-competitive trucks.

- *Calculate the Contribution of Emissions by Goods Transport Mode* — The air quality planning processes employed by states and metropolitan planning organizations across the country do not focus specifically on emissions from freight transport activities. The relative contribution of freight modes to emissions in a region is seldom reported in State Implementation Plans or regional Air Quality Management Plans. Therefore, one objective of this study is to isolate freight-related emissions by mode and to ascertain changes in modal emissions resulting solely from economic and/or demographic growth.

- *Perform a Comprehensive Review and Evaluation of Mode Choice Models* — To ensure that the ARB is fully cognizant of the factors that determine mode choice or mode shifts, and to ensure that the best possible forecasting tools are used in this study, another objective is to conduct a comprehensive review and evaluation of previous mode shift analyses.

- *Assess the Direction and Magnitude of Mode Shifts Attributable to Locomotive Emissions Regulations* — Using the best possible mode shift model, the central objective of this study is to determine the mode choice impacts of various locomotive emissions control strategies and to determine the consequent emissions repercussions.

- *Develop the Framework for an Active Locomotive Emissions Market* — The final objective of this study is to determine the best possible framework for an active market in locomotive emissions reduction credits.

This report documents the results of the analysis conducted to achieve each of these goals. The report is divided into seven sections, including this introduction. The following section, Section 2, presents the base year (1987) and forecast (2010) commodity flows for rail and rail competitive trucks.

Section 3 illustrates the relative contribution of freight transport modes to emissions in California and develops truck and rail emissions by 2010 associated solely with economic and/or demographic growth.

Section 4 reviews and evaluates the various models that are used to estimate the effect of policies on mode choice in the freight arena. It also discusses the rationale for selecting the CALFED model for use in this study.

Section 5 describes the mode shift and resulting emissions impacts of the various emissions control strategies investigated in this analysis. Both locomotive and truck emissions control strategies are estimated.

Finally, Section 6 presents the results of a comprehensive literature review and evaluation of previous emissions credit programs, while Section 7 presents the framework for an active locomotive emissions reduction credits market.

2. Commodity Flow in California

As stated in the introduction, the main purpose of this report is to estimate changes in locomotive emissions due to potential regulations being considered by the ARB. One possible outcome of any type of regulation on locomotives is that rail traffic could divert to truck traffic due to the relatively higher costs that may have to be passed on to consumers. Since trucks have higher emissions per ton-mile than rail, such diversion would offset reduced locomotive emissions due to the regulations. As a result, in order to estimate how proposed locomotive emissions regulations would affect total emissions levels, it is necessary to calculate the amount of diversion that would likely take place.

To understand the effects that locomotive emissions regulations would have on freight transportation patterns in California, however, it is necessary to become familiar with some basic concepts that economists and transportation planners use to describe goods movement and the choice of freight transportation modes. At the most disaggregate level, there are individual shipments. These shipments consist of a specific commodity that is being shipped and a quantity of that commodity that is being shipped. When examining the choice of transportation mode for this shipment, the commodity characteristics are an important consideration. For example, certain commodities are shipped in bulk, the products have a relatively long shelf life, and the transport time is not that critical to the buyer. Products such as coal and grain are typical of these types of commodities. These commodities are more likely to be shipped by rail than by truck and they are unlikely to be very sensitive to the difference in cost between rail and truck. Thus, in describing goods movement, the commodity and the typical size of shipment are both important variables.

Each shipment also has an origin and a destination. Knowledge of origins and destinations are important when looking at mode choice for individual shipments because they determine the availability of modal options (some locations do not have easy access to rail lines or highways) and the length of the haul (longer haul shipments are more likely to travel by rail than by truck).

In addition to characteristics of the shipment, modal characteristics also determine the choice of mode for freight transportation. Characteristics such as freight rates, transit time between origins and destinations, reliability, and other factors are important to the shipper/receiver in selecting what mode to use for an individual shipment.

Some economists and planners have developed mode choice models taking this disaggregate perspective. **Disaggregate models** essentially predict the probability that any individual shipment will travel on a particular mode (e.g., rail or truck). These models are frequently estimated using regression techniques and can include any or all of the variables described above (e.g., commodity, shipment size, length of haul, freight rates, transit time, etc.). Parameters are estimated for each variable in the model based on the characteristics of a sample of actual shipments. When these disaggregate models are used to predict mode choice, usually there is a data base containing the characteristics of a sample of shipments. The values of individual variables can be altered for each individual shipment and when the results of the model computations are summed over all of the shipments in the sample, the model will predict what proportion of the shipments will select a particular mode. For example, if the assumption is that the only impact of locomotive emissions regulations would be an increase in freight rates (e.g., due to more expensive technology requirements), this could be plugged into the model to determine what share of the shipments would travel by rail given the new freight rates.

Disaggregate, shipment-by-shipment data bases are relatively rare in the freight transportation literature. Typically, they are frequently collected on a case-by-case basis for the use of a particular researcher. More often, data on freight transportation are aggregated into what is described as transportation or commodity flows. For example, all of the shipments of a particular commodity travelling between the same origin and destination locations might be aggregated to describe a particular commodity flow. In some cases, these data bases may include modal split information (i.e., the percentage of the shipments made by rail, truck, air, etc.). One of the ways that these flow data bases differ is in the level of commodity and geographic detail they contain. For example, many data bases which use the Standard Transportation Commodity Classification (STCC) system to classify commodities may report data at the 1-digit level (very aggregate) or the 5-digit level (very disaggregate). Data bases may report commodity flows between states, between regions within a state, or between cities.

Because commodity flow data are generally more available than disaggregate shipment data, some economists and planners have developed **aggregate models** to predict mode choice. These models assume a set of average characteristics for many of the same variables that are included in disaggregate models (e.g., average length of haul for flows between two states). Nonetheless, these models are useful when the analyst is interested in mode choice effects on aggregate flows (e.g., how do mode shares change for all shipments in California) and disaggregate data are unavailable.

Mode choice models can be used to examine modal diversion questions such as how much freight transportation shifts from rail to trucking if the relative cost of rail increases. The approach is to change the value of one of the variables in the model and compute the new modal shares. In the case of aggregate models, it is necessary to have data on the baseline commodity flows and modal shares in order to exercise the models. If these flow data are not available for a particular time period that is the subject of the analysis, they may often be estimated using economic data and projections. This approach was applied by JFA in this project, as discussed below. Section 4 present detailed reviews of disaggregate and aggregate models.

CALFED, an aggregate model, was chosen to assess the diversion impacts of the proposed locomotive emissions regulations (for a detailed description of CALFED see Section 4). Before CALFED could be used to estimate the amount of diversion that could take place, two tasks had to be completed. First, it was necessary to quantify the amount of base year (1987) traffic by mode for ten commodity groups. These commodities are presented in Exhibit 2-1 and were specified by the model, which calculates the extent of diversion separately for each group. Section 2.1 details the procedure that was used for this purpose. Second, forecasts of the base year traffic had to be developed for the year 2010, the year chosen for evaluating the impacts of the proposed locomotive emissions regulations. The method used to produce these forecasts is presented in Section 2.2.

All traffic estimates were developed in ton-miles.

2.1 Development of Baseline Commodity Flows

No comprehensive source of data has provided complete modal share information by commodity since the 1977 Commodity Trade Survey (CTS); and the 1993 Commodity Flow Survey (CFS) has yet to be published. Since 1977, commodity freight flow data by origin and destination have been collected separately by the Interstate Commerce Commission (ICC) for rail. Similar freight flow data for trucking, however, have been especially scarce. As a result, the base year traffic by truck was estimated in this study. The basic approach consisted of estimating total commodity flows for each commodity, and then subtracting the known flows by other modes to produce a set of trucking residuals.

For each commodity, interstate flows were developed for goods moving between California and other U.S. states. These interstate flows were divided into movements originating in other states and terminating in California and movements originating in California and terminating in other states. Separate flows were estimated for each state. Intrastate commodity flows were also estimated for goods both originating and terminating in California. The flows were initially estimated at the two-digit Standard Industrial Classification (SIC) level and later aggregated into the commodity groups shown in Exhibit 2-1.

The first step in developing these flows entailed deriving 1977 and 1987 supply and consumption estimates by commodity for each U.S. state.[2] State supply was defined to include production and imports that entered U.S. consumption channels via a custom's district in the state. State production estimates were derived by using state employment data to allocate U.S. production data obtained from the U.S. Bureau of Labor Statistics (BLS). The state employment data were taken from the U.S. Bureau of Economic Analysis' *Regional Economic Information System* (REIS) CD-ROM and were adjusted to reflect changes in the SIC codes. Vectors of U.S. imports by state of unlading were developed by Jack Faucett Associates (JFA) in previous work; the major source of this data was the *U.S. Imports of Merchandise* CD-ROM prepared by the U.S. Bureau of the Census. State consumption was defined to include intermediate demand for production and the following final demand categories: personal consumption expenditures, gross private investment, state and local government expenditures, federal government defense expenditures, federal government non-defense expenditures, and U.S. exports with exit points in the respective state. Each state's total intermediate demand for a particular commodity was computed by summing intermediate demands for the commodity across industries. Intermediate demand by commodity for each state industry was calculated by multiplying state industry output by input-output coefficients developed from BLS' national input-output tables. The remaining

[2]As discussed in Section 4, CALFED is estimated with 1977 CTS data, while 1987 represents the base year in this study.

Exhibit 2-1

Freight Model Commodity Groups

1. Fruits and Vegetables
2. Other Agriculture
3. Construction and Minerals
4. Timber and Lumber
5. Food Products
6. Paper Products
7. Chemicals
8. Primary Metals
9. Machinery
10. Other Manufacturing

final demand components were developed by JFA in previous work. All of these estimates are in constant 1977 dollars.

The 1987 estimates of California supply and consumption were then allocated to each state. These allocations were based upon supply and consumption shares developed from JFA's 1977 Multi-Regional Input Output (MRIO) accounts. These accounts reflect a balanced comprehensive model of the 1977 U.S. economy and trace value and ton flows between producing and consuming states. The supply shares indicate the percentage of California supply that was distributed to each state in 1977. Consumption shares refer to the percentage of California consumption that originated in each state in 1977. These 1977 shares were then adjusted for relative changes in supply and consumption that took place between 1977 and 1987 (developed from the estimates discussed in the preceding paragraph). That is, supply shares were adjusted for relative changes in consumption while consumption shares were adjusted for relative changes in supply. Applying the new supply and consumption shares to 1987 estimates of California supply and consumption generated a preliminary set of value flows between California and each U.S. state. These preliminary flows were not balanced, however. Theoretically, production plus flows into a region should equal consumption plus all flows out of the region. In this study, flows were balanced by adjusting the California 1987 consumption estimates so that the two sets of intrastate flows, generated by applying the supply and consumption shares, were equal to each other.

The resulting value flows were converted into ton flows by multiplying them by ton per dollar ratios developed from the MRIO accounts. The MRIO model yields separate ton per dollar ratios for each commodity and state-to-state origin-destination (O-D) pairing.

Known state-to-state flows by rail and water (in tons) were then subtracted from these total ton flows to produce estimates of the amount of California supply and consumption moved by truck (in tons) in 1987. Rail data were obtained from the confidential *1987 ICC Waybill Sample* controlled by the ICC. These data are more accurate than ICC's public use file, in which they do not provide some of the origin and destination information to prevent disclosure of proprietary information. Data for water flows were taken from *Waterborne Commerce of the United States*, published by the Army Corps of Engineers. For a few commodities, further adjustments had to be made for movements by pipeline.

To use the CALFED diversion model to evaluate the effect of locomotive emissions regulations on mode choice and emissions from freight activities within California, it was necessary to develop estimates of the amount of traffic "within" California. That was accomplished by allocating each state-to-state truck flow to a sub-state origin and/or destination in California. For example, each particular commodity flow that originated in California and terminated in a given state was divided into several different flows with several different sub-state California origins but the same state destination. In a similar fashion, each flow that originated outside of California was divided into several flows with different California sub-state destinations but the same state origin. Available data at the county level are too sparse and are questionable for this purpose. As a result, JFA decided to use data for business economic areas (BEA), which are not as sparse and are more reliable. These eight areas are groups of counties and are presented in Exhibit 2-2.

The allocation of the origin and/or destination of the flows was based upon the distributions of supply and consumption across the BEA regions. These distributions were created by allocating the state level estimates to the areas. For a given commodity, each component of supply and consumption was allocated separately. For supply, distributions of state production estimates were based upon employment data from *County Business Patterns* (CBP). Unlike many data sources, CBP provides employment ranges when data are withheld to avoid disclosing proprietary information; in a few cases, it was necessary to use the midpoint of those ranges to circumvent data disclosure restrictions. CBP does not provide data for the railroad industry or agriculture. Earnings data were used to allocate railroad output and farm employment was used to allocate agricultural output; both data were obtained from *REIS*. Import data on the *U.S. Imports of Merchandise* CD-ROM are reported by districts of unlading. These districts were mapped into the corresponding BEA area and the imports were distributed accordingly.

For consumption, intermediate demand was calculated as follows. Personal consumption expenditures were distributed according to personal income data. State and local government expenditures were distributed according to state and local government employment and federal non-defense expenditures were allocated by federal civilian employment. *REIS* furnished all of the data necessary to make these allocations. The Federal Procurement Data System records data for all government contract awards that exceed $25,000. Data from this system were used to distribute federal defense expenditures. Export data on the U.S. Exports of Merchandise CD-ROM are reported by customs districts that are U.S. exit points. These districts were mapped into the corresponding BEA area and the exports were distributed accordingly. Using capital flow data from the MRIO accounts, gross private investment at the state level was divided into investment by total manufacturing and investment by total non-manufacturing. These two vectors were then distributed to BEA areas using manufacturing and non-manufacturing employment data.

For intrastate truck flows, the allocations of supply and consumption to BEA areas were not that useful by themselves. For example, the allocation of supply resulted in a distribution of supply by California BEA area but it did not yield where in California those flows terminated. Likewise, the allocation of consumption produced a distribution of consumption by California BEA areas but it did not indicate where those flows originated. It was necessary to tie these two allocations together before the results could be meaningful. To do that, JFA developed a simple linear programming algorithm to estimate the flows. First, each BEA region's supply estimate was distributed to the eight California BEA regions according to consumption, yielding an eight by eight matrix of flows for each commodity. These initial matrices were not balanced because the summation of the flows into a region generally did not equal the consumption that had previously been allocated to it. To balance the flows, a linear programming problem was specified that constrained the sum of the flows into a region to equal its consumption and the sum of the flows out of a region to equal its supply. These were not enough constraints to solve the model; additional constraints specified certain ranges within which each flow had to fall (i.e., limiting the amount that the initial values could be perturbed). These ranges were defined in terms of a common percentage, which was the smallest one available for solving the model.

Exhibit 2-2

California Business Economic Areas

BEA Area	County	BEA Area	County
Redding	Lassen	Stockton	Alpine
	Modoc		Amador
	Plumas		Calaveras
	Shasta		Mariposa
	Siskiyou		Merced
	Tehama		San Joaquin
			Stanislaus
Eureka	Del Norte		Tuolumne
	Humboldt		
	Trinity	Fresno	Fresno
			Kern
San Francisco	Alameda		Kings
	Contra Costa		Madera
	Lake		Tulare
	Marin		
	Mendocino	Los Angeles	Inyo
	Monterey		Los Angeles
	Napa		Mono
	San Benito		Orange
	San Francisco		Riverside
	San Mateo		San Bernardino
	Santa Clara		San Luis Obispo
	Santa Cruz		Santa Barbara
	Solano		Ventura
	Sonoma		
		San Diego	Imperial
Sacramento	Butte		San Diego
	Colusa		
	El Dorado		
	Glenn		
	Nevada		
	Placer		
	Sacramento		
	Sierra		
	Sutter		
	Yolo		
	Yuba		

The next step in estimating truck traffic within California required converting the ton flows into ton-miles. The CALFED diversion model dictated that those ton-miles refer only to the leg of the trip that occurred within California. For each flow originating in a given BEA region and going to a particular state, it was necessary to guess at the most likely route that would be taken and then compute the mileage along that route between a point in the region and the border. The chosen points were the metropolitan statistical areas that define each BEA region. Mileage was computed from a Rand McNally road atlas. A similar procedure was used to compute flows originating in other states and terminating in California BEA regions. For an intrastate flow between two given BEA areas, the mileage was assumed to be equal to the distance between the two centroids. The mileage estimates were then multiplied by the corresponding ton flows to yield the number of truck ton-miles within California. Highway mileage estimates are shown in Appendix B.

One final adjustment had to be made to these truck ton-mile estimates before they could be used in the diversion model. Not all truck and rail movements are competitive with each other. Local trucking, for example, probably does not compete with rail. Since the CALFED diversion model is based only upon truck traffic that competes with rail, it was necessary to isolate that component of traffic estimates. The *1987 Truck Inventory and Use Survey* (TIUS), published by the U.S. Bureau of the Census, contains data on the number of vehicle miles travelled (VMT) within California by gross vehicle weight (GVW) and primary product carried. For each product, the percentage of VMT by trucks with GVWs over 33,000 pounds was calculated. It is assumed that only trucks with GVWs over 33,000 are competitive with rail and that these percentages reflect the amount of truck ton-mile traffic that is rail competitive. The final adjustment consisted of multiplying the truck ton-miles within California by these percentages, producing ton-mile estimates of truck traffic that is competitive with rail.

For comparison purposes, it was necessary to convert rail ton flows into ton-mile flows within California. The procedure used to make that conversion is similar to the one used for trucking. First, likely routes in and out of the state were determined; then, mileage from the border to the point of origin or destination was assessed using estimates published in the documentation to CALFED. Since the Waybill provides ton-mile estimates for each BEA origin-destination pairing, these numbers were used for the intrastate rail movements. Waybill ton-mile estimates for interstate movements could not be used because they refer to the total length of the trip, not just to that portion that takes place within California. Rail mileage estimates are shown in Appendix C.

Exhibit 2-3 presents the total base year traffic estimates by commodity and mode.

2.2 Forecasts of Commodity Flows

The procedure used to forecast the amount of freight traffic within California in 2010 resulting solely from economic and demographic growth is very similar to the one used to develop the baseline 1987 estimates. The main difference is that supply and consumption figures had to be projected for each state as well as for the California BEA areas. In summary, relative changes in supply and consumption that were predicted to occur at the state level were used to adjust the 1987 supply and consumption shares defined in Section 2.1. The new shares were then applied to California's 2010 supply and consumption estimates, generating state-to-state value flows. Values were converted to tons using ton/value ratios developed from JFA's MRIO accounts. For the 2010 projections, it was assumed that the 1987 modal shares would remain constant for a given commodity and state-to-state O-D pairing. The interstate ton flows were then distributed to California BEA origins and destinations based upon expected changes in supply and consumption in those areas; intrastate flows were generated using the same linear programming algorithm described in Section 2.1. Multiplying the ton flows by the corresponding mileage estimates (shown in Appendix B and Appendix C) resulted in 2010 projections of the amount of ton-mile traffic within California. A final adjustment was made to the truck ton-mile estimates to isolate only the traffic that is competitive with rail.

Two sources were used to project the supply and consumption estimates to 2010. In November 1993, BLS released a publication entitled *The American Work Force: 1992-2005*. This publication forecasts the U.S. economy to the year 2005 and includes projections of employment and output by industry and final demand by category. In addition, every five years the U.S. Bureau of Economic Analysis prepares long-range regional forecasts of population, employment, and income. The last regional projections were released in 1990 and presented state and sub-state level forecasts to the year 2040.

For the supply forecasts, separate projections were made for each commodity and supply component (production and imports). Development of the output projections required using both data sources. The Bureau of Economic Analysis does not make regional projections of output, which were needed to estimate supply and to calculate intermediate demand. The regional employment growth rates are not adequate by themselves for forecasting output because technological change affects labor productivity rates (output per employee). As a result, it was necessary to use changes in labor productivity projected at the national level by BLS in conjunction with the state level employment forecasts developed by the Bureau of Economic Analysis (BEA). BLS labor productivity rates by industry were extended to 2010 using average annual growth rates from 2001-2005. It should be noted that the Bureau of Economic Analysis does not revise its projections when revisions are made to the base year data (1988) on which those projections are based. In order to reflect changes that were made to the base year data, JFA adjusted the regional projections by applying the initial growth rates to the revised data.

Import projections by commodity were made by assuming that each state's share of the total U.S. imports will remain constant. BLS' projected growth rates for imports were used to forecast total U.S. imports to 2010.

In terms of consumption, intermediate demand was estimated by using the same procedure described in Section 2.1. BLS's projected growth rates of the remaining final demand categories (personal consumption expenditures, state and local government expenditures, federal non-defense expenditures, federal defense expenditures, exports, and gross private investment) were used to forecast U.S. totals to the year 2010. 1987 state shares of personal consumption expenditures were adjusted for relative changes in personal income that were projected to take

Exhibit 2-3
1987 Freight Traffic Within California

Commodity	Total Truck Traffic (Millions of Ton-Miles)	Percent of VMT Carried by Heavy-Heavy Duty Diesel Truck	Truck Traffic Competitive With Rail (Millions of Ton-Miles)	Rail Traffic (Millions of Ton-Miles)	Truck Share of Competitive Traffic (Percent)	Rail Share of Competitive Traffic (Percent)
Fruits and Vegetables	13,338	22	2,934	497	86	14
Other Agriculture Products	13,765	24	3,303	2,879	53	47
Construction and Minerals	10,405	41	4,266	2,862	60	40
Timber and Lumber	10,449	17	1,776	4,106	30	70
Food and Kindred Products	14,935	46	6,870	4,451	61	39
Paper and Allied Products	4,127	47	1,940	2,849	41	59
Chemicals and Allied Products	9,448	23	2,173	2,783	44	56
Primary Metals	4,331	31	1,343	1,631	45	55
Machinery	3,423	28	958	199	83	17
Other MFG	21,646	33	7,143	2,337	75	25
Total	105,867		32,707	24,592	57	43

place. 1987 state shares of state and local government expenditures and 1987 state shares of federal non-defense expenditures were adjusted for relative changes in the corresponding employment sectors that are likely to occur. State shares of exports and federal defense expenditures were assumed to remain constant. Adjustments to state shares of gross private investment were based upon projected changes in output.

Except for production, the components of supply and consumption for California BEA areas were projected in the same way as their state counterparts (i.e., BEA shares of California state totals were forecasted and then applied to projected state levels to distribute them). BEA shares of personal consumption expenditures were adjusted for expected changes in income. Shares of state and local government expenditures and of federal non-defense expenditures were adjusted for employment changes projected by the Bureau of Economic Analysis. BEA shares of California imports, exports, and federal defense expenditures were held constant. BEA shares of gross private investment were adjusted for relative changes in output. To forecast intermediate commodity demand for the California BEA areas, it was necessary to develop 2010 production estimates at the two digit SIC level for each BEA region. The Bureau of Economic Analysis projects employment at the two digit SIC level for the state of California. However, BEA only publishes such projections at the one digit SIC level for sub-state regions. Developing projections at the sub-state level required several steps. First, preliminary estimates of output at the SIC two digit level were developed for each BEA region by taking into account each BEA area's initial two digit output levels (described in Section 2.1), growth in two digit output at the state level, and relative growth in one-digit output at the BEA regional level. These estimates were then balanced using a linear programming algorithm similar to the one presented in Section 2.1.

Exhibit 2-4 shows the 2010 traffic estimates that resulted from this procedure.

Exhibit 2-4
2010 Freight Traffic Within California

Commodity	Total Truck Traffic (Millions of Ton-Miles)	Percent of VMT Carried by Heavy-Heavy Duty Diesel Truck	Truck Traffic Competitive With Rail (Millions of Ton-Miles)	Rail Traffic (Millions of Ton-Miles)	Truck Share of Competitive Traffic (Percent)	Rail Share of Competitive Traffic (Percent)
Fruits and Vegetables	20,034	22	4,408	723	86	14
Other Agriculture Products	20,848	24	5,003	4,066	55	45
Construction and Minerals	15,288	41	6,268	4,070	61	39
Timber and Lumber	14,601	17	2,482	5,034	33	67
Food and Kindred Products	14,427	46	6,636	6,387	51	49
Paper and Allied Products	4,188	47	1,968	4,632	30	70
Chemicals and Allied Products	8,728	23	2,007	5,473	27	73
Primary Metals	5,787	31	1,807	2,109	46	54
Machinery	16,023	28	4,486	647	87	13
Other MFG	51,762	33	17,082	3,400	83	17
Total	171,686		52,148	36,541	59	41

3. Emissions Contributions of Goods Transport in California

The previous section described current goods movement in California by freight transport mode and changes in mode shares irrespective of emissions regulations that may be promulgated in the future. The purpose of this section is to characterize the base year (1987) contributions of goods transport modes to California's emissions inventory and to assess future rail emissions in 2010 given no emissions control regulations. Information derived in Section 2 with that presented in this section allows for the computation of mode specific emissions on a per ton-mile basis. In this manner, the relative emissions rate (i.e., emissions/ton-mile) of rail versus trucking operations in the state can be assessed, thereby facilitating the evaluation of emissions control strategies for each mode which is the subject of Section 5.

This section is divided into two sub-sections. Section 3.1 presents the baseline (1987) emissions contributions of rail, heavy-duty trucks, ocean-going commercial marine vessels, and aircraft, although the focus of this study is on rail versus truck. Section 3.2 presents estimates of rail emissions in 2010 under a scenario of "no emissions control" and discusses in detail the forecast methodology employed for this purpose. While the focus of Section 3.2 is on future (uncontrolled) rail emissions, future heavy duty truck emissions are also presented using a simple extrapolation technique which assumes truck emissions on a ton-mile basis remain constant under a no-control scenario.

Together, results presented in Section 2 and in this section provide the basis from which the impact of locomotive emissions regulations can be assessed, assuming that regulations change mode choice and the emissions rates of locomotives and heavy-duty trucks.

3.1 Baseline Emissions Inventory by Mode

To determine the effects of proposed or forecast California emissions regulations on the contribution of rail emissions to air quality, the baseline emissions contribution of this mode, as well as any potential competitors to this mode, must first be determined. Potential competitors with railroads in California were initially determined to be (in descending order of significance): heavy-duty truck lines, marine carriers, and cargo airlines. Considering the types of freight typically shipped by rail and the other modes, and the level of service required by the shippers of that freight, heavy-duty linehaul trucks are the only mode likely to compete significantly with railroads.

The estimated annual emissions from these four modes within California are tabulated in Exhibit 3-1 and discussed in this sub-section, with emphasis on oxides of nitrogen (NO_x) emissions. This study used the 1987 California Air Resources Board (ARB) statewide emissions inventory (March 1990) as the baseline because it contains the most recent estimated emissions inventories for all four modes, as well as for all other sources in California. As discussed below, the ARB inventories were adjusted for this study to reflect improved estimates, where available.

Exhibit 3-1

1987 California Base Year Emissions Inventory (Tons/Day)

Freight Mode	NO_x	ROG	CO	PM	PM10	Sox
Rail	155	7	22	4	3	11
Heavy-Duty Trucks*	622	174	1,847	104	88	58
Gasoline	149	105	1,631	9	4	8
Diesel	473	69	216	95	83	50
Ocean-Going-Commercial (OGC) Marine**	186	12	22	16	--	131
Aircraft (Non-Gov)	27	26	211	0.45	0.44	2
Total Mobile Sources	2,619	2,483	17,943	295	206	231
Total State Emissions	3,487	5,057	24,024	10,237	5,732	424

Source: California Air Resources Board, "1987 Hybrid Emissions Inventory (Statewide)".
* Includes all trucks weighing above 8,500 lbs. GVW
** Source: Booz-Allen & Hamilton, "Inventory of Air Pollutant Emissions from Marine Vessels", March 1991.

3.1.1 Rail Emissions

Railroad operations within the state of California generated approximately 155 tons of NO_x per day on the average in 1987, as shown in Exhibit 3-1. Although this value includes passenger rail operations, these are a small portion of total California rail operations. Therefore, no effort was made (or deemed necessary) to quantify emissions from passenger and freight operations separately in this sub-section.

Estimated California rail emissions are based on the Booz●Allen & Hamilton report, *Locomotive Emission Study*, which was prepared for the ARB in August 1991 (hereafter called the Booz●Allen report). The Booz●Allen estimate was obtained by analyzing distinct trip segments with average locomotive consists[3] based on data supplied by the railroads. For NO_x, the Booz●Allen estimate is approximately 2 percent higher than the estimate shown in Exhibit 3-1 which reflects the most recent ARB inventory estimates by mode for 1987. Booz●Allen estimates that the combined influence in the uncertainty of duty cycle and emissions factor data results in a confidence interval of ± 20 percent.

3.1.2 Heavy-Duty Truck Emissions

As shown in Exhibit 3-1, the ARB estimates that California heavy-duty truck operations generated over 600 tons of NO_x per day in 1987, substantially more than any other freight-shipping mode. Although data on trip routes were not obtained, intuition suggests that a greater percentage of truck emissions occur within nonattainment areas relative to the other three modes. Assuming that this is true, reducing aggregate emissions from trucks would have a greater impact on air quality than identical aggregate reductions from other modes.

Data used in this report were the most reliable data available, however they do not accurately reflect emissions generated due to rail-competitive freight shipments by truck. Used for this purpose, the ARB inventory overestimates such emissions, as it defines heavy-duty trucks as those weighing over 8,500 pounds Gross Vehicle Weight (GVW). Therefore, many types of trucks that do not haul intercity freight, such as local-delivery trucks, fire trucks, garbage trucks, utility service trucks, etc., are included in the inventory totals shown in Exhibit 3-1.

To accurately compare truck versus rail emissions, it is necessary to isolate the emissions contribution of trucks that compete directly with rail. Given the types of commodities that generally are hauled by rail and the distances of the shipments, only those trucks that haul intercity freight and relatively dense commodities are likely to compete directly with rail. Such trucks commonly weigh over 33,000 pounds GVW and have 5 or more axles. Currently, the ARB classifies heavy-duty trucks into three weight classes: light-heavy trucks weighing between

[3]Most trains are so heavy that several locomotives must be used to generate enough power to climb hills and complete the trip in a reasonable time. The group of locomotives is called a "consist" and may include up to six locomotives, although most consists are made up of three or four locomotives.

8,500 to 14,000 pounds GVW; medium-heavy weighing from 14,000 to 33,000 pounds GVW; and heavy-heavy weighing over 33,000 pounds GVW. Although the ARB's current emissions factor model (EMFAC7F) does not provide emissions by each of these truck classes, the next generation of EMFAC (EMFAC7G) will disaggregate truck emissions in this manner. For this study, the ARB provided estimates of the heavy-duty truck emissions breakdown by truck class. These distributions are shown in Exhibit 3-2. Using these estimates as a proxy for the actual breakdown in 1987, the relative emissions contribution of those trucks that can be expected to compete directly with rail can be approximated. Exhibit 3-3 presents the revised NO_x emissions data for heavy-heavy-duty diesel trucks, as well as emissions from the other modes originally shown in Exhibit 3-1. The heavy-heavy-duty diesel truck emissions estimates and the rail estimates in Exhibit 3-3 form the basis for the rail/truck comparisons investigated in this study.

There are still a number of additional contributors to uncertainty in the emissions estimation process for heavy-duty trucks that should be noted, however. First, actual vehicle-miles-traveled (VMT) data were not collected, rather VMT data are estimated from traffic count data. Second, trip emissions are calculated based on average speeds, average trip lengths, and average emissions factors. Finally, important operational activities that contribute to total emissions, such as idling and engine starts, are not included in current emissions inventory models. The ARB is currently updating the methodology to estimate truck emissions in an effort to address these problem areas.

3.1.3 Marine Emissions

As shown in Exhibit 3-3, ocean-going commercial marine vessels (the only vessels deemed to compete with railroads) generated an estimated 186 tons of NO_x per day in California waters in 1987. This estimate is based on the Booz•Allen report, *Inventory of Air Pollutant Emissions from Marine Vessels*, March 1991.

Although Booz•Allen obtained some of the best data ever compiled on ship movements in California, the emissions factor data available were based on very limited testing, most of which was performed over 15 years ago. Booz•Allen's own estimate of the accuracy of its marine vessel emissions inventory is $\pm$ 30 percent.

3.1.4 Aircraft Emissions

The ARB estimated that all civil aircraft operations in California generated approximately 27 tons of NO_x per day in 1987, as shown in Exhibit 3-3. Cargo aircraft operations contributed substantially less NO_x and are not a significant source of this pollutant in California.

Exhibit 3-2

Heavy-Duty Truck Emissions Distribution by GVW Class (1987)

Truck Class	NOx (Tons/Day)	ROG (Tons/Day)
Gasoline	149	105
Light-Heavy	89	56
(% of Total Gasoline)	60%	53%
Medium-Heavy	59	49
(% of Total Gasoline)	40%	47%
Diesel	473	69
Light-Heavy	9	1
(% of Total Diesel)	2%	2%
Medium-Heavy	62	9
(% of Total Diesel)	13%	13%
Heavy-Heavy	402	59
(% of Total Diesel)	85%	85%

Source: California Air Resources Board, L. Hrynchuk

Exhibit 3-3

Adjusted Emissions Contributions by Freight Mode (1987)

Freight Mode	NO_x (Tons/Day)	Percent of Total	ROG (Tons/Day)	Percent of Total
Rail	155	20%	7	6%
Truck*	402	52%	68	60%
Water	186	24%	12	11%
Air	27	3%	26	23%
Total	771		112	

* Only includes diesel trucks weighing over 33,000 lbs. GVW.

3.1.5 Relative Modal NO_x Emissions in California

The relative NO_x emissions from the four freight transport modes are compared in Exhibit 3-4. Railroad locomotives contributed approximately 20 percent of the 1987 California NO_x emissions from the four modes representing the freight transportation sector. They also contribute about 6 percent of mobile source NO_x emissions and about 4 percent of total NO_x emissions.

Of the four competing freight shipping modes, heavy-heavy-duty diesel trucks (i.e., diesel trucks weighing over 33,000 pounds GVW) contribute the greatest percentage of NO_x emissions; nearly 52 percent of the NO_x emissions from the four freight-shipping modes and almost 12 percent of all NO_x emissions in the state. Truck lines are also the primary competitor with railroads for freight revenues. Therefore, the modal diversion analysis only considers the possibility of diversions between these two modes. As shown in Exhibit 2-3 (see Section 2), heavy-heavy-duty diesel vehicles accounted for almost 60 percent of rail-truck competitive freight transport in 1987.

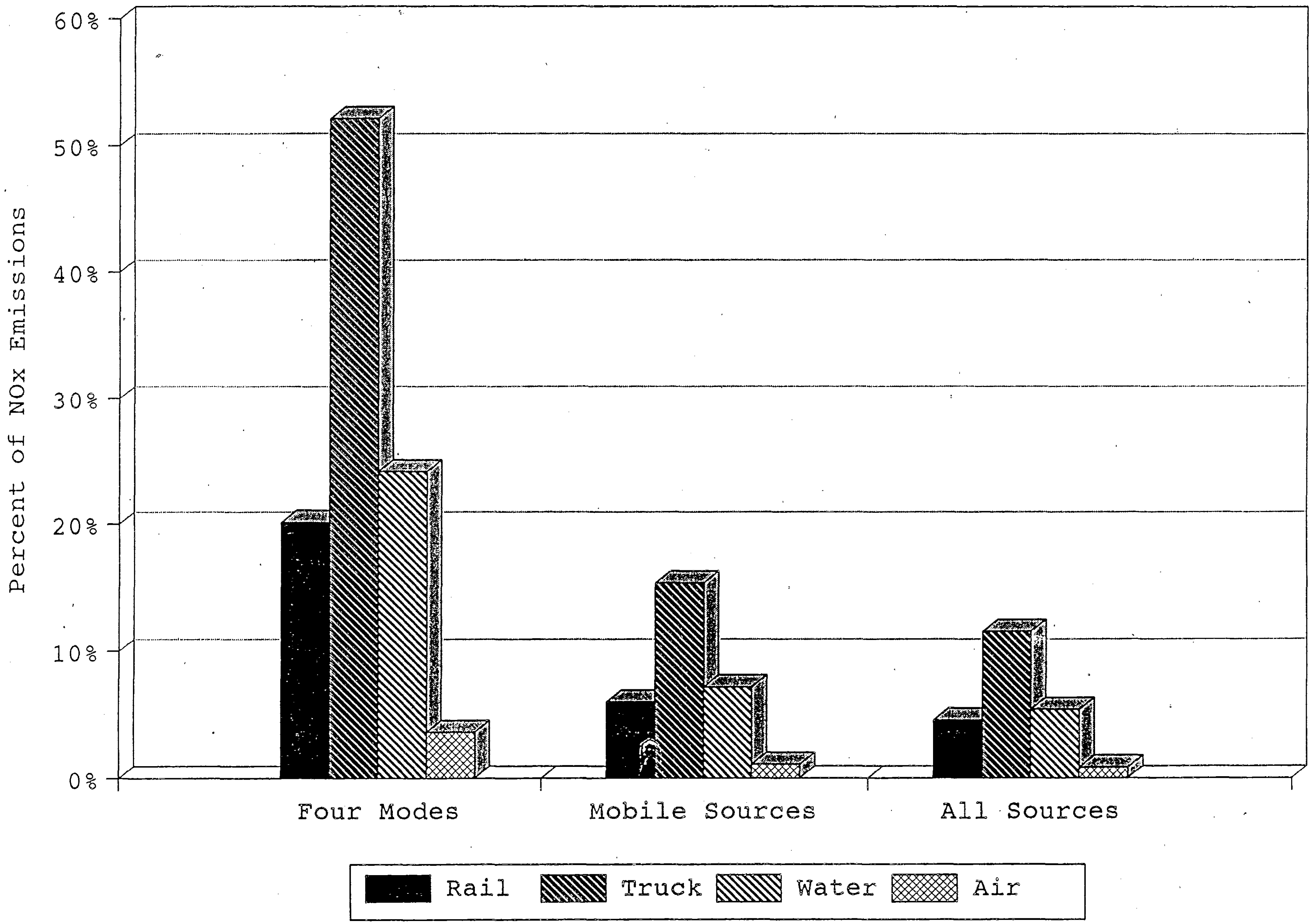
If NO_x emissions from locomotives could be totally eliminated, this would reduce airborne NO_x levels by about 4 percent—a worthwhile, but not dramatic reduction. There is clearly a greater potential to improve California's air quality by reducing NO_x emissions from heavy-heavy-duty diesel trucks. Imposing emissions caps on railroads can only be justified, therefore, as a component of a program to reduce NO_x emissions from all significant sources.

Marine vessels operating in California waters contribute slightly greater estimated NO_x emissions than locomotives and are therefore good candidates for control measures. Ships offer more flexibility for accommodating the weight and volume of emissions control hardware than trucks and locomotives. On the other hand, enforcing emissions limits on ships is probably more difficult than for any other mode. Nonetheless, such efforts are underway. The potential for diversion of freight from rail to ships, however, is judged in this study to be small.[4]

Overall, civil aircraft contribute only about 3 percent of the NO_x emissions from the four modes, and the majority of those emissions are from passenger operations. Air freight operations are therefore not a significant source of NO_x emissions in California. Furthermore, because cargos that are typically shipped by rail are very unlikely to be diverted to air freight, aircraft were not considered in the diversion analysis.

[4]It is possible that increased rail costs could cause diversion of marine cargo from California ports to other West Coast ports. The analysis of this possibility is complicated by a variety of factors including the distribution of origins and destinations of the traffic, the relative in-port and ocean costs of shipments to specific locations from different West Coast ports, the mix of commodities shipped from each port and their sensitivity to changes in relative transportation costs, the availability of facilities (e.g., berthing, loading and unloading, harbor depth), and a host of institutional factors including contractual relationships between shippers and carriers, rotations of ports-on-call, and logistical concerns. The consideration of these issues in diversion analysis is beyond the scope of this study, and conjectures regarding the impact of changes in rail freight rates on port diversion cannot be made with any degree of confidence.

Exhibit 3-4
Relative Modal NOx Emissions



3.1.6 Baseline Rail and Truck Emissions per Ton-Mile

Exhibit 3-5 presents truck and rail NO_x emissions on a ton-mile basis. Emissions per ton-mile for truck and rail simply reflect the NO_x emissions contributions of each mode shown in Exhibit 3-3 (converted to a yearly basis) divided by the truck and rail flows derived in Section 2. In this manner, the relative emissions factors can be compared using a common unit (i.e., pounds/ton-mile).

As demonstrated in Exhibit 3-5, in 1987 heavy-heavy-duty diesel trucks emitted almost twice the amount of NO_x per ton-mile than rail. Truck movements emit, on average, 0.009 pounds per ton-mile of freight moved, while rail movements emit 0.005 pounds per ton-mile of freight moved in California. This result has important ramifications when developing emissions control strategies for freight transport in the state. Regulations must be developed that approach emissions control at the system level by accounting for the relative contribution of each mode at the margin. Furthermore, strategies that result in large diversion shifts from rail to truck may be counter productive from the perspective of total freight emissions. These issues are further investigated in Sections 5, 6, and 7 of this study.

3.2 Predicted Rail and Truck Emissions (No New Regulatory Initiatives)

To fully evaluate the effect of locomotive regulations on mode choice and freight emissions (truck and rail), it is necessary to evaluate first rail and truck emissions under a no-control scenario. This ensures that only the marginal changes in mode-specific emissions are evaluated when regulations are imposed, thereby isolating the actual impacts of the regulations.

This sub-section forecasts both rail and truck emissions in 2010 that are solely attributable to growth in activity and changes in the mix of locomotives. The analysis focuses on locomotive emissions, since the central theme of this study is to evaluate the impact of emissions regulations for this mode of freight transport. A detailed description of the methodology used to estimate locomotive emissions is explained in this sub-section. This methodology is used to estimate rail emissions under a no-control scenario and to estimate rail emissions under the various regulatory options that are the focus of Section 5.

3.2.1 Methodologies Considered to Estimate Rail Emissions

Rail emissions in California were estimated with a spreadsheet-based model utilizing actual or estimated data on California locomotive fleet size, locomotive emissions rates, and locomotive utilization. Three methodologies for estimating baseline and future California rail emissions under various regulatory and economic scenarios were evaluated for the present study. As discussed below, each has certain advantages and disadvantages, both related to the degree of detail.

Exhibit 3-5

1987 Rail and Truck NO_x Emissions per Ton-Mile of Freight Moved

	Rail[5]	Truck*
Ton-Miles (millions/year)	24,592	32,717
NO_x Emissions (tons/day)**	155	402
NO_x Emissions (lbs/ton-mile)	0.005	0.009

* According to EMFAC7, the 1987 heavy-duty diesel truck fleet average NO_x emissions rate was 7.83 g/Bhp-hr. The truck emissions estimates shown above reflect this fleet average.

** Numbers may not add up exactly because of rounding.

[5] Includes passenger-related operations. Adjustments are made at the end of this section to isolate freight-related contributions.

Specific Trains (with Average Duty Cycles), Specific Emissions Factors, Proportional Consists— The first approach considered was to adapt the railroad emissions estimation methodology developed by Booz•Allen & Hamilton (Booz•Allen) for the California Air Resources Board (ARB).[6] Booz•Allen collected detailed duty cycle data (i.e., locomotive operating time in each throttle notch) for most of the trains—defined as a typical freight movement over a particular route—operating in the state, and used these data to derive duty cycles for trains where data were not available. Booz•Allen also obtained a significant, though far from complete, body of locomotive emissions factor data (i.e., grams of pollutant emitted per hour in each throttle notch) for many locomotive types. Booz•Allen also collected locomotive roster data and used a simple proportionality approach to determine the average locomotive consist (i.e., the number and types of locomotives used to pull a single train) based on the average trailing tons and the average horsepower per trailing ton for each train and for each California railroad's mix of locomotives. Operational emissions for each train were estimated by multiplying the time in each notch by the emissions factor for that notch for each locomotive (or fraction thereof) in the average consist. The statewide emissions inventory was determined by summing the emissions from each train.

Due to the level of detail in Booz•Allen's analysis, the ARB has endorsed the Booz•Allen estimate over its own estimate. Although it is probably the most thorough analysis of California railroad emissions performed to date, the Booz•Allen study was still forced by the available data to make assumptions and generalizations about the makeup of locomotive consists. It is therefore an aggregate model, despite the level of detail of its segment-by-segment duty cycle data.

Specific Emissions Factors, Average Duty Cycles, Assumed Locomotive Populations — The second approach considered was to adapt an aggregate methodology used by Engine, Fuel, and Emissions Engineering (EF&EE).[7] EF&EE developed average California duty cycles for each major type of railroad operation: linehaul (which included mixed freight and intermodal), passenger, local, and yard/switch. These duty cycles were based on data from the Booz•Allen report, with the addition of an "off" throttle notch to account for time when the locomotive is not running. EF&EE also obtained emissions factor data for representative locomotives and estimated the size of the locomotive population in California. To obtain an hourly emissions rate for each locomotive type in each service type, EF&EE multiplied the time in each notch by the appropriate emissions factor and summed the weighted emissions in each notch. The hourly emissions rate was multiplied by the assumed number of hours the locomotive was in service annually to obtain an annual emissions rate. To obtain a statewide emissions inventory, EF&EE multiplied the annual emissions rates for each locomotive type in each service type by the number of such locomotives assumed to be operating in the state and summed the results.

---

[6]Booz•Allen & Hamilton, *Locomotive Emission Study*, prepared for the California Air Resources Board, August 1991.

[7]Engine, Fuel, and Emissions Engineering, Inc., *Controlling Locomotive Emissions in California: Technology, Cost-Effectiveness, and Regulatory Strategy*, revised final report under California Air Resources Board Contract Nos. A032-169 and 92-917, Engine, Fuel, and Emissions Engineering, Inc., Sacramento, CA, March 29, 1995.

Although this methodology does not evaluate individual route segments like the Booz•Allen methodology, it still results in very similar predictions of statewide emissions. It is also substantially less difficult to implement than the Booz•Allen methodology, particularly if multiple scenarios are to be modeled.

Ton-Mileage Moved, Ton-Mileage-Based Emissions Factor — The third approach considered for this study was to combine the average "pounds of emissions per 1,000 gallons of fuel" factors from the Booz•Allen report with an average ton-mile-per-gallon factor derived by JFA and Abacus Technology from California rail operations data to develop an emissions factor expressed in pounds of emissions per ton-mile.

This is the most highly aggregated approach considered. It is the simplest, but potentially the least accurate.

3.2.2 Methodology Selected for this Study

The Booz•Allen methodology (or at least the resulting emissions estimate) has been officially endorsed by the ARB, making it an attractive approach. The complexity of this methodology, however, makes it prohibitively time consuming given the resources available for the present study. For example, duty cycles cannot be modified, except by manually re-entering time-in-notch data for all 230 track segments in the state. Furthermore, the accuracy gained by using the train-by-train approach is compromised by the assumption of average locomotive consists based on average locomotive rosters and horsepower requirements.

The ton-mile-based approach is attractive for its simplicity, as well as its direct applicability to other shipping modes. Unfortunately, it does not offer enough flexibility to model the effects of specific regulatory and economic scenarios on rail emissions.

The EF&EE-based methodology combines reasonable accuracy with minimal complexity. Like the Booz•Allen methodology, it can directly indicate the effects on emissions levels of changes in locomotive emissions control technologies, locomotive populations, and locomotive duty cycles arising from both regulatory and economic pressures. It can also easily model the effects of changes that only affect a portion of the locomotive fleet. Unlike the Booz•Allen methodology, it does not require extensive manual revisions when input parameters change. Therefore, an approach based on the EF&EE methodology was selected for this study.

However, the limited time and budget available for this study precluded a thorough re-evaluation of all the existing data required as input to the rail emissions model. Input data were therefore obtained from several previous studies.

Baseline California Locomotive Duty Cycles — Baseline average duty cycles for California rail operations were obtained from the EF&EE report. That report adopted these duty cycles from the Booz•Allen report basically unchanged, except that the percentage of an average 24-hour day that a locomotive spends with its engine off was added to the duty cycle.

The baseline California locomotive duty cycles used in this analysis are presented in Exhibit 3-6. Note that the same locomotive may be operated in different types of service. The SD40-2, for example, is used in significant numbers for both linehaul and local service in California. Sufficient information to predict the changes in average duty cycles for the 2010 forecast year was not available for this study.

There is sufficient variability in the factors that determine the actual duty cycle experienced by an individual locomotive on an individual assignment (e.g., trailing tonnage, schedule requirements, etc.), so that obtaining such data would be prohibitively time consuming given currently available data collection methods. For the same reason, such detailed data would probably not be much more representative of a future assignment than the average duty cycles used for this study. As data acquisition and management technologies continue to improve, however, it may one day be practical to collect extensive duty cycle data based on actual operations, perhaps even in real-time. Future studies of rail emissions could benefit from such highly accurate data.

Representative, or Equivalent, Locomotive Types — The locomotive types used in the present analysis include the GP60, SD40-2, F40-PH, and GP38-2 built by the Electro-Motive Division of General Motors (EMD), and the B40-8 built by General Electric Transportation Systems (GE). These locomotives are representative of the most common types in the fleets of California railroads. Although there are a substantial number of other locomotive types used by the California railroads, most are derivatives of these models and would be expected to produce similar (though not identical) emissions. As a result, locomotive populations developed in this analysis reflect the assumption that the locomotive models described above are representative of the total state population. Populations derived on this basis are referred to as *equivalent* populations in this study.

The methodology used for this study can accommodate a larger number of locomotive types, and emissions factor data were available for some of them. It was not, however, deemed necessary to include this level of detail, considering the unavoidable magnitude of the other uncertainties in the input data and assumptions, as well as the limited budget for this study.

Emissions Factors — Baseline locomotive emissions factors were obtained from the EF&EE report. That report, in turn, obtained emissions factors from a report by the Association of American Railroads (AAR)[8], from the Booz●Allen report, and from data compiled by Caltrans

[8]Conlon, Peter C.L. (1988), ***Exhaust Emission Testing of In-Service Diesel-Electric Locomotives, 1981 to 1983***; AAR Publication R-688.

Exhibit 3-6

Baseline California Locomotive Duty Cycles

Throttle Notch	Percent Time in Notch			
	LINEHAUL	LOCAL	YARD/SWITCH	PASSENGER
off	23.0%	35.8%	31.6%	41.4%
brake	6.1%	1.2%	0.0%	0.4%
idle	39.7%	47.1%	55.4%	29.7%
1	3.0%	2.9%	3.2%	0.0%
2	3.2%	2.7%	3.2%	0.0%
3	3.1%	2.6%	2.2%	6.2%
4	3.9%	2.2%	2.2%	6.0%
5	3.1%	1.4%	0.8%	4.0%
6	2.9%	1.1%	0.4%	2.9%
7	2.2%	1.0%	0.0%	1.1%
8	9.9%	2.1%	0.9%	8.3%
	100%	100%	100%	100%

Source: EF&EE, Controlling Locomotive Emissions in California:
Technology, Cost-Effectiveness and Regulatory Strategy, March 29, 1995,
Tables 8, 9, 10, and 11.

and the Southwest Research Institute.[9] Some of the emissions factors used are up to approximately 25 percent different than the emissions factors used by Booz•Allen, but as the emissions factors from the more recent EF&EE report are apparently based on more extensive testing than those in the Booz•Allen report, they were selected for the present study.

Modified emissions factors representing the expected NO_x reductions possible with several control technologies were also obtained from the EF&EE report, which again obtained these data from other studies. For the present report, only the most cost-effective NO_x control technologies, as determined by the EF&EE report, were included. These technologies are described in Exhibit 3-7. Exhibit 3-8 presents expected emissions factor reductions with the selected control strategies.

Exhibit 3-9 shows the process by which the annual NO_x emissions of an EMD GP60 locomotive were estimated. Similar spreadsheets for the other representative locomotives are contained in Appendix D. The second column of the spreadsheet contains the average duty cycle data for California linehaul locomotives. The baseline NO_x emissions rates for this locomotive operating in each throttle notch are in the third column, and the emissions rates for locomotives with various control technologies are in the next four columns. The spreadsheet multiplies the time in each notch by the emissions factor for that notch to obtain the weighted hourly emissions rates for each notch, which are in the last five columns. These are summed to obtain the overall weighted average NO_x emissions rate in pounds per hour. This weighted average hourly NO_x emissions rate is multiplied by the number of hours per year, corrected for locomotive availability which accounts for the time a locomotive spends in the shop for scheduled and unscheduled maintenance, and converted from pounds to tons to determine the total annual NO_x emissions from one GP60 locomotive in California linehaul service.

Estimates of Locomotive Population — Estimates of the California locomotive population were developed for the 1987 base year. A second estimate was forecasted for the year 2010. As discussed previously, the estimates are of *equivalent*, rather than actual locomotive populations.

Due to the lack of resources available to perform an estimate of the 1987 California locomotive population, and in the absence of any compelling reason to doubt the EF&EE estimate, its estimate was incorporated into this study. Population estimates by locomotive type are presented in Exhibit 3-10.

The equivalent locomotive population in 2010 was estimated based on Booz•Allen's forecast of future trends in railroad activity, motive power, and supporting technologies. Unfortunately, the Booz•Allen forecast was not presented in a format that cannot be directly applied to the methodology used for this study. Rather, it was expressed as percent increases or decreases in the four general areas of (1) application of rail flange lubrication and aerodynamic improvements, (2) more efficient train dispatching and scheduling, (3) phasing-out of old

[9] Fritz, S.G. (1992), *Exhaust Emissions From Two Intercity Passenger Locomotives*; by Southwest Research Institute; for California Department of Transportation, Division of Rail.

Exhibit 3-7
Selected Locomotive NO_x Emissions Control Technologies

Technology	Description
Dual-Fuel (DF)	Natural gas fuel is mixed with engine intake air; ignition in the cylinder is accomplished by injecting a small amount of diesel fuel near top-dead-center of the piston stroke, as in a conventional diesel engine.
Liquid Natural Gas with Spark-Ignited Engine (LNG-SI)	A spark-ignited (Otto cycle) engine is fueled by natural gas.
Selective Catalytic Reduction (SCR)	A chemical reductant (ammonia or urea) is mixed with the engine exhaust gas; this mixture undergoes a catalyst-promoted reaction, reducing NO_x to harmless N_2 and water (and CO_2 if urea is used as the reductant).
Dual Fuel plus Selective Catalytic Reduction (DF+SCR)	A dual-fuel locomotive is equipped with selective catalytic reduction.

Exhibit 3-8

NO_x Emissions Factor Reductions with Selected Control Strategies

Throttle Notch	NOx Emissions in Notch (lb/hr)			
	Dual-Fuel	LNG-SI	SCR	Dual-Fuel+SCR
off	----	----	----	----
brake	85.0%	85.0%	----	85.0%
idle	----	85.0%	----	----
1	----	85.0%	----	----
2	----	85.0%	----	----
3	85.0%	85.0%	----	85.0%
4	85.0%	85.0%	80.0%	97.0%
5	85.0%	85.0%	90.0%	98.5%
6	85.0%	85.0%	90.0%	98.5%
7	85.0%	85.0%	90.0%	98.5%
8	85.0%	85.0%	90.0%	98.5%

Exhibit 3-9

Emissions Calculation for EMD GP60 Locomotive in California Linehaul Service

Throttle Notch	Percent Time in Notch	NOx Emissions in Notch (lb/hr)					Weighted NOx Emissions in Notch (lb/hr)				
		Baseline	Dual-Fuel	LNG-SI	SCR	DF+SCR	Baseline	Dual-Fuel	LNG-SI	SCR	DF+SCR
off	23.0%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
brake	6.1%	6.8	1.0	1.0	6.8	1.0	0.4	0.1	0.1	0.4	0.1
idle	39.7%	3.4	3.4	0.5	3.4	3.4	1.3	1.3	0.2	1.3	1.3
1	3.0%	10.2	10.2	1.5	10.2	10.2	0.3	0.3	0.0	0.3	0.3
2	3.2%	18.1	18.1	2.7	18.1	18.1	0.6	0.6	0.1	0.6	0.6
3	3.1%	32.8	4.9	4.9	32.8	4.9	1.0	0.2	0.2	1.0	0.2
4	3.9%	37.4	5.6	5.6	7.5	1.1	1.5	0.2	0.2	0.3	0.0
5	3.1%	43.6	6.5	6.5	4.4	0.7	1.4	0.2	0.2	0.1	0.0
6	2.9%	51.6	7.7	7.7	5.2	0.8	1.5	0.2	0.2	0.1	0.0
7	2.2%	74.7	11.2	11.2	7.5	1.1	1.6	0.2	0.2	0.2	0.0
8	9.9%	112.3	16.8	16.8	11.2	1.7	11.1	1.7	1.7	1.1	0.2
Weighted Average NOx Emissions (lb/hr)							20.7	5.0	3.1	5.5	2.7
Annual NOx Emissions (tons)				88% Availability			**79.9**	**19.3**	**12.0**	**21.3**	**10.5**

Exhibit 3-10

Estimated Equivalent California Locomotive Population in 1987

Locomotive Type/ Service Type	Estimated Number in California
EMD GP38-2 / Yard	271
EMD SD40-2 / Local	235
EMD SD40-2 / Linehaul	375
EMD GP60 / Linehaul	70
GE B40-8 / Linehaul	141
EMD F40-PH / Passenger	97

Exhibit 3-11

Changes in 2010 Emissions Inventory Forecast by Booz•Allen (1987 Base Year)

Service Type	Rail Flange Lubrication and Aerodynamic Improvements	More Efficient Dispatching and Scheduling	Locomotive Turnover	Changes in Activity Levels	Total
Yard	0	0	-11%	-36%	-43%
Local	-4%	0	-15%	-12%	-28%
Intermodal	-9%	-3%	-14%	+46%	+11%
Mixed Freight	-9%	-3%	-14%	+2%	-23%
Passenger	-9%	-3%	-14%	+27%	-4%

locomotives and replacement by new ones, and (4) changes in overall activity levels. The Booz•Allen forecast is summarized in Exhibit 3-11. Due to its incompatible format, a number of assumptions had to be made to apply the Booz•Allen forecast to the methodology employed in this study.

Rail flange lubrication, improved train aerodynamics, and better dispatching practices directly improve the efficiency of rail operations, with the result that a given freight movement by rail can be accomplished with a smaller amount of horsepower. This effectively reduces the number of locomotives required to perform a given level of service. Therefore, the percentage of emissions reductions forecast by Booz•Allen due to these factors were instead applied to locomotive population estimates developed in this analysis.

New locomotive types were assumed to be phased in under the following assumptions:

- by 2010, all "2nd-generation" locomotives (e.g., SD40-2) will have been replaced by locomotives equivalent to "3rd-generation" locomotives (e.g., GP60 and B40-8);
- three of these new locomotives will replace four of the older types in linehaul and local service, due to their relative maximum horsepower ratings;
- one-third of these new locomotives will be equivalent to the GP60, two-thirds will be equivalent to the B40-8 (based on the California fleet ratio of these types in 1987); and
- passenger and yard locomotives will be upgraded during rebuild and replace cycles to have 3rd-generation-equivalent emissions.

The first and last of the four assumptions are from the Booz•Allen report. The second and third assumptions were necessary for this study. The number of new locomotives that replaced older types was added to the forecast populations of these types that would be expected from changes in efficiency and activity, even without any overall turnover of locomotive types in the fleet. In contrast to the situation for linehaul and local freight locomotives, passenger and yard locomotives would not likely be replaced by 4,000 horsepower freight locomotives. Their baseline emissions factors were, therefore, simply adjusted downward by 15 percent to make their emissions essentially equivalent to 3rd-generation freight locomotive types, as forecast by Booz•Allen.

Booz•Allen provided separate estimates of changes in activity levels for intermodal and bulk/ mixed freight operations. Because these service types were lumped together as "linehaul" service, it was necessary to apportion the changes in activity to the two types. This was accomplished by dividing the estimate derived in this analysis of the number of locomotives in linehaul service into intermodal and mixed subgroups based on the 57/43 ratio of 1987 base year emissions estimated by Booz•Allen. The activity adjustments were then made to these subgroups, and then the subgroups were re-combined to obtain the total forecast linehaul fleet in 2010.

The result of applying these assumptions to the assumed equivalent 1987 base year locomotive population yielded a forecast of the equivalent California locomotive population in 2010. This forecast is presented in Exhibit 3-12.

3.2.3 Rail Emissions Under a No-Control Scenario

Using the methodology described above, baseline California rail emissions were estimated for the 1987 base year and emissions were forecast for the year 2010 under a no-control scenario.

1987 Rail Emissions — For comparison purpose, the total annual California locomotive NO_x emissions predicted by the model for the 1987 base year were 57,128 tons (or 156.5 tons/day). Contributions from each type of locomotive are shown in greater detail in Exhibit 3-13. The model's prediction is within two percent of Booz•Allen's estimate of 58,248 tons (or 159.6 tons/day), lending credibility to both methodologies. The estimate of base year rail emissions is also very close to the ARB's estimate of 155 tons/day (see Exhibit 3-3), which is based on the methodology developed by Booz•Allen. The difference between these estimates is smaller than the likely uncertainty in the input data.[10]

2010 Rail Emissions — The forecast California locomotive NO_x emissions in 2010, under a no-control scenario, is 57,583 tons (or almost 158 tons/day). Contributions from each type of locomotive are shown in greater detail in Exhibit 3-14. The 2010 emissions forecast represents an increase of less than one percent over the 1987 base year emissions estimate. It suggests that technical and operational improvements (aerodynamics, dispatching, etc.) will combine with the decreased activity expected in the local and yard sectors to offset increases in emissions from the anticipated increase in linehaul activity, particularly in relatively pollution-intensive intermodal operations. These factors also account for the reduction in locomotive emissions per ton-mile of freight moved. As shown in Section 2, rail is expected to account for 36,541 million ton-miles of freight by 2010 under a no-control scenario (see Exhibit 2-4). Consequently, rail is expected to emit 0.003 pounds of NO_x per ton-mile in 2010, a decrease of 40 percent from the 1987 baseline of 0.005 pounds of NO_x per ton-mile (see Exhibit 3-5).

It should be noted that Booz•Allen's emissions forecast for 2010 is approximately 10 percent less than the estimate developed in this analysis. This can be attributed primarily to the lower hourly emissions factors that Booz•Allen used for the 3rd generation locomotive types (GP60 and B40-8), which are anticipated to dominate the railroads' future fleets. As discussed before, the emissions factors used for this study were based on more recent and numerous locomotive emissions tests and were therefore judged to be more reliable than those used by Booz•Allen.

[10] Note that the estimate shown in Exhibit 3-13 of 156.6 tons/day includes NO_x emissions from passenger operations. Freight-related rail emissions are estimated to be 134 tons/day in 1987. On a ton-mile basis, this translated to 0.004 pounds/ton-mile.

Exhibit 3-12

Forecast Equivalent California Locomotive Population in 2010

Locomotive Type/ Service Type	Estimated Number in California
EMD GP38-2 / Yard	174
EMD GP60 / Local	50
GE B40-8 /Local	100
EMD GP60 / Linehaul	175
GE B40-8 / Linehaul	353
EMD F40-PH / Passenger	109

Exhibit 3-13

Estimated Unregulated California Railroad NO_x Emissions in 1987

Locomotive and Service Type	Emission Control Strategy	Assumed Number in California fleet	Annual NOx Emissions per Locomotive (tons)	Total Annual NOx Emissions (tons)
EMD GP38-2 / Yard	Baseline (Diesel)	271	16.0	4332.3
	Dual-Fuel LNG		8.8	0.0
	LNG-SI		2.4	0.0
	SCR		10.0	0.0
	DF+SCR		7.9	0.0
EMD SD40-2 / Local	Baseline (Diesel)	235	24.1	5665.5
	Dual-Fuel LNG		10.0	0.0
	LNG-SI		3.6	0.0
	SCR		11.4	0.0
	DF+SCR		8.1	0.0
EMD SD40-2 / Linehaul	Baseline (Diesel)	375	58.1	21768.9
	Dual-Fuel LNG		14.6	0.0
	LNG-SI		8.7	0.0
	SCR		16.1	0.0
	DF+SCR		8.3	0.0
EMD GP60 / Linehaul	Baseline (Diesel)	70	79.9	5594.3
	Dual-Fuel LNG		19.3	0.0
	LNG-SI		12.0	0.0
	SCR		21.3	0.0
	DF+SCR		10.5	0.0
GE B40-8 / Linehaul	Baseline (Diesel)	141	81.2	11443.8
	Dual-Fuel LNG		15.1	0.0
	LNG-SI		12.2	0.0
	SCR		15.6	0.0
	DF+SCR		5.3	0.0
EMD F40-PH / Passenger	Baseline (Diesel)	97	85.8	8323.0
	Dual-Fuel LNG		31.5	0.0
	LNG-SI		12.9	0.0
	SCR		34.1	0.0
	DF+SCR		23.8	0.0
Total Annual California Railroad NOx Emissions (tons)				**57127.7**

Exhibit 3-14

Forecast Unregulated California Railroad Emissions in 2010

Locomotive and Service Type	Emission Control Strategy	Assumed Number in California fleet	Annual NOx Emissions per Locomotive (tons)	Total Annual NOx Emissions (tons)
EMD GP38-2 / Yard	Baseline (Diesel)	174	13.6	2364.4
	Dual-Fuel LNG		7.5	0.0
	LNG-SI		2.0	0.0
	SCR		8.5	0.0
	DF+SCR		6.7	0.0
EMD GP60 / Local	Baseline (Diesel)	50	32.5	1623.9
	Dual-Fuel LNG		12.7	0.0
	LNG-SI		4.9	0.0
	SCR		15.1	0.0
	DF+SCR		10.1	0.0
GE B40-8 / Local	Baseline (Diesel)	100	30.1	3009.6
	Dual-Fuel LNG		7.4	0.0
	LNG-SI		4.5	0.0
	SCR		9.1	0.0
	DF+SCR		4.2	0.0
EMD GP60 / Linehaul	Baseline (Diesel)	175	79.9	13985.7
	Dual-Fuel LNG		19.3	0.0
	LNG-SI		12.0	0.0
	SCR		21.3	0.0
	DF+SCR		10.5	0.0
GE B40-8 / Linehaul	Baseline (Diesel)	353	81.2	28650.1
	Dual-Fuel LNG		15.1	0.0
	LNG-SI		12.2	0.0
	SCR		15.6	0.0
	DF+SCR		5.3	0.0
EMD F40-PH / Passenger	Baseline (Diesel)	109	72.9	7949.7
	Dual-Fuel LNG		26.8	0.0
	LNG-SI		10.9	0.0
	SCR		29.0	0.0
	DF+SCR		20.2	0.0
Total Annual California Railroad NOx Emissions (tons)				**57583.4**

The results of this analysis suggest that California rail emissions will remain essentially unchanged in the future. Predicted increases in linehaul activity will be offset by decreased local and switching activity and technological improvements that will increase the efficiency of all rail operations.

This estimate for the year 2010 is reasonably close to the Booz•Allen estimate for that year. The roughly 10 percent difference is smaller than the difference in emissions factors used for some locomotive types in the two studies. Because both the model developed for this study and the Booz•Allen model require several steps of calculation, small uncertainties in the input parameters of either model produce larger uncertainties in the results. To generate truly accurate estimates of locomotive emissions, it is essential to ensure that the most accurate duty cycle, emissions factor, and activity (population) data are collected.

3.2.4 Truck Emissions Under a No-Further-Control Scenario

Although various regulatory initiatives have been suggested to further control NO_x emissions from heavy-duty diesel vehicles, an assessment of future NO_x emissions from these vehicles is needed that reflects changes that are solely attributable to growth in activity. A rudimentary approach is employed to estimate heavy-heavy-duty diesel truck NO_x emissions for 2010 under a no-further-control scenario. This is due to the scope and focus of this study on rail and associated resource allocation priorities.

As shown in Exhibit 3-5, NO_x emissions from trucks operating in California during 1987 contributed 0.009 pounds/ton-mile of freight moved. This contribution reflects a fleet average NO_x emissions rate of 7.83 grams/Bhp-hr, as estimated by EMFAC7, and the prevailing NO_x standard during that year of 6 grams/Bhp-hr. In 1991, the NO_x standard was reduced by the ARB to 5 grams/Bhp-hr, and EMFAC estimates the 2010 fleet average NO_x emissions rate to be 4.6 grams/Bhp-hr—not including the proposed drop in the standard to 4 grams/Bhp-hr in 1998. Furthermore, by 2010 many technologies may be incorporated that affect truck emissions rates during a given trip. For example, aerodynamic improvements that are implemented to reduce fuel consumption may have emissions reduction consequences on a grams/Bhp-hr basis. Improvements in fuel management may also result with decreases in emissions rates. These technologies, as well as others that are deployed to comply with more stringent standards, will penetrate the fleet slowly since the operational life of a heavy-heavy-duty diesel truck often exceeds 10 to 15 years. Consequently, this analysis assumes that, on average, heavy-heavy duty diesel trucks will emit NO_x at a rate of 5 grams/Bhp-hr (i.e., the prevailing standard).

Assuming that the percentage change in average emissions from 7.83 to 5 grams/Bhp-hr holds on a ton-mile basis, trucks are expected to emit 0.006 pounds/ton-mile of freight moved in 2010 under the no-further-control scenario. Using this study's forecast for heavy-heavy-duty diesel truck ton-mileage in 2010 of 52,148 million, it is estimated that these vehicles will contribute roughly 410 tons/day of NO_x emissions during that year.

4. Review of Mode Shift Models

The principal objective of the study of the economic impacts of proposed locomotive emissions regulations in California is to determine how increased costs of rail freight transportation due to emissions regulations would impact freight movement patterns in the state. Ultimately, impacts on the amount of cargo shipped through California, the modal choice for these shipments, and the relative emissions characteristics of each mode are the significant factors which will determine how changes in the goods movement marketplace due to locomotive emissions regulations will affect overall emissions from freight transportation. In this study, the primary focus is on the extent to which locomotive emissions regulations might cause diversion of freight traffic from rail to trucks. This diversion from rail could occur if the cost of complying with new emissions regulations raises rail rates relative to other modes. It could also occur if rail shipments have to stop at the California border to switch to locomotives with lower emissions rated and these delays are perceived by customers as a reduction in the level of service from the railroads. If freight transportation diverts from rail to another mode which has higher emissions per ton-mile than does rail, the net effect of the regulations may not be a significant reduction in emissions. It is the ARB's intent to investigate this possibility prior to implementing any new regulations.

While the potential for new regulations to cause diversion from rail to other modes is the focus of this study, locomotive emissions regulations could cause other changes in the goods movement marketplace that are significant. These impacts include:

- increased rail costs or decreased level of service could cause diversion of international trade from California ports to other West Coast ports;
- increased rail costs could change intermodal shipment patterns by displacing truck-rail transfer points to locations out of state; and
- increased rail costs could cause substitution of non-transport factors for transportation—for example, companies could relocate to reduce transportation requirements or they could invest in new equipment to produce parts internally that were previously out-sourced in order to eliminate high transportation costs.

While these impacts are mentioned here, they are considered to be outside the scope of the current study. These impacts are difficult to analyze with existing models and data bases and would require significant resources beyond those available for this study. Thus, the primary focus of the study is on modal diversion impacts.

The purpose of this section is to present a review of studies and modeling approaches which address modal diversion and to assess the applicability of these studies and models to the current effort. In order to accomplish this task, a comprehensive review of the literature was conducted. The literature review focused on the following topics.

- Modal diversion models and studies. Specifically, models that could be used to estimate diversion of freight traffic from rail to truck given changes in rail costs or level of service. Modal diversion models that could be re-estimated using more current data were also investigated.

- California commodity flow data with some level of origin-destination and modal share detail which could be used to either re-estimate non-California models or as input data into existing models in order to adjust these models to better reflect California freight transportation markets.

- Techniques both for developing base year commodity flows by mode and for forecasting those freight flows.

Two major sources were used to conduct the literature review. The first was a review of *Memorandum on Past and Current Efforts Related to Intermodal Goods Movement*, which was prepared by Mercer Management Consulting, Inc. for the Southern California Association of Governments (SCAG) Interregional Goods Movement Study. This memorandum contains a detailed bibliography of studies on this subject. The memorandum was reviewed to determine the most relevant literature, and efforts were made to obtain as many of these studies as possible. In addition, a thorough literature search was conducted using the University of California's MELVYL bibliographic search system and reports were obtained from the University of California-Berkeley's Institute for Transportation Studies library. A search was also conducted through the Washington Resource Library Consortium.

4.1 Overview of Modal Diversion Models

Based on the literature review, a number of mode choice models were identified as candidates for use in this study. The models are categorized based on the two major types of mode choice models as described above—aggregate models and disaggregate models.

4.1.1 Aggregate Mode Choice Models

California Freight Energy Demand Model — One of the most significant freight forecasting projects which deals specifically with California goods movement is the California Energy Commission's Freight Energy Demand Model (CALFED) which was developed by Jack Faucett Associates in 1983. This model projects VMT by mode and rail-truck modal diversion as part of an overall framework for forecasting freight energy consumption. It was the original intent of JFA to use the modal diversion component of this model to project impacts of the proposed locomotive emissions regulations. Thus, the focus here is an explanation of the modal diversion techniques and their applicability to the current effort.

CALFED disaggregates freight flows in California by 16 commodity/activity categories, five sub-state regions, and six origin-destination (O-D) regions. These are illustrated in Exhibits 4-1, 4-2, and 4-3. Modal diversion is determined as a function of the relative cost of rail and trucking. Diversion is calculated for each commodity and each O-D region. A parameter that measures the sensitivity to service cost (i.e., rail costs as compared to truck costs) has been calculated for each commodity and this is applied to the change in the rail cost advantage per ton-mile for transport of each commodity to or from each O-D region. This parameter is a measure of how much the rail share (expressed in terms of ton-miles) of the shipments of a given commodity will change for every dollar change in the rail cost advantage per ton-mile as compared to truck costs. An adjustment is made which takes into account the current mode split for each commodity shipped between each O-D pair. Thus, flows which have a relatively even mode split are assumed to be very competitive and the sensitivity to each mode's cost of service is the major determinant of mode shift when the relative costs of rail and trucking change. Whereas, flows which are dominated by one mode or the other are less competitive and experience less relative diversion in response to a change in rail or trucking costs. Aside from this adjustment (which implicitly takes into account the importance of non-cost variables on the historic mode split for a given commodity shipped between a given origin and destination), the CALFED modal diversion algorithm only considers explicitly the impacts of changes in the relative costs of rail and trucking and does not consider the impacts of changes in other service variables, such as time delays that might be associated with changing locomotives to comply with California locomotive emissions regulations.

The key parameter in this model is the sensitivity to each mode's cost of service. In order to estimate this parameter for each commodity, JFA used the following data for shipments of each commodity group originating and/or terminating in California.

- Data from the 1977 Commodity Transportation Survey (CTS) were used to determine the mode share for truck and rail at each length of haul. That is, for commodity x, the CTS data were used to determine what percent of traffic traveling a distance of y miles was carried by rail and by truck.

- Data from the CTS were also used to develop a density function specifying the fraction of <u>all</u> freight transported at each length of haul. If the analyst knows the total amount of freight shipped in California for a particular commodity group, this density function can be used to determine how much of that commodity was shipped for a particular length of haul (say, 500 miles). If the information described above which determines the mode share at each length of haul is multiplied by the total freight shipped at each length of haul, the amount of freight shipped by each mode can be determined.

- Data from the 1977 Federal Railroad Administration (FRA)/ICC waybill files for similar types of shipments as described above were used to develop a rail cost curve which indicates the rail cost per ton-mile at each length of haul.

Exhibit 4-1

CALFED Commodity/Activity Categories

Agriculture

Construction and Mining

Timber and Lumber

Food Products

Paper Products

Chemicals

Primary Metals

Machinery

Other Manufacturing

Household Goods Movement

Motor Homes

Retail Trade

Wholesale Trade

Utilities

Services

Personal-Use Trucks

Exhibit 4-2

California Sub-state Regions Used in CALFED
(Counties contained in each region)

<u>San Francisco</u>

Alameda
Contra Costa
Marin
San Mateo
Santa Clara
Solano
Sonoma
San Francisco

<u>Los Angeles</u>

Los Angeles
Orange
Riverside
San Bernardino

<u>San Diego</u>

San Diego

<u>Sacramento</u>

El Dorado
Placer
Sacramento
Yolo

<u>All Other Counties</u>

Exhibit 4-3

Origin-Destination Regions Used in CALFED

California (Intrastate)

Arizona

Nevada and Utah

Oregon and Idaho

Washington and Montana

The 40 remaining contiguous states

The CALFED documentation[11] describes an approximating procedure which uses the above described data to determine the change in freight shipped by rail for a unit change in the cost advantage of rail relative to truck.

This approach incorporates several important features which determine mode choice. First, by computing the parameter separately for each commodity, the methodology takes into account commodity characteristics which create a preference for one mode relative to another. That is, some commodities are more sensitive to the service characteristics of each mode than they are to cost of service. Second, the methodology takes into account the sensitivity of mode choice for each commodity to the length of haul. That is, longer-haul shipments are more likely to travel by rail than are short-haul shipments. The cost advantage of rail as compared to trucking also tends to increase with length of haul. Third, by computing the mode cost sensitivities using actual mode share data from California, the methodology implicitly takes into account the unique service characteristics of each mode in California, given the flow patterns that were present in California when the shipment data were collected.

Babcock and German's Changing Determinants of Truck-Rail Market Shares — The primary focus of Babcock and German's study was to determine the impact of deregulation on truck and rail market shares at the national level. Two equations are estimated separately for the periods before and after deregulation. For each period, each equation was also estimated separately for seven two digit manufacturing groups.

The equations were estimated using ordinary least squares and specified rail market share as a function of relative rail and truck rates, the nominal interest rate, and relative services. The equations estimated for the post deregulation period also included yearly dummy variables to measure the effects of deregulation and changes in the truck size and weight regulations. Rail market share in all of the equations was defined as rail tons divided by total production. Any change in this ratio was interpreted as diversion to/from trucking. Rates were defined as revenue per ton-mile for all of U.S. traffic for truck and revenue per ton for rail. The authors proxy truck and rail services with interstate highway miles as a percent of total highway miles and average daily freight car miles, respectively.

This model was estimated for the entire U.S. with no origin-destination pairings or length of haul distinctions. The truck and rail rates the authors used are suspect because they employ different units for rail and truck, they assume that trucking rates do not differ by commodity, and they use national rates without O-D detail, which does not account for local variations or distance of haul. For these reasons, the parameters that they estimated could not be used for the current effort. Estimating a new model would be possible, although it would be time consuming and it is unclear whether it would yield satisfactory results. This approach was ultimately rejected for use in this study.

[11] *California Freight Energy Demand Model: Final Report*, Jack Faucett Associates, for the California Energy Commission, June 1983.

Friedlander and Spady: A Derived Demand Function for Freight Transportation — Friedlander and Spady model the demands for truck and rail services to deliver outbound goods as factors in the production process. Their approach estimates a system of non-linear equations which calculate the total cost of production for an industry and the share of total costs which each input in the production process comprises. The equations included rail cost share equations and truck cost share equations to represent transportation inputs. The equations included among their independent variables truck rates and rail rates. Thus, if rail rates were increased, the model could be used to determine the change in the rail cost share and the truck cost share for a given industry. The model does include service characteristics, such as value of shipment, density of commodity, average length of haul, and average shipment size, as variables but only as determinants of inventory costs and not as determinants of rail or truck costs.

While this model is one of the most sophisticated reviewed as part of this study, and probably rests on the most secure theoretical foundation, there are a number of issues that would make it difficult to use for this effort. The biggest problem is that the model estimates diversion from rail to truck in terms of changes in cost share for each industry (i.e., for a particular industry if you raise the rail rates the model will tell you how much the industry spends on rail transportation and how much it spends on truck transportation, compared to how much it spent before the increase in rail rates). These cost share changes are difficult to translate into units such as shifts in ton-miles which are necessary to determine the emissions impacts of modal diversion. Another concern is that the parameters were estimated with 1972 data that were not specific to California. For use in this study, the model would have to be re-estimated with data that are not readily available.

Oum: A Cross Sectional Study of Freight Transport Demand and Rail-Truck Competition in Canada — This study is somewhat similar to the Friedlander and Spady study in that the model is based on a system of cost and input demand equations which specifies transportation services used to deliver outbound goods as a factor of production. However, a major difference between the two studies is that Oum estimated his model with cross-sectional data of inter-regional commodity flows rather than regional industry data. For each commodity, truck and rail expenditure shares to deliver a ton on a given link were defined as a function of the modal freight rates on the link, average speeds of the modes on the link, reliability of the modes on the link (i.e., mean transit time or standard deviation of transit time), and distance of the link. This aspect of the model is somewhat appealing. Unfortunately, the model parameters were estimated using 1970 vintage Canadian data. The model would need to be re-estimated for California with data that are generally unavailable without additional survey work.

University of Montreal Box-Cox Logit Model of Intercity Freight Mode Choice — In recently published work[12], Picard and Gaudry of the University of Montreal, describe an approach to calculating mode choice which applies the Box-Cox transformation to explanatory variables in

[12]Picard and Gaudry, *A Box-Cox Logit Model for Intercity Freight Mode Choice*, Centre de Recherche sur les Transports, Universite de Montreal, September 1993.

a logit model.[13] The Box-Cox transformation is thought to be an improvement over the linear logit form because the impact of a unit change in any of the independent variables changes in a non-linear fashion depending on the value of the independent variable when the change is made. Thus, for example, the impact of a $1 increase in shipping rates is greater for a $50 shipment than for a $100 shipment.

The models estimated by Picard and Gaudry include freight charges and transit time as the independent variables. The models were estimated for Canadian freight flows in 1979. Picard and Gaudry constructed intercity commodity flows for 64 commodity groups using aggregate interprovincial flow data which were disaggregated to the intercity level using input-output techniques and a modified gravity model. Transportation fares and travel times were estimated from regression equations.

While this model provides some useful improvements over earlier aggregate models, it is estimated with Canadian data and these data are as out-of-date as those used by the CALFED model.

4.1.2 Disaggregate Mode Choice Models

The Association of American Railroads (AAR) Intermodal Competition Model (ICM) — The AAR ICM was originally developed at the Massachusetts Institute of Technology (MIT) by Chiang, Roberts, and Ben-Akiva.[14] The model uses a logit formulation to predict mode choice probabilities for each shipment in a sample of shipments. A weighted sum of these probabilities based on the distribution of shipments in the sample, provides an estimate of market share for each mode. The utility functions in the model are a function of transport rates, storage costs,

---

[13]The logit model is often used to estimate a variable which is a proportion (for example, mode share). This is a non-linear functional form that is used when it is believed that the impact of a unit change in an independent variables does not have a constant impact on the proportion being estimated. The standard form of the logit model for two choices is:

$$S = \frac{exp U_1}{exp U_1 + exp U_2}$$

where $U_1 = a_0 + a_1 X_1^b$
$U_2 = a_2 X_1^b$

are called utility functions, and there can be as many explanatory variables X_n as are necessary. If the parameter b=1, the equation is called the linear logit form, and this applies to a situation in which the impact of the explanatory variable on the share variable, S, is constant over most values of X but which varies as S approaches either 0 or 1. In cases in which the impact of X on S depends on the value of X over all values of X (such as the example provided above for the impact of shipping rates on mode shares), the Box-Cox transformation can be used to convert the terms in the equations for U_1 and U_2 to non-linear terms for all values of the parameter b.

[14]*Development of a Policy Sensitive Model for Forecasting Freight Demand, Final Report*, Y.S. Chiang, P.O. Roberts, and M.Ben-Akiva, Center for Transportation Studies, Massachusetts Institute of Technology, Cambridge, MA, for Office of the Secretary, U.S. Department of Transportation, December 1980.

capital costs in transit, loss and damage costs, order costs, loss of value in shipment, shipping distance, shipment value, and commodity use rate.

To estimate the model, a detailed disaggregate data base of shipments needed to be developed. In the original formulation of the model, the intercity freight flows were developed from the 1972 Commodity Transportation Survey. The current version of the model has been updated with data on rail and truck flows, some of which are proprietary and collected for AAR. Commodity use rates were developed using data on production and consumption of commodities derived from *County Business Patterns* and input-output methodologies. Originally, transport rates were estimated using a model developed at MIT. In the current version, rail costs are computed using the Uniform Rail Costing System and truck costs are estimated using a detailed truck costing model developed for AAR. Most other level of service attributes are estimated with models based on survey data collected by AAR or others and maintained in proprietary data bases. Commodity attributes, such as value, shelf life, etc., are contained in a commodity attribute file which has been periodically updated for AAR by Roberts.

The model is solved by taking a sample of rail shipments from the ICC Waybill Sample as a starting point. The rail costs for these shipments are then calculated by the model, taking into account any changes in costs associated with the policy scenario being analyzed. The alternative trucking modes are then identified and the AAR WINET model is then used to compute the trucking costs. Total logistics costs for rail and trucking alternatives for each shipment are calculated, and the logit model is used to determine the probability that the shipment will go by rail. The probabilities for each shipment are weighted by the percent of the total tons that each shipment represents in the sample. These weighted probabilities are summed to get the rail share.

The ICM is an attractive mode share model because of the its level of detail and its disaggregate approach. JFA investigated the possibility of using the model, but the AAR was unwilling to provide access to the ICM for contractor use, nor were they willing to run the model for us. The original published version of the model was estimated with data which by now are extremely dated and much of the input data which are necessary to solve the model are in proprietary data bases which were never published (such as the Commodity Attribute File). Because of the level of detail contained in the model, it is infeasible to construct these data files from published sources given the resources available for this project. Given these problems, use of the ICM was rejected for this analysis.

Winston Disaggregated Qualitative Mode Choice Model for Intercity Freight — This model was developed by Winston at the University of California at Berkeley in the late 1970s at the same time that the original version of the ICM was being developed at MIT. As with the MIT work, Winston sought to model shipper/receiver behavior in mode choice using disaggregate probability techniques. His model is estimated using a probit form and includes variables such as shipment size, commodity value, freight charges, transit time, service reliability, location relative to a rail siding, and annual sales as explanatory variables for mode choice.

Sample data used to estimate the model were taken from a variety of sources. Most of these sources date to the 1973-78 period and were applied to a sample of shipments from the 1975-76 period. These data were determined to be too out of date to be useful in the current project, and the Winston model was therefore rejected.

University of Calgary Logit Model for Intercity Goods Movement — This model approaches the goods movement problem in much the same way as does a disaggregate model. The modelers develop a disaggregate data base from aggregate sources and apply the logit probability form. In a manner similar to the University of Montreal work, interprovincial commodity flow data are disaggregated to intercity flows. The data are further disaggregated to determine the number of shipments by commodity in each of several weight groups for each city pair. Using regression equations developed by Oum[15] and Chiang, et al.,[16] travel times are estimated for each mode and city pair based on distances. Freight rates were obtained from the Canadian Tariff Bureau and the Canadian Freight Association.

A logit model was estimated with rail and truck utility functions determined as a function of travel time and the product of freight rates and shipment size. The test model was estimated for meat shipments only using 1981 data from the Statistics Canada Record. While the model is useful for identifying modeling techniques and their reliability, the actual parameter estimates are only for a single commodity and are based on outdated Canadian data. Therefore, this model was rejected.

4.1.3 Other Relevant Studies

There are no comprehensive models which have been identified which forecast freight movement or modal diversion in California. Several studies have been done which forecast growth of traffic for specific modes and facilities. These are discussed below.

Development of A California Freight Network Model: Phase I Report, by Edward C. Sullivan and Juan Manuel Guell-Camacho, University of California, Berkeley, Institute for Transportation Studies, June 1986, reports on Phase I of the subject project. The project attempted to develop a multimodal freight network model for California. The project chose to adapt the Princeton Transportation Network Model and Graphics Information System (PNTM/GIS) to California conditions. Ultimately, the project intended to "enhance the network to include explicit representation of routes and service frequencies and capacities of established rail and trucking routes, and implement a path-building and traffic assignment procedure which splits traffic among the different available services on the basis of prevailing costs, travel times, and service frequencies. By accomplishing this, the assignment routine applied to the multi-modal network can provide a simultaneous solution to both the mode and route choice problems." At the

[15]T.H. Oum, *A Cross Sectional Study of Freight Transport Demand and Rail-Truck Competition in Canada*, *Bell Journal of Economics 10*, 463-482, 1979.

[16]Y.S. Chiang, P.O. Roberts, and M. Ben-Akiva, *Op Cit.*

conclusion of this phase of the project, work had just begun on adapting and loading the multi-modal network model and work had not begun on developing the mode choice components of the model.

In 1989, Munshi and Sullivan continued the development of the California Freight Network Model where the previous project left off. In *A Freight Network Model for Mode and Route Choice* they describe a procedure for determining mode split between rail and truck as a function of delay time, transit time, and headway of each mode. They reason that for commodities for which rail and trucking compete, tariffs yield similar costs per ton-mile for the two modes and they therefore drop out of the mode split equations. The model was tested by computing mode split for lumber shipments between two Northern California counties and San Diego. Reebie Associates' 1989 **Transearch** data on commodity flows and telephone surveys of sawmills, rail companies, and trucking firms were used to estimate the model. The calculated rail shares tended to be lower than the actual shares and several explanations are offered. After this project was completed, there was no further funding for the California Freight Network Model, and the work was discontinued.

In 1989, the Ports Advisory Committee for SCAG published *International Trade and Goods Movement: The Southern California Experience and Its Future*, which forecasts international trade impacts on the SCAG region. The capacity of the current goods movement corridors and their ability to handle forecasted increases in international trade are discussed. This was not viewed as terribly useful for this analysis because of its local orientation and concern specifically with port intermodal connections. Several similar studies were conducted for the San Francisco Bay Area ports and the San Pedro Bay ports which have similar limitations.

In October 1990, Wilbur Smith Associates conducted *A Study of Goods Movement at Los Angeles International Airport* for SCAG. This study forecasts future growth in air cargo movements at Los Angeles International Airport and establishes a relationship between truck traffic on major arterials and the effects of growth in air cargo on access traffic. This study is too localized to be of use to the current effort and does not deal with modal competition.

There are three other studies that were reviewed which have potential relevance to the development of a modal diversion analysis methodology for use in this project. The first is a study funded by the National Cooperative Highway Research Program (NCHRP) in 1983.[17] In this study, Memmott developed a methodology for freight forecasting which is based loosely on the traditional four-step urban transportation planning process. For the first two steps in the process, trip generation and trip distribution, Memmott proposes a methodology for forecasting commodity flows and assigning these to origin-destination pairs based on economic modeling techniques. These techniques are very similar to the approaches used to estimate baseline commodity flows, which are described in Section 2 of this report. The approach to mode split

[17] *Application of Statewide Freight Demand Forecasting Techniques*, F.W. Memmott, Roger Creighton Associates, Inc., for the National Cooperative Highway Research Program, Report No. 260, Washington, DC, September 1983.

analysis suggests that mode choice be based on the cost differential between competing modes, and the report focuses most of its attention on defining approaches to estimating modal costs for each freight mode. Sparse detail is provided as to methods for determining how costs will influence mode choice in a modeling context. There appear to be no published applications of this methodology and the lack of detail on how to model the cost sensitivity aspects of mode choice make it difficult to apply to the current project. NCHRP is currently funding another study to develop freight forecasting techniques for state departments of transportation and metropolitan planning organizations (MPO). However, this new study will not be completed for another year.

The second study of interest is a truck size and weight study conducted by Sydec, Inc. with assistance from Jack Faucett Associates. This study was conducted for the Federal Rail Administration (FRA) and the Federal Highway Administration (FHWA) in order to examine how changes in the truck size and weight limits on interstate and other major highways would influence the costs of freight movement. A major element of the study was a determination of the effects which increased size and weight limits would have on modal diversion between rail and trucking. Increases in truck size and weight limits will, for the most part, reduce trucking costs for long haul freight movements and this could cause diversion from rail to trucking. For Sydec/JFA's study, the AAR made runs of the ICM to evaluate rail-truck diversion using cost data supplied by Sydec/JFA. Several scenarios were examined. In each case changes in trucking costs were calculated and the corresponding decrease in rail ton-miles was determined. One possible way of using these data would be to plot a relationship between the change in the relative costs of rail and trucking per ton-mile and the rail share of competitive freight movements. This relationship could then be used in this study to determine how rail share would change for a given change in the relative costs of rail and trucking. This approach was not elected for use in this study for several reasons. First, the number of scenarios which could be use to fit the curve is relatively small and the fit to the data is not likely to be very good. Second, the levels of modal diversion calculated in the study are very sensitive to the nature of the scenarios defined and it is not clear that the same relationship between relative costs of rail and trucking and rail share would hold for a different set of scenarios.

The third study of interest is the previously mentioned SCAG Interregional Goods Movement Study which provided a bibliography that was used in the initial identification of modeling methodologies for this project. In April 1995, Mercer Management Consulting released an evaluation of key methodologies for mode choice modeling.[18] The report presents evaluations of 14 mode choice models. Two of these are proprietary models developed by Mercer and these are based on stated preference surveys rather than actual mode choices in the marketplace. Of the remaining 12 methodologies, six are already reviewed in this report. While the remaining six methodologies include some interesting approaches. For the most part these are unacceptable for the following reasons:

[18] *Interregional Goods Movement Study, Task 2C Report: Evaluation of Key Methodologies*, Mercer Management Consulting for Southern California Association of Governments, April 25, 1995.

- they do not address mode choice directly;
- they lack sufficient detail with respect to how critical variables (e.g., non-transport logistics costs) are calculated
- the model parameters were estimated with data that are extremely dated (pre-1977)
- they would require substantial resources to collect new data for inputs and calibration.

For these reasons, and given the late date at which these models were identified, they were not considered for further application in this study.

4.2 Modal Diversion Methodologies: Summary of Key Issues

Exhibits 4-3 and 4-4 provide a critical review and summary of the models that are discussed above. One of the most disconcerting findings to come out of the literature review was that, with the exception of the current AAR model (which is proprietary), few of the models reviewed were estimated with post-1977 data. In the U.S. this is because no comprehensive shipper survey has been conducted since the 1977 CTS. While there are more current data for rail shipments, there are no other shipment data bases for trucking. The U.S. Census Bureau is in the process of disseminating information contained in the 1993 Commodity Flow Survey (CFS) which will replace the old CTS as a primary commodity flow data base. However, these data were not available during the preparation of this report. At present, any current data that can be developed or used to estimate modal diversion has an aggregate nature, meaning that an aggregate model will have to be used for this effort.

Unfortunately, the parameters that were estimated with these models are now all biased because freight markets have undergone tremendous changes since 1977. For instance, the 1980 Motor Carrier Act (MCA) and the 1982 Surface Transportation Assistance Act (STAA) both relaxed federal regulations in the trucking industry. Prior to deregulation, trucking firms competed through levels of service rather than through rates, since rates were regulated. Rates, therefore, probably did not accurately reflect differences in service between truck and rail. After deregulation, however, rates began to more accurately reflect those differences. As a result, the information contained in rate variables today is different than it was in 1977. The STAA also helped to bias parameters estimated in 1977 because it led to efficiency improvements through changes in average shipment sizes.

Another factor contributing to the bias of these parameters is the change in the product mix of aggregate commodity groups that has taken place since 1977. As commodity groups change in consistency from relatively heavy, lower valued goods to relatively light, higher valued goods, the likelihood increases that certain commodities will be hauled by truck.

Exhibit 4-4

Aggregate Models

Model	Variables	Pros	Cons
California Freight Energy Demand Model (1983)	• Transport Cost • Prior Year Mode Split	• Provides O-D detail • Provides commodity detail • Modal cost sensitivities based on length of haul • Based on California shipment data	• Estimated with 1977 CTS data • Does not include time variable or other non-transport logistics costs
Babcock and German: Changing Determinants of Truck-Rail Market Shares (1989)	• Truck and rail rate • Prime interest rate • Truck/rail services • 1982 STAA	• Simple regression • Requires minimum amount of data • Accounts for inventory costs	• National level study: no length of haul, shipment size, or OD distinction. • Can't use parameter estimates • Model is based on time series
Friedlander and Spady: A Derived Demand Function for Freight Transportation (1980)	• Prices and quantities of production inputs • Price and quantity of output • Truck and rail rates • Density, length of haul, shipment size	• Models freight transportation as a factor in production process. • Addresses simultaneity of transport rates, inventory costs, length of haul, and shipment size. • Translog specification	• Estimated with 1972 cross-sectional data of 3-digit manufacturing industries. • Inventory specification suspect • Difficult to implement, especially at BEA regional level
Oum: A Cross Sectional Study of Freight Transport Demand and Rail-Truck Competition in Canada (1979)	• Total tons by commodity by mode for each link • Modal freight rates • Distance of link • Transit time • Reliability	• Freight transportation modeled as input into production process • Designed around same data limitations faced in this study. • Translog specification • Addresses speed, distance, reliability, commodity characteristics. • Feasible to estimate	• Estimated with 1970 Canadian traffic flows • Specification may be more accurate for commodities delivered primarily by private trucks • Assumes constant returns to scale and strict separability of transport related variables
Picard and Gaudry: A Box-Cox Logit Model of Intercity Freight Mode Choice (1993)	• Transport Cost • Transit time	• Provides O-D and commodity detail • Includes important policy variables • Non-linear model	• Estimated with 1979 Canadian data • Difficult to implement; required data are not available

Exhibit 4-5

Disaggregate Models

Model	Variables	Pros	Cons
AAR Intermodal Competition Model	• Transport Cost • Inventory Carrying Cost • Ordering Cost • Loss and Damage Cost • Loss of Value in Shipment • Distance • Shipment Value	• Detailed representation of mode choice with all relevant decision variables • Commodity characteristics and shipment characteristics specified in detail • Focuses on rail-truck diversion • Parameters and commodity attributes estimated with recent data: e.g., rail shipment taken from recent ICC Waybill	• Published version of the model uses 1977 CTS and earlier data sources • Current parameters and commodity attributes are proprietary • Relies on survey data to estimate values of key variables • Most variables are not policy sensitive for ARB analyses
Winston Disaggregated Qualitative Mode Choice Model for Intercity Freight Transportation (1979)	• Shipment Size • Commodity Value • Freight Charges • Transit Time • Reliability of Service • Location relative to rail siding	• Estimates separate models by commodity group • Includes most of relevant service characteristic variables • Estimates rail and truck diversion in both directions	• Parameters estimated with 1975-77 data • Requires survey data to solve model, which are generally unavailable
Sargious and Tam: Data Disaggregation Procedure for Calibrating a Logit Model for Intercity Goods Movement (1984)	• Transport Cost • Transit time • Shipment Value • Length of haul (dummy)	• Simulates a disaggregate approach with disaggregated data • Provides commodity and O-D detail • Includes all key policy variables	• Estimated with 1981 Canadian data for one commodity group • Costly to estimate with U.S. data • The quality of disaggregated data are questionable

Other changes that could have biased parameters estimated in 1977 are the length of haul distributions of commodities. Shifts in these distributions toward longer or shorter hauls will increase the tendency for a commodity to move by rail or truck, respectively. Furthermore, deregulation resulted in changes in the relative costs of truck and rail.

4.2.1 Selecting the Modal Diversion Model

In view of the above considerations, JFA evaluated the possibility of estimating a new model. However, given the resource constraints associated with this project and the improvements in source data which will become available in the next few years, it would not be cost-effective to use this project's funds to develop a new modal diversion model. Besides, both Caltrans and the California Energy Commission have plans to develop new modal diversion analysis capabilities in the next year and the resources available in each of these efforts are very substantial as compared to the current project. After reviewing the available modal diversion models that reported parameters which could be used for the current effort, the CALFED modal diversion algorithm was selected as the most useful modal diversion analysis tool for the present study. There are several obvious advantages of the CALFED model. These are listed below:

- it is based on actual California shipment data;
- mode cost sensitivities are developed by commodity group and thus reflect the unique commodity characteristics which would favor one mode over another irrespective of mode cost (e.g., commodity value, use rate, shelf life, etc.);
- modal diversion is calculated for O-D pairs which reflects the actual production and consumption patterns of California economic regions and their trade relationships with the rest of the nation;
- it uses aggregate shipment data which are the only data readily available without additional survey work;
- it implicitly considers the impact of length of haul on mode choice through the procedure used to calculate the model parameters; and
- it includes a variable which takes into account the current competitive position of rail versus truck for each commodity group which helps offset some of the bias in other model parameters which are estimated with 1977 data.

The one option which was considered the leading alternative to CALFED was the AAR ICM. This model, because of its emphasis on shipper behavior, its highly disaggregate method of choice simulation, its use of current data sources, and its preference by the rail industry, seemed to be a strong candidate for use in this study. The complexity of this model would require that an experienced user be available to actually run the model. JFA approached the AAR to determine if an arrangement could be agreed upon whereby JFA would supply critical model inputs and AAR, or its contractors, would actually run the model. This approach was used by Sydec and JFA for the previously mentioned truck size and weight study. AAR stated that their current policy is to not make the model available for analysis by outside contractors, primarily because they want control over how the results are used. AAR feels that in the past contractors have made extrapolations and modifications of results that violated the theoretical assumptions and methodology inherent in the ICM. Yet, these extrapolations were represented as based on the ICM in order to give them a certain legitimacy. To prevent this from happening in the future, AAR no longer makes the model available and does not provide any documentation on the current version of the model.

Since the ICM was considered the favored analytical tool by the rail industry, it seems appropriate to ask how the results of an analysis conducted with CALFED might compare with results from the ICM. Such a comparison was conducted by JFA for the truck size and weight study.[19] In assessing which model to use for the truck size and weight study, JFA compared cross-elasticities produced by ICM and CALFED for comparable policy scenarios.[20] In order to use any of these comparisons as an indicator of the relative performance of the two models in the analysis of proposed locomotive emissions regulations, the appropriate cross elasticities to use are those associated with scenarios which represent across the board reductions in trucking costs for rail-competitive shipments. This is because locomotive emissions regulations will raise costs on all rail shipments, even those which have low modal cost sensitivities due to the characteristics of the commodities being shipped, such as low value bulk commodities (e.g., coal). The outcome of such a comparison is that the two models produce similar results in order of magnitude: 0.39 for CALFED and 0.52 for ICM.[21]

---

[19]In that study, various changes in truck size and weight regulations were being evaluated with respect to how they would affect the competition between rail and trucking. Various policy scenarios were evaluated which, for the most part, increased truck size and weight limits on different parts of the national highway network. The effect of these regulatory changes in most cases would be to lower the cost of trucking for some types of operations. Thus, competitive traffic might shift to trucking from rail.

[20]These elasticities were defined as the percentage change in rail share due to a one percent change in the truck rate. While cross elasticities are not given explicitly in CALFED, there were sufficient data from the original CALFED report with which to compute cross elasticities for each of the commodity/activity groups in CALFED, as well as a weighted average based on base year ton-mile distributions across commodities.

[21]Unlike the studies referenced above, this study is concerned with the percentage change in rail ton-miles associated with a percentage change in the relative costs of rail and trucking. It is possible to use the cross-elasticities reported above for the ICM and CALFED models to calculate an elasticity which represents the percentage change in rail ton-miles per percentage change in the rail cost advantage as compared to trucking. The same relationship between these elasticities would exist as was demonstrated above for the rail ton-mile to truck cost elasticity (i.e., the elasticity of rail ton-miles to rail cost advantage calculated with CALFED would be 25 percent lower than if it were calculated using ICM data). For example, if a particular decrease in the rail cost advantage relative to trucking caused a 6 percent reduction in rail ton-miles as calculated with CALFED, it should cause an 8 percent reduction in rail ton-miles as calculated with the ICM model. The reader should be reminded, however, that since the elasticities calculated with these models can change depending on how the scenario is specified, the numbers reported herein are only illustrative of how the two models compare.

It is expected that using CALFED will result in an underestimation of modal diversion. The biases outlined above should all bias the parameters downward, since many of the changes since 1977 have increased the tendency of goods to move by truck. As pointed out, one impact of deregulation has been a change in the content of freight rates. Those rates now reflect more information than they did in 1977, which means that modal shares will now be more responsive to changes in them. In addition, if the 1980 MCA or the 1982 STAA reduced the cost advantage of rail proportionately across all lengths of haul, it is likely that trucking has picked up a portion of the longer haul markets. A shift in the distribution of commodities from long haul movements to short haul movements would also bias diversion parameters downward. Such a shift could have occurred if long haul rail movements shifted to intermodal movements. Since intermodal movements in the 1977 data are treated as two separate moves (a long haul rail move and a short haul truck move), a density function determined in like fashion with current data showing more intermodal movements would show an increase in the share of total ton-miles shipped shorter distances at the expense of moves shipped longer distances. The fact that these biases move in the same direction allows a floor to be placed on the estimated amount of diversion. From that point, sensitivity analyses will be conducted in this study to determine a range within which the actual amount of diversion is thought to lie. Sensitivity analyses are presented in Section 5.

One other disadvantage of the CALFED parameters is that they do not incorporate non-transportation costs as explanatory variables for mode share. While transport costs are taken into account in the calculation of the mode cost sensitivity parameters, the impact of changes in these other factors cannot be determined. For instance, the CALFED parameters cannot be used to evaluate a regulatory strategy which causes an increase in the travel time associated with rail. Other aggregate models include transit time in their specification. However, these models are generally estimated with data sets which are inappropriate for the current analysis.

The following section presents the mode choice and associated emissions impacts of proposed locomotive emissions regulations for trains operating in California.

5. Impacts of Locomotive Emissions Regulations

The central purpose of this section is to assess the effects of proposed locomotive emissions regulations on mode choice and locomotive emissions. Currently, locomotives operating in California are not subject to NO_x emissions regulations. The promulgation of regulations is expected to result in changes in the cost of moving freight by rail, possibly leading to an increase in the amount of freight transported via truck. Mode shifts from rail to truck will also impact the emissions contribution of each mode, and possibly result in higher overall emissions levels since, as shown in Section 3, trucks pollute more on a ton-mile basis. However, focusing solely on the impact of locomotive emissions regulations on mode choice and freight emissions ignores the impacts of more stringent future NO_x emissions regulations that likely will be promulgated for heavy-heavy-duty diesel trucks operating in California. Consequently, to fully assess the **net** impact of locomotive regulations on mode choice and emissions, it is necessary to evaluate the impacts of regulatory strategies recommended for each mode.

But before doing so, a more comprehensive description of the CALFED diversion sensitivity parameters employed in this analysis is provided in Section 5.1. As discussed in Section 5.1, CALFED estimates diversion from rail to truck using sensitivity parameters that measure the impacts of the change in the cost advantage (in cents/ton-mile) of transporting freight by rail versus truck. Section 5.2 discusses baseline freight rates for rail and truck from which changes in the relative rates will be determined for each regulatory scenario to calculate the change in the cost advantage needed to determine diversion using CALFED. Section 5.3 presents the regulatory scenarios that are investigated in this study, and estimates the effect of each scenario on rail and truck freight rates. Section 5.4 presents the modal diversion impacts of each regulatory scenario and the associated emissions consequences. Finally, Section 5.5 places confidence intervals on the estimated diversion using sensitivity analysis that adjusts the CALFED mode shift parameters.

5.1 CALFED Modal Sensitivity Parameters

As discussed in Section 4, CALFED determines modal diversion as a function of the relative cost of transporting freight by rail versus truck. The methodology employed in CALFED results in modal sensitivity parameters to which changes in the rail cost advantage are applied to determine diversion from rail to truck. Modal sensitivities were estimated in CALFED for each commodity group, defined in Section 2 of this report, from mode share data for movements originating and/or terminating in California as reported in the 1977 Commodity Transportation Survey (CTS), and from railroad rate data for such movements as reported in the 1977 Waybill files. CALFED's modal sensitivities are shown in Exhibit 5-1 for each of the ten commodities included in the CALFED methodology. The development of these sensitivities is described below.

Exhibit 5-2 shows the generalized effect of distance on transport cost (to the shipper) per ton-mile for rail and truck shipments. Both modes demonstrate economies of scale with increasing

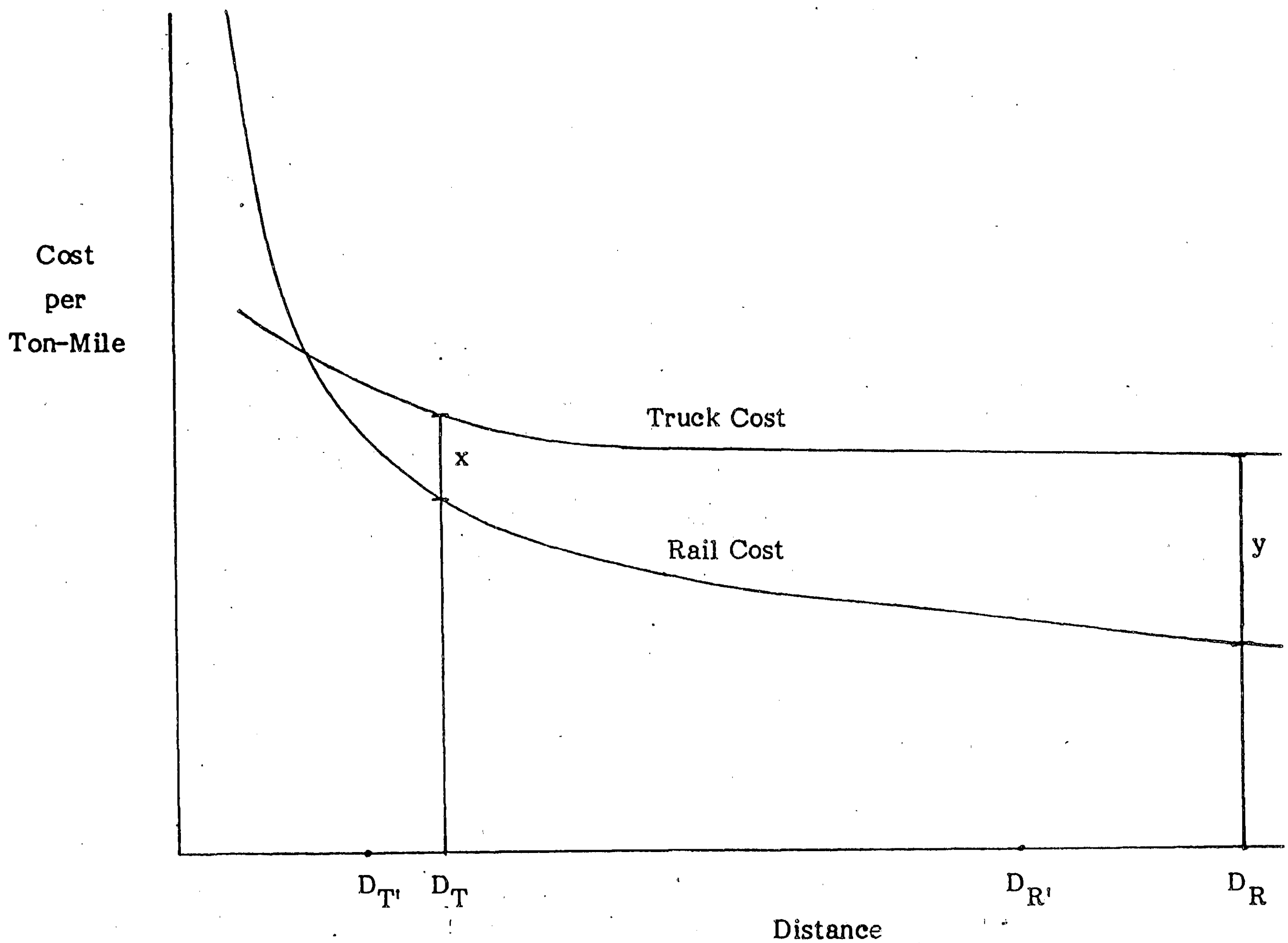
Exhibit 5-1

CALFED's Modal Sensitivity Parameters (per Ton-Mile, in 1977$)

Commodity Group		Modal Sensitivity Parameter
1.	Fruits and Vegetables	0.0268
2.	Other Agricultural Products	0.1201
3.	Minerals and Construction Materials	0.1112
4.	Timber and Lumber	0.0837
5.	Food Products	0.0261
6.	Paper Products	0.0787
7.	Chemicals	0.0568
8.	Primary Metals	0.0263
9.	Machinery	0.0269
10.	Other Manufactured Products	0.0268

Exhibit 5-2

Generalized Rail and Truck Costs per Ton-Mile as a Function of Distance



distance—that is, as distance increases, cost decreases. However, these economies are greater for rail than for truck. The curves shown in Exhibit 5-2 are meant to represent average costs for transporting relatively competitive freight (e.g., freight that can be transported by heavy-heavy-duty diesel trucks or by rail).

As depicted in Exhibit 5-2, for most moderate-size shipments, truck is likely to be the cheaper mode for very short hauls. At distance D_T, the rail cost advantage is represented by x. This cost advantage ensures that rail will compete for hauls moving a distance of D_T—for example 20 percent of ton-miles transported this distance may move by rail and 80 percent may move by truck since D_T represents a relatively short haul. Similarly, for some (but not all) commodity groups there will be a rail cost advantage, y, which corresponds to a distance, D_R, at which there is, for instance, an 80 percent probability that tonnage will move by rail. However, for distances that are less than D_T, rail becomes a decreasingly significant competitive factor and truck is the dominant mode. On the other hand, for distances greater than D_R, truck is decreasingly important and rail becomes the dominant mode. For intermediate distances, both modes are competitive.

Consider next the effect of a change in the cost advantage—for example, an increase in this advantage resulting from either a decrease in the cost of shipping freight by rail and/or an increase in the cost of shipping freight by truck. As the rail cost advantage increases, rail becomes the dominant mode at shorter haul distances, represented by a shift from D_R to D'_R. Likewise, the length of haul required for trucking to be the dominant mode decreases from D_T to D'_T, as shown in Exhibit 5-2. The resulting increase in the rail share of tonnage is approximated through the following equation:

$$\textit{Increase in Rail Share} = \sum_{D=D_T,D_R} \frac{f(D)*\Delta C}{2*(m_{CT}(D) - m_{CR}(D))}$$

where

ΔC = the increase in the rail cost advantage (in cents per ton-mile);
$m_{CT}(D)$ = the slope of the truck cost curve at distance D (in cents/ton-mile);
$m_{CR}(D)$ = the slope of the rail cost curve at D; and
$f(D)$ = a density function specifying the fraction of freight transported D miles.

Recognizing that for all but the shortest distances, the slope of the truck-cost curve is almost zero—that is, the curve is almost flat—the equation described above collapses to the following expression:

$$\textit{Increase in Rail Share} = \sum_{D=D_T,D_R} \frac{f(D)*\Delta C}{2*m_{CR}(D)}$$

This last equation is used in CALFED to estimate the effect of a change in the cost of transport by rail and/or truck on mode shares, as represented by the modal sensitivity parameters shown in Exhibit 5-1. As shown in Exhibit 5-1, the most cost-sensitive commodity groups are "other agricultural products" and "minerals and construction materials", while the least cost-sensitive commodity groups are "fruits and vegetables", "food products", "primary metals", "machinery", and "other manufactured products" which basically represents general freight.

Given that CALFED estimates mode shifts resulting from changes in the relative rates of transporting freight by truck, or more precisely from changes in the cost advantage of rail, which is expressed by

$$\frac{\text{Rail Rate (cents/ton-mile)}}{\text{Truck Rate (cents/ton-mile)}},$$

the impact of emissions regulations on this relative transport cost must be assessed to estimate mode shift in this analysis. Before doing so, however, the baseline freight rates for rail and truck must be determined. These will form the basis from which changes in the cost advantage of rail versus truck will be estimated.

5.2 Baseline Freight Rates (Truck and Rail)

The purpose of this part of the analysis is to collect and analyze information on the rates charged for transport by railways operating in California. Those rates then provide a basis from which to estimate the costs those railways incur in their own operations within the state.

Railway lines consider their shipping rates to be highly proprietary. Limited, if any, specific information about prices and rates are published in trade, business, or scientific journals. As part of this effort, two previous attempts to obtain transport or shipping rate information for California—both by literature reviews and by direct inquiry to the railways—were unsuccessful.

The initial scope of this investigation was limited to rates for shipments within California. However, that scope was extended slightly during the course of this particular effort for reasons explained later in this sub-section.

5.2.1 Railway Shipping Lines

California has three commercial rail transport lines. Each of the three lines has specific rail routes within the state that are closely regulated by government agencies. Customers may transport goods with any one of the lines only along the specific rail routes allocated to that rail line. To get to a destination outside of the approved route or range of a rail carrier, goods may be transferred from one rail line to another. However, that transfer would entail an extra charge to the customer.

The three rail transport lines that serve California are as follows.

1. *Union Pacific Lines* — Union Pacific runs east-and-west and it serves California primarily as an interstate carrier. It is the primary rail carrier for California goods transported to the Northeast and Northern Midwest. Union Pacific has destination points in both Northern and Southern California, but the line has no direct north-south routes within the state. Therefore, its intrastate shipping business is limited. Any north-south shipments (e.g., between San Francisco and Los Angeles) must go through a hub of Union Pacific located in Salt Lake City, UT. Such shipments not only are cumbersome, but they also take longer and are more costly to the customer.

2. *Santa Fe (a.k.a. Atchison Topeka & Santa Fe)* — The Santa Fe mostly is an east-west interstate carrier that connects California with the Southwestern and Southeastern U.S. Within California, Santa Fe also serves as a short line carrier in the southern parts of the state. Santa Fe's most northern depot in California is Stockton. Shipments going to or coming from north of Stockton transfer to or from Southern Pacific Lines. Santa Fe sometimes collaborates with Burlington Northern for longer hauls in the west.

3. *Southern Pacific Lines* — Southern Pacific is the principal intrastate carrier for California. It runs north-south through almost the whole state. Because of California's geographic shape, any railway lines that run north and south will span much greater distances than lines running east and west. Southern Pacific also extends along the coast into Oregon for interstate shipments going north. Currently, Southern Pacific is in the process of relocating its headquarters staff and operations from San Francisco to Denver.

5.2.2 Rail Freight Rate Estimates

Intrastate price quotations from each of the three rail lines were solicited in order to estimate the normal cost of rail shipping in California. The request was for transportation from Northern California to Southern California for a bulk product that required no special handling.

Commodity Selection — The railways that operate in California do not have a single fee or rate structure that can be applied to all types of product shipments. The cost of shipments may vary considerably depending upon the type of commodity being transported. For example, perishable products often entail more expense in transport than nonperishable products because of losses (e.g., spoilage) that might result from any delays. Usually, insurance protection is added to the cost of shipments of perishables as protection against such losses. Therefore, the total cost paid by the customer would be greater for perishable products than for nonperishables.

Likewise, virtually all commodities that are the result of a manufacturing or refining process will possess a value greater than the raw materials from which they were made. For example, automobiles will have far greater value than the steel from which they are made because of their labor intensive manufacturing process. Steel, in turn, will have greater value than the iron ore from which it was made because of the refining process it underwent. Therefore, the shipment of those commodities may entail the additional costs of insurance protection against loss or damage during transport.

Exhibit 5-3 provides the potential cost considerations that factor into the freight rate for select commodities shipped by railways in California.[22] For each of these seven commodities, Exhibit 5-3 also provides examples of some of the more frequent considerations entailed in the cost of rail transport. Not all of the cost considerations shown in Exhibit 5-3 necessarily apply to the shipment of all products in their respective categories. For example, some shipments of paper products may require weather protection, depending upon how they were packaged, but lumber may not require such protection.

Commodity for Shipment Estimation — The product that was selected as part of this effort for transport pricing was scrap fire wood. As a transportation commodity, it was non-fragile, nonperishable, and it not did not need special packaging, liability insurance, or hazard protection. All of those factors would have increased the transportation costs. Therefore, the only components of the prices that were obtained were the weight and volume of the product and the distance it needed to travel.

In order to determine the typical rate for shipping this commodity, the points of origin and destination were specified to each railroad. The selected O-D points provided about as long of a distance as possible for intrastate shipment. The selected origin also appeared to be reasonably consistent with the origin of a forestry products shipment.[23]

Rail Car Classification — Data were categorized according to the type of rail car used for commodity transport. Five types of cars are commonly used in the state's commercial rail transport.

- *Box Car* — A box car is the "classic" rail car. It is a rectangular car with four walls (usually made of metal) and a roof. Sliding doors on two sides of the car allow access to the interior for loading and unloading freight. Box cars provide a moderate amount of protection from weather elements and, for additional costs, they can be sealed and refrigerated. Box cars hold approximately 150 to 160 tons of freight.

- *Gondola* — A gondola is an open car that allows loose materials to be piled up higher than in a box car. That allows a gondola to hold more freight—approximately 180 tons—than a box car of the same size. It is often used for shipping ores and loose minerals. Loading often is performed by pouring or dropping commodities into the car. Unloading may be performed by opening a hatch in the floor of the car and allowing the

---

[22]Although the commodity groupings shown in Exhibit 5-3 are more general than those used in CALFED, they are discussed here to exemplify the factors that may determine variability in rail freight rates. For the purpose of developing mode shift estimates, CALFED's commodity groupings will be retained later in this section.

[23]Actual city names are not provided in the discussion for reasons of confidentiality.

Exhibit 5-3

Cost Implications for Commodities Transport

#	*Commodity Type*	*Potential Cost Considerations*
1	Food, agricultural and consumer products	Perishable or non-perishable Refrigerated or non-refrigerated Protection from weather elements Sanitation Insurance against damage or spoilage
2	Forestry and paper products	Protection from weather elements Fire insurance
3	Metals and ores	Refined or unrefined Chemical contents Contamination potential
4	Coal	Chemical contents Contamination potential
5	Construction materials and machines	Size Fragility Insurance against damage
6	Chemicals, plastics & petroleum products	Perishable or non-perishable Refrigerated or non-refrigerated Sanitation Protection from weather elements Contamination potential
7	Automobiles and trucks	Fragility Insurance against damage

contents to pour out.

- *Flat Car* — A flat car is a platform on wheels. It has no walls or ceiling, making it easy to load and unload. Large machinery and equipment, such as a tractor or bulldozer, usually travel on flat cars. Loose freight must be bundled together securely. Flat cars do not hold specific ranges of weight. Instead, they are classified by length—either greater or lesser than 67 feet long.

- *Container Car* — Containers are miniature box cars, and they hold approximately 40 tons each. Because of their smaller capacity, container cars are used less frequently than the preceding three car types for intrastate shipments of bulky commodities. Their use in multimodal transport has increased considerably over the past 15 years, since containers can be transferred directly to cargo ships and to trucks without needing to be unloaded.

- *Tanker* — Several different types and sizes of tanker cars are used to haul liquid freight, such as water, petroleum products, and liquefied gases.

Only the first three classifications of rail cars were used as part of this effort to assess typical rail freight rates in California. Container cars were inappropriate (i.e., too expensive) for the type of freight and destination specified. Tanker cars were designed for a different type of freight. Rates obtained for flat cars could not be further classified according to weight. The capacity of flat cars is heavily dependent upon packaging and the freight's unit volume.

All distances between the shipment origin and destination were calculated as highway miles. Those usually were shorter than the rail miles because the shortest highway routes make use of more choices. For example, the distance between two cities in California was stated as 594 miles by one of the rail lines. For this analysis, however, 450 miles was used as the distance between those two cities which may reflect a more direct route than is available to the rail line.

5.2.3 Results of Primary Rail Rate Data Collection Effort

Data were collected on total cost to the customer at the point of destination. Costs did not include loading or unloading, nor did they include storage after a normal two-day unloading period after arrival at the destination. To ensure confidentiality, costs shown below do not identify the specific railroad, but are used solely to exemplify the types of cost considerations that form the basis for rail freight rates in the state.

The results for Railway #1 are summarized in Exhibit 5-4. Points of origin and destination are specified, along with highway mileage, types of rail cars used, weight, and costs per three units of rate—car, ton, and ton-mile.

Exhibit 5-4

Transportation Cost Estimate: Sample for Railway #1

#	*Origin*	*Destination*	*Miles*	*Car*	*Tons*	*Cost ($) per*		
						Car	*Ton*	*Ton-Mile*
1	City 1	City 2	665	Boxcar	150	2750	18.333	0.0276
			665	Gondola	180	2941	16.339	0.0246
2	City 3	City 2	700	Boxcar	150	2750	18.333	0.0262
			700	Gondola	180	2941	16.339	0.0233
3	City 4	City 2	800	Boxcar	150	2750	18.333	0.0229
			800	Gondola	180	2941	16.339	0.0204
						Arithmetic Mean		0.0242
						Range		0.0072
						Midrange		0.024

The initial inquiry was only for intrastate shipments. However, for this particular railway, charges are the same even for longer shipping distances. Both City 3 and City 4 could be points of origin at the same price as City 1, thus yielding slightly lower ratios of cost per mile. For that reason, those origins are shown in Exhibit 5-4 along with the costs of shipping from the selected origin of City 1.

Data on costs per car were used to calculate costs per ton and costs per ton-mile. The data in Exhibit 5-4 illustrate two features about pricing. First, the type of car influenced shipping prices. Gondola cars offered the potential of carrying more weight than did box cars and, if fully loaded, gondolas provided lower ratios on a cost per ton basis. Second, the costs per mile diminished as the route increased in distance. Since the same price governs for three shipping distances, the longest distance provided the best bargain in cost per mile.

Two measures of central tendency were calculated as the average cost per ton-mile, and those measures are presented in Exhibit 5-4. The arithmetic mean is the most common calculation of average, and it needs no further explanation. The midrange is an alternative measure of central tendency that may be useful for small sample statistics, and for data from distributions that have unknown characteristics (e.g., that potentially are not normally distributed). The mean and the midrange will be approximately equal to one another when data come from a normal distribution (or from a non-normal distribution that is not highly skewed).

The mean cost per ton-mile based for shipping the chosen commodity on Railway #1 was $0.0242, or 2.42 cents per ton-mile. The midrange for those same data was $0.0240, which was nearly identical to the mean. Costs per ton-mile ranged from a low of $0.0204 to a high of $0.0276 for a gondola originating at City 4 and a boxcar originating at City 1, respectively.

Results of the data for Railway #2 are summarized in Exhibit 5-5.[24] As with Railway #1, this railroad's costs per ton for gondolas were lower than for boxcars. All other comparisons between the two railway lines indicated that the rates for the Railway #2, shown in Exhibit 5-5, are higher than those for Railway #1, shown in Exhibit 5-4. Both the mean and midrange cost per ton-mile was $0.0294 per ton-mile for the second railway. Compared to average of $0.024 for the first, this represents a difference of about 23 percent.

It is likely that the shorter distance used as the basis for the Railway #2's price contributed to that railway's higher cost (i.e., originating at City 5 instead of City 1 or City 4). However, it could not be determined whether the differences in distance could fully account for the differences in cost between the two railways. The directness of the two railways' shipping routes also could have contributed, for example. The second railroad's price showed that the railway distance between City 5 and City 2 was 594 miles instead of the 450 highway miles reported in Exhibit 5-5. It is possible that this railway based its price on a route to City 2 that went by way of other cities in California such as Los Angeles.

---

[24]One of the three railroads abstained from providing price data.

Exhibit 5-5

Transportation Cost Estimate: Sample for Railway #2

Origin	*Destination*	*Miles*	*Car*	*Tons*	*Cost per*			
					100 Wt.	*Car*	*Ton*	*Ton-Mile*
City 5	City 2	450	Boxcar	150	1.37	2055	13.7	0.0304
		450	Gondola	180	1.28	2304	12.8	0.0284
		450	Flat 67'			1691		na
		450	Flat > 67'			1857		na
					Arithmetic Mean			0.0294
					Range			0.002
					Midrange			0.0294

If railway miles were used as the basis for calculating cost per ton-mile, the resulting ratio for Railway #2 would have been $0.0231 per ton-mile, or slightly lower than the rate of Railway #1. Railway miles were not obtained from Railway #1, however, so further analyses of this question could not be performed.

5.2.4 Conclusions of Typical Rail Rate Analysis

Based upon all the price data collected, the single best estimate of the cost per ton-mile was the average of the figures obtained from the two railways that participated in this study. The combined mean of the cost per ton-mile was calculated to be $0.0267, or 2.67 cents. The accuracy of that estimate can be improved upon if more information about railway prices, routes, and traffic volume were available. For example, if it were found that Railway #1 carried twice as much freight as Railway #2, then applying an appropriate statistical weight to the Railway #1's mean (in this example, the appropriate weight would be 2.00) would make the combined mean more accurate.

This analysis was of limited scope, but it has provided a quantitative indication of railway transport costs in California. Two of the three major railways that serve the state participated in this part of the study. Combined, those two lines probably account for a clear majority of the railway traffic in California. A variety of issues on railway pricing remain to be explored by further research. Those include factors related to *direct* customer costs, such as different types of commodities, rail cars, and shipping distances. Sources of *indirect* costs also remain unexplored, such as charges for different types, sources, and amounts of freight insurance charged to customers by the different rail lines.

Nevertheless, the average cost of moving a typical shipment by rail in California likely approximates the estimate developed in this analysis of 2.67 cents per ton-mile. The following sub-section compares this estimate with information available from secondary data sources on rail rates at the national level.

5.2.5 Average National Rail and Truck Shipment Rates

Truck shipment rates specific to freight movements within California were not readily available for this study. Furthermore, in order to ensure that the estimates derived above for typical rail shipment rates in California reflect actual rates, data against which those estimates can be compared are required. As a result, effort was expended to gather average freight rates by mode. Secondary data sources, however, only provide national level freight rate estimates. It is expected that given the interstate nature of freight movements, national estimates will generally resemble California-specific freight shipping rates for truck and rail.

Exhibit 5-6 presents historic national average freight rates for both rail and truck shipments. These data actually reflect the average revenue (in cents) per ton-mile accrued by each mode for an average shipment. However, assuming that the freight transport industry is competitive,

Exhibit 5-6

Historic National Average Freight Rates for Rail and Truck (Current Dollars)

Year	Average Rail Price Cents per Ton-Mile	Average Truck Price Cents per Ton-Mile	Relative Price (Rail/Truck)
1977	2.29	12.70	0.18
1978	2.36	13.40	0.18
1979	2.61	15.20	0.17
1980	2.87	18.00	0.16
1981	3.18	20.00	0.16
1982	3.21	20.77	0.15
1983	3.12	21.23	0.15
1984	3.09	21.54	0.14
1985	3.04	22.90	0.13
1986	2.92	21.63	0.13
1987	2.73	22.48	0.12
1988	2.72	23.17	0.12
1989	2.67	23.91	0.11
1990	2.66	24.83	0.11
1991	2.59	24.82	0.10
1992	2.58	22.40	0.12
1995*	2.67	23.18**	0.12

Source: Eno Transportation Foundation, *Transportation in America, 12th Edition*, 1994.
* Reflects California-specific estimate derived from primary data.
** Based on 1.03 times the 1992 rate of 22.40. The adjustment factor of 1.03 reflects the difference between the California-specific rail rate of 2.67 in 1995 and the 1992 national rate of 2.58.

average revenue will correspond with the average price that is charged to customers. Consequently, data on the average revenue per ton-mile can be employed as a close proxy for the average price per ton-mile charged by providers of transport services.

Data shown in Exhibit 5-6 demonstrate the relative price of shipping freight by rail versus truck. The truck mode has historically been much more expensive that the rail mode on a ton-mile basis. In 1987 (this study's base year), for example, the relative price of moving one ton-mile of freight on rail as opposed to truck was 0.12 (i.e., 2.73/22.48). This relative price index steadily decreased in value from 1977 to 1987, indicating that the cost advantage of rail has increased during that period. Various factors led to this increase in the rail cost advantage. Principal among them was the effect of ICC deregulation in the early 1980s. Deregulation promoted increased modal competition and the railways responded by implementing strategies that increased the efficiency of operations and the productivity of their equipment. For example, deployment of more modern locomotives resulted in large fuel efficiency benefits to the railways that helped to reduce operating costs and increase the rail cost advantage over truck. This trend continued until 1992.

Data in Exhibit 5-6 for 1992 also demonstrate the comparability of rail shipment cost estimates derived for California-specific movements from primary sources that were discussed earlier in Section 5.2. That investigation demonstrated that the average price of moving a specific shipment by rail in California is currently 2.67 cents per ton-mile. Exhibit 5-6 demonstrates the national average, presumably across all shipments, to be 2.58 cents per ton-mile in 1992. The difference is well inside the range that could be expected given the differences in geographic scope and the isolation of the California-specific estimate on one commodity. As a result, this study employs the national freight rates per ton-mile shown in Exhibit 5-6 for 1987 (i.e., 2.73 cents per ton-mile) as the basis from which changes in rail cost advantages will be developed for each emissions control regulatory scenario. The following section describes the regulatory scenarios employed in this study and the resulting impacts on rail and truck freight rates.

5.3 Impact of Emissions Regulations on Rail and Truck Freight Rates

The effects of locomotive and/or truck emissions regulations on mode shifts and overall emissions from these two sources will be directly related to the impact of regulations on the prices that railways and trucking firms charge shippers once compliance is mandated. Given the competitive nature of the freight transport industry, increases in transport costs associated with compliance likely will be passed on to customers. Consequently, an assessment of the price impacts of various proposed regulatory strategies is necessary to determine indirect economic effects, as measured by mode shift, and subsequent emissions repercussions.

This section defines the regulatory strategies for both rail and truck that have been proposed for implementation in California. As discussed in Section 3, four regulatory strategies for locomotives are investigated in this study: the deployment of dual-fuel locomotives (DF), the deployment of locomotives that are powered by spark-ignited engines fueled by LNG (LNG-SI), the use of selective catalytic reduction equipment in locomotive engines (SCR), and the deployment of dual-fuel locomotives with selective catalytic reduction devices (DF+SCR). These strategies were deemed to be the most cost-effective by EF&EE in its analysis of strategies to control locomotive emissions operating in California. This section reviews the annual costs of each strategy and estimates the effect of each strategy on rail freight rates.

As with locomotives, various regulatory strategies have been proposed for heavy-heavy-duty diesel vehicles. This analysis draws on information developed by Acurex Environmental Corporation for the ARB on the costs and potential emissions reductions of various technologies that reduce both NO_x and particulate matter (PM) emissions from heavy-duty diesel engines.[25] Although many strategies are investigated in Acurex's study, only two are considered in this analysis. These are compressed natural gas (CNG) with lean-burn spark-ignition and liquified natural gas (LNG) with lean-burn spark-ignition.[26]

This section also develops the regulatory scenarios for which the mode shift and emissions impacts will be estimated. Given that the focus of this study is to determine the specific mode shift and emissions repercussions of locomotive emissions regulations, regulatory scenarios are developed that only account for changes in the rail cost advantage attributable to locomotive emissions policy. In this manner, the effects of each of the four strategies on mode shift and emissions are isolated. However, more stringent truck emissions regulations will also be promulgated by 2010. Consequently, scenarios are also formulated that account for the combined effects of locomotive and heavy-heavy-duty diesel truck regulations on the rail cost advantage, mode shifts, and rail and truck emissions.

5.3.1 Locomotive Emissions Regulations

The results of EF&EE's study show that substantial control of emissions from locomotives is possible at moderate cost. The following emissions control measures were investigated by EF&EE:

- changes in diesel fuel composition;
- improvements in operating efficiency to reduce fuel consumption;
- modifications to existing diesel engines to reduce their emissions;
- replacement and rebuilding of diesel locomotives with lower-emitting engine designs;

[25]Acurex Environmental Corporation, *Technical Feasibility of Reducing NO_x and Particulate Emissions from Heavy-Duty Engines*, ARB Contract No. A132-085, 1993.

[26]CNG with lean-burn spark ignition represents the lowest cost strategy investigated by Acurex (low-end estimate), while LNG with lean-burn spark ignition represents the highest cost strategy (high-end estimate) and exhibits the largest difference between the low-end and high-end cost estimates as illustrated below on page 5-21.

- alternative fuels (methanol and natural gas);
- retrofitting selective catalytic reduction (SCR) to existing diesel locomotives;
- a combination of natural gas plus SCR; and
- electrification of linehaul operations.

Of these regulatory approaches, only four are investigated in this study, as discussed in Section 3. The rationale for choosing Dual-Fuel, LNG-SI, LNG+SCR, and SCR as the control strategies in this study included the following criteria.

- First, the impact of a specific regulation on mode shift will be directly related to the cost of the regulation on freight rates. Consequently, a spectrum of program costs is needed to evaluate the range of mode shift effects that may occur in the future.
- Second, strategies that showed relatively poor cost-effectiveness, such as rail electrification, are not likely to be promulgated by the ARB on a state-wide basis. So, including such strategies in this analysis is not warranted.
- Third, strategies that have small emissions impacts, such as low aromatic fuel, are not attractive from the standpoint of emissions mitigation. Such strategies also have relatively poor cost-effectiveness ratios.

EF&EE calculates the cost-effectiveness of the four strategies included in this study to be as follows: Dual-Fuel shows a cost-effectiveness of $858 per ton of NO_x reduction, LNG-SI shows a cost-effectiveness of $1,376 per ton of NO_x reduction, DF+SCR shows a cost-effectiveness of $1,911 per ton of NO_x reduction, and SCR shows a cost-effectiveness of $2,909 per ton of NO_x reduction. These cost-effectiveness estimates reflect the deployment of the control strategies on locomotives used in linehaul, local, and switcher operations. The four strategies chosen in this analysis are the most cost-effective for linehaul operations, exactly those operations that will compete with truck for market share.

Exhibit 5-7 presents the impact of the four strategies investigated in this analysis on the cost per ton-mile. The promulgation of a locomotive emissions regulation that requires dual-fuel, for example, will cost an estimated $21.5 million per year (1987 dollars). On a ton-mile basis, this cost translates to 0.09 cents in 1987 dollars. At the other end of the spectrum, SCR will cost an estimated $92.9 million per year, or 0.38 cents per ton-mile in 1987 dollars. Given that the CALFED sensitivity parameters were calculated in 1977, the impact of each strategy on the cost per ton-mile must be deflated to 1977 dollars, since these impacts will be used to calculate the change in the cost advantage of rail versus truck needed to determine mode shift. Impacts expressed in 1977 dollars are also shown in Exhibit 5-7.

Exhibit 5-7

Cost of Locomotive Regulations

	Dual-Fuel (DF)	LNG-SI	DF+SCR	SCR
Strategy Cost (1987$) (1) in millions	21.5	42.1	65.5	92.9
1987 Ton-Miles in millions	24,592	24,592	24,592	24,592
Cost/Ton Mile in Cents (1987$)	0.09	0.17	0.27	0.38
Cost/Ton Mile in Cents (1977$)	0.08	0.15	0.23	0.31

Source: (1) Engine Fuel, and Emission Engineering Inc., "Controlling Locomotive Emissions in California: Technology, Cost-Effectiveness and Regulatory Strategies", March 29, 1995.