Insititute of Transportation Studies
University of California at Berkeley

The Full Cost of Intercity Transportation – A Comparison of High Speed Rail, Air and Highway Transportation in California

David Levinson
David Gillen
Adib Kanafani
Jean-Michel Mathieu

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EXECUTIVE SUMMARY:

This study evaluates the full cost of three modes of intercity transportation: air, highway, and high speed rail. The evaluation is done within the context of the California Corridor, connecting the Los Angeles Basin and the San Francisco Bay Area. The purpose of evaluating full cost is to compare the economic implications of investment in, or expansion of, any of these three modes. The scope of the analysis is full transportation cost. Full transportation costs includes external, or social cost, in addition to the internal costs of construction, operation and maintenance. In this study we include estimates of four types of external, social costs: accidents, congestion, noise, and air pollution.

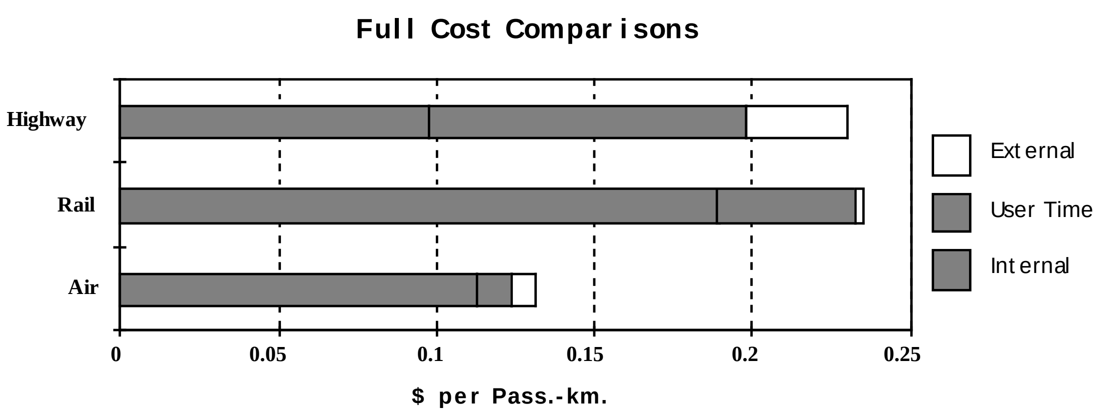
The 677 kilometer corridor for which these estimates are computed represents one of the alignments of a proposed high speed rail system between Los Angeles and San Francisco. The methodology used is to construct cost functions that relate costs to levels of output, as measured by passenger-kms. or vehicle-kms. Different types of costs are estimated as permitted by available data. These include short run costs, in which the physical capacity is held fixed; and long run functions in which capacity is allowed to expand to meet higher levels of demand. Average and marginal costs are computed for highway and for air transportation. But given the absence of high speed rail systems in California only average costs are estimated. The highway and air cost models are developed from basic principles and are estimated with actual data and system design characteristics observed in the California corridor. Rail costs are estimated with models that have been adapted from estimates for the French high speed rail system, the TGV, using available data for their estimation.

Based on the results summarized in Chapter 7 and shown in Table 7.1, we find that the full cost of air transportation for the California Corridor ($0.1315 per passenger-kilometer traveled (pkt)) is significantly less costly than the other two modes. The full cost of high speed rail and highway transportation cost approximately the same; rail costs $0.2350/pkt and highway costs $0.2302/pkt.

The internal, or private, monetary costs comprising infrastructure, carrier, and vehicle operating costs are clearly highest for rail ($0.19/pkt), followed by air ($0.11/pkt) and then highway ($0.10/pkt). And as is to be expected, user time costs are highest for the slowest mode, the highway system, followed by rail and then air. Adding user travel time costs to the monetary costs results in the total internal system costs per passenger-km. of $0.124 for air; $0.233 for rail; and $0.198 for highway. In other words, if we disregard external costs then we find that high speed rail is nearly twice as costly as air and that the highway is not far behind.

However, if we look at social costs alone -- congestion, air pollution, noise, and accidents -- we find that high speed rail is clearly less costly than the other modes. In this research the only measurable social cost of high speed rail is that of noise, which at $0.002/pkt, is significantly lower than that of air at $0.0043/pkt and highway at $0.0045/pkt. Highway transportation, on the other hand, has a relatively high cost in terms of air pollution and accidents, two externalities which are virtually absent in high speed rail. In this study, we consider that the pollution resulting from the electric power generation used to drive a train is to be allocated to the energy, and not the transportation sector. Thus, any pollution externality associated with high speed rail should be already internalized in a higher price for electricity. Similarly, a 100% safe system, such as high speed rail, implies higher capital costs due to construction of grade separations, more intelligent systems, etc... Hence, the avoidance of accidents by high speed trains is not "free".

Therefore, high speed rail, while more costly than highway transportation in terms of internal costs, primarily due to its high capital cost, is significantly less costly than highway in terms of social costs. This comparison is illustrated in the following figure, where full costs are broken down into three categories: internal, travel time, and external.



The study also compares the total full cost of a trip within the corridor by each of the modes. As an example, these results are shown in the table below for a trip between San Francisco and Los Angeles. The social costs imposed by a trip in each of these modes would be about $21 by highway; $4.50 by air; and $1.35 by high speed rail. It is interesting to note that the recovery of these social costs might imply the addition of fare premiums in the air and rail systems equal to these amounts. But for highway transportation they would imply a premium of $1.50 per gallon of gasoline!

Comparative Full Cost of S.F.- L.A. Trip

	Internal	External	Total
Highway	135	21	156
Air	77.5	4.50	82
H.S. Rail	157.65	1.35	159

In dollars per passenger

Notwithstanding these results, it should be noted that social costs, due to their small magnitude, play a minor role in the comparison of total costs across modes. The externalities defined in this study amount to 1% of the full cost of high speed rail, 6% of the full cost of air, and a relatively large 14% of the full cost of highway transportation.

Taking these cost estimates into account, the study also looks at the effect of high speed rail development on other modes and the resulting economic impacts. If high speed rail is to divert traffic away from air transportation, then there is clearly an increase in cost, and a significant one when considering the increase in total cost of about $0.1035 for every passenger-km. diverted. If, on other hand, rail is to divert traffic away from highway transportation then the change in total cost is probably negligible given the results of this study. But, there will probably be a measurable reduction in social costs of about $0.0302 per passenger-km. diverted, primarily in the form of environmental impacts. There would also be a measurable saving in the value of time spent in transportation of about $0.056 for each passenger-km. diverted from highway to high speed rail.

The implications of this are clear and far reaching. They suggest that the most cost effective high speed rail configuration in California would be as an alternative to highway, rather than to air transportation. Any new high speed rail line should be designed to complement rather than compete with air transportation. Perhaps design alternatives which favor shorter distance markets (such as Los Angeles-San Diego or San Francisco-Sacramento,) and that act as regional access connections to airports and tie in with local mass transit systems would be more advantageous than those in this study.

Finally, the reader should be reminded that the results of this study are based on a number of models that include assumptions and approximations. Some of these are fairly accurate, and other are less so. The quality of the results and the confidence with which one should make interpretations or policy analyses on the basis of these results are only as good as the state of the art in cost modeling. While this study may be judged as a contribution to the transportation field, we recognize that it is a modest one and that much more research is needed on the full cost of transportation systems.

CHAPTER ONE: INTRODUCTION

1.1 OBJECTIVES

Price, cost and investment issues in transportation garner intense interest in the United States. This is certainly to be expected from a sector that has been subject to continued public intervention since the ninteenth century. While arguments of market failure, where the private sector would not provide the socially optimal amount of transportation service, have previously been used to justify the economic regulations which characterized the airline, bus, trucking, and rail industries, it is now generally agreed, and supported by empirical evidence, that the move to a deregulated system, in which the structure and conduct of the different modes are a result of the interplay of market forces occurring within and between modes, will result in greater efficiency and service.

Many factors have led to a reexamination of where, and in which mode, transportation investments should take place. First, and perhaps most importantly, is the general move to place traditional government activities in a market setting. The privatization and corporatization of roadways and parts of the aviation systems are good examples of this phenomenon. Second, there is now a continual and increasing fiscal pressure exerted on all parts of the economy as the nation reduces the proportion of the economy's resources which are appropriated by government. Third, there is increasing pressure to fully reflect the environmental, noise, congestion, and safety costs in prices paid by transportation system users. Finally, there is an avid interest in California, as well as other parts of the United States, in the prospect of high speed rail (HSR) as a solution to airport congestion and improvement in environmental quality. Such a major investment decision cannot be made without understanding the full cost implications of HSR technology as opposed to alternatives such as air or highway transportation. In the interest of all concerned, a clear and accurate portrayal of the benefits and costs of high speed rail -- in comparison with other modes of transportation -- is needed.

An essential first step in examining transportation issues and in making sound decisions on transportation systems is to understand the full cost of transportation today, including the social costs of accidents, air pollution, noise, and congestion as well as the internal costs of providing and operating the infrastructure. Furthermore, if cross subsidies between modes, user groups, or areas of the country or states are to be avoided, and if users are to pay the full cost of providing and maintaining the transportation system, then it is important to know what proportion of total costs users currently pay and what proportion is borne by others. Such a complete assessment of the full cost of the different modes of transportation for intercity travel has been lacking. While there is strong evidence that the social costs of high speed rail are lower than those of highway transportation for example, it has remained unclear whether these reduced social costs offset rail's high capital and operating costs. The development of cost models and estimates of the type presented in this research are essential to gauging the true costs of transportation in the different modes, and is a prerequisite to sound investment decisions.

The objectives of this study are ambitious but straightforward: to develop and estimate long and short run average and marginal cost functions of intercity passenger transportation services by auto, air, and high speed rail and to apply these models to estimate the full costs by each of the three modes in the California Corridor. Cost calculations include the costs of building, operating, and maintaining infrastructure, as well as carrier, user, and social costs. Social, or external costs, include noise, air pollution, safety or accident costs, and congestion costs. User costs including the cost of purchasing, maintaining and operating a vehicle such as a car, as well as the cost of travel time are also included. As mentioned earlier, our purpose is to provide a comparative evaluation among the three modes within the context of the California Corridor. An important policy question that underlies these intended comparisons is: how does the full cost of developing a high speed rail system in the California Corridor compare with the cost of the alternative -- expanding the air transportation system or the highway system capacities to meet anticipated (e.g. year 2010) demand for passenger transportation.

1.2 SCOPE OF RESEARCH AND OUTLINE OF REPORT

We begin this report with a review of conceptual and analytical frameworks for cost estimation. In Chapter 2 we provide a review of the literature on infrastructure and carrier costing. One of the important areas of investigation in this literature is the extent to which there may be economies of scale, scope or density in the cost structures in the different modes. The presence of economies would suggest a dependence of costs on a number of attributes of the system, such as flow, network structure, and network utilization. This dependence implies that the use of point estimates of average, say per passenger-km., costs may not be adequate for comparisons among modes. Instead, it would require cost functions that relate average and marginal costs to these causal factors. As we see in Chapter 2, the presence of economies is evident in many respects in the provision of transportation services. Consequently, cost functions are developed and then applied to specific parts of the California network. Other important issues addressed in Chapter 2 include the question of average versus marginal costs, joint costs, and short run versus long run costs. Definitions of the system and its output are also dealt with, as those affect the delineation between internal and external costs.

To begin this modeling process, a detailed discussion of the categories of social costs is contained in Chapter 3. We adopt a definition of social costs and identify the ranges of the costs associated with the different types of externalities (pollution, noise, accident, and congestion). Models of noise and air emissions are used to develop the impacts for each mode, and costing models are used to convert these into social costs. The incidence of accidents is analyzed and valuation methods that are currently accepted in the literature are used to develop accident cost models. Traffic engineering models are used to estimate travel time and delay as a function of flow for each mode and these can be converted to cost functions.

The social cost analysis is followed in chapters 4, 5 and 6, by detailed calculations of the full costs of highway (auto), air and high speed rail. Table 1. 2-1 lists the cost elements that are analyzed for each mode. Despite the different natures of these technologies, it is nonetheless possible to compare three categories broadly defined as: infrastructure costs, user operating costs, carrier operating costs, and social costs.

Table 1. 2-1: Cost Elements Analyzed for Each Mode

Auto:	Infrastructure - land, capital, operating, signaling, maintenance User costs: vehicle ownership and operation, time Social costs - air pollution, noise pollution, safety, congestion
Air:	Aviation System: ATC, ANS, capital and operating Airport - land, capital, maintenance, operating Carrier costs User costs: time Social costs - air pollution, noise pollution, safety, congestion
HSR:	Infrastructure - land, rail capital, operating and maintenance Rolling stock - capital, operating, maintenance User costs: time Social costs - air pollution, noise pollution, safety, congestion

For each mode we also distinguish between short and long run costs, where the difference between them is in the exclusion or inclusion of infrastructure capital costs. The argument for making this distinction is that existing modes can be operating at different levels of capacity utilization but that capacity may have been the result of non-economic investments. Too little or too much capacity may, therefore, exist. In subsequent work it would, therefore, be possible to evaluate the welfare gains resulting from economically efficient modal management, in particular roadway pricing, for existing capacity and the welfare gains available from both efficient pricing and investment policies. A second reason for making the short-long run distinction is to provide a more reasonable approach to comparing existing modes with 'prospective' modes such as HSR. Comparing the additional cost of an increment (passenger, passenger-mile, vehicle or vehicle-mile) to the roadway or airway system with the incremental cost to a HSR system is only reasonable if we include capital costs for all modes and we are able to consider a reasonable distribution of travelers across modes since unit costs depend on load factors.

Social costs from Chapter 3 are then added to provide a full cost model for each mode. Costs for the highway mode, developed in Chapter 4, include those for owning and operating a vehicle and costs for infrastructure. Vehicle costs include both capital costs, for which a price depreciation model is constructed, and operating costs including fuel, oil, and times. Highway infrastructure costs are based or a cross sectional analysis of government expenditures in the fifty states. Costs for the air mode, described in Chapter 5, are estimated separately for the air traffic control system, airport capital and operating costs, and airline capital and operating costs. We note that due to the absence of empirical evidence on operating high speed rail in California, we use models that are adapted from the French TGV system in Chapter 6. Capital costs for constructing the HSR system are adapted from work by Leavitt et. al (1994).

Full cost comparisons for the California Corridor, connecting between Los Angeles and San Francisco are conduced in Chapter 7. Here we identify network configurations representing the major travel markets in the Corridor, and we adopt a sample configuration of a high speed rail system proposed for California. We apply the models to estimate average and marginal costs for travel in the corridor. In the comparison we segment the cost data to illustrate the source of differences in the alternative modes among the cost categories. We then provide a summary and conclusions, and recommendations for future research.

CHAPTER TWO: A FRAMEWORK FOR COST ANALYSIS

In this chapter we review the theoretical and empirical literature on the cost structure of modal services (carriers) and of the provision of infrastructure. We also develop a conceptual framework for modeling the full costs of the three modes in question: high speed rail, air and highway transportation. In defining this framework, we distinguish between internal (private) and external (social) costs, long and short run costs, and average and marginal costs. We also explore the various economies that arise in the provision of transportation services; economies of scale, scope and density. We then look at available evidence regarding the cost structure of the three modes of transportation as a way of leading into the construction of full cost functions that permit the comparison among them. We conclude this chapter with an analytical framework for the cost modeling that is done in the subsequent chapters.

2.1. CONCEPTUAL FRAMEWORK

2.1.1 External and Internal Costs

Economics has a long tradition of distinguishing those costs which are fully internalized by economic agents (internal or private costs) and those which are not (external or social costs). The difference comes from the way that economics views the series of interrelated markets. Agents (individuals, households, firms and governments) in these markets interact by buying and selling goods are services, as inputs to and outputs from production. A firm pays an individual for labor services performed and that individual pays the grocery store for the food purchased and the grocery store pays the utility for the electricity and heat it uses in the store. Through these market transactions, the cost of providing the good or service in each case is reflected in the price which one agent pays to another. As long as these prices reflect all costs, markets will provide the required, desirable, and economically efficient amount of the good or service in question.

The interaction of economic agents, the costs and benefits they convey or impose on one another are fully reflected in the prices which are charged. However, when the actions of one economic agent alter the environment of another economic agent, there is an externality. An action by which one consumers purchase changes the prices paid by another is dubbed a “pecuniary externality” and is not analyzed here further; rather it is the non-pecuniary externalities with which we are concerned. More formally, “an externality refers to a commodity bundle that is supplied by an economic agent to another economic agent in the absence of any related economic transaction between the agents" (Spulber, 1989). Note that this definition requires that there not be any transaction or negotiation between either of the two agents. The essential distinction which is made is harm committed between strangers which is an external cost and harm committed between parties in an economic transaction which is an internal cost. A factory which emits smoke forcing nearby residents to clean their clothes, cars and windows more often, and using real resources to do so, is generating an externality or, if we return to our example above, the grocery store is generating an externality if it generates a lot of garbage in the surrounding area, forcing nearby residents to spend time and money cleaning their yards and street.

There are alternative solutions proposed for the mitigation of these externalities. One is to use pricing to internalize the externalities; that is, including the cost which the externalities impose in the price of the product/service which generate them. If in fact the store charged its customers a fee and this fee was used to pay for the cleanup we can say the externality of 'unsightly garbage' has been internalized. Closer to our research focus, an automobile user inflicts a pollution externality on others when the car emits smoke and noxious gases from its tailpipe, or a jet aircraft generates a noise externality as it flies its landing approach over communities near the airport. However, without property rights to the commodities of clean air or quiet, it is difficult to imagine the formation of markets. The individual demand for commodities is not clearly defined unless commodities are owned and have transferable property rights. It is generally argued that property rights will arise when it is economic for those affected by externalities to internalize the externalities. These two issues are important elements to this research since the implicit assumption is that pricing any of the externalities is desirable. Secondly, we assume that the property rights for clean air, safety and quiet rest with the community not auto, rail and air users. Finally, we are assuming that pricing, meaning the exchange of property rights, is possible. These issues are considered in greater detail in Chapter 3 where the broad range of estimates for the costs of the externalities are considered.

2.1.2 Short Run versus Long Run Costs

Long run costs, using the standard economic definition, are all variable; there are no fixed costs. However, in the short run, the ability to vary costs in response to changing output levels and mixes differs among the various modes of transportation. Since some inputs are fixed, short run average cost is likely to continue to fall as more output is produced until full capacity utilization is reached. Another potential source of cost economies in transportation are economies of traffic density; unit cost per passenger-kilometer decreases as traffic flows increase over a fixed network. Density economies are a result of using a network more efficiently. The potential for density economies will depend upon the configuration of the network. Carriers in some modes, such as air, have reorganized their network, in part, to realize these economies.

In the long run, additional investment is needed to increase capacity and/or other fixed inputs. The long run average cost curve, however, is formed by the envelope of the short run average cost curves. For some industries, the long run average cost often decreases over a broad range of output as firm size (both output and capacity) expands. This is called economies of scale. The presence of economies at the relevant range of firm size means that the larger the size of the firm, the lower the per-unit cost of output. These economies of scale may potentially take a variety of forms in transportation services and may be thought to vary significantly according to the mode of transportation involved.

2.1.3 Common and Joint Costs

The production of transport services in most modes involves joint and common costs. A joint cost occurs when the production of one good inevitably results in the production of another good in some fixed proportion. For example, consider a rail line running only from point A to point B. The movement of a train from A to B will result in a return movement from B to A. Since the trip from A to B inevitably results in the costs of the return trip, joint costs arise. Some of the costs are not traceable to the production of a specific trip, so it is not possible to fully allocate all costs nor to identify separate marginal costs for each of the joint products. For example, it is not possible to identify a marginal cost for an i to j trip and a separate marginal cost for a j to i trip. Only the marginal cost of the round trip, what is produced, is identifiable.

Common costs arise when the facilities used to produce one transport service are also used to produce other transport services (e.g. when track or terminals used to produce freight services are also used for passenger services). The production of a unit of freight transportation does not, however, automatically lead to the production of passenger services. Thus, unlike joint costs, the use of transport facilities to produce one good does not inevitably lead to the production of some other transport service since output proportions can be varied. The question arises whether or not the presence of joint and common costs will prevent the market mechanism from generating efficient prices. Substantial literature in transport economics (Mohring, 1976; Button, 1982; Kahn, 1970) has clearly shown that conditions of joint, common or non-allocable costs will not preclude economically efficient pricing.

2.1.4 Economies of Scale

Economies of scale refer to a long run average cost curve which slopes down as the size of the transport firm increases. The presence of economies of scale means that as the size of the transport firm gets larger, the average or unit cost gets smaller. Since most industries have variable returns to scale cost characteristics, whether or not a particular firm enjoys increasing, constant or decreasing returns to scale depends on the overall market size and the organization of the industry.

The presence or absence of scale economies is important for the industrial structure of the mode. If there were significant scale economies, it would imply fewer larger carriers would be more efficient and this, under competitive market circumstances, would naturally evolve over time. Scale economies are important for pricing purposes since the greater are the scale economies, the more do average and marginal costs deviate. It would, therefore, be impossible to avoid a deficit from long run marginal [social] cost pricing.

Another note of terminology should be mentioned. Economics of scale is a cost concept, returns to scale is a related idea but refers to production, and the quantity of inputs needed. If we double all inputs, and more than double outputs, we have increasing returns to scale. If we have less than twice the number of outputs, we have decreasing returns to scale. If we get exactly twice the output, then there are constant returns to scale. In this study, since we are referring to costs, we use economies of scale. The presence of economies of scale does not imply the presence of returns to scale.

2.1.5 Economies of Traffic Density

There has been some confusion in the literature between economies of scale and economies of density. These two distinct concepts have been erroneously used interchangeably in a number of studies where the purpose was to determine whether or not a particular mode of transportation (the railway mode has been the subject of considerable attention) is characterized by increasing economies or diseconomies of scale. There is a distinction between density and scale economies. Density economies are said to exist when a one percent increase in all outputs, holding network size, production technology, and input prices constant, increase the firm's cost by less than one percent. In contrast, scale economies exist when a one percent increase in output and size of network increases the cost by less than one percent, with production technology and input prices held constant.

Economies of density, although they have a different basis than scale economies, can also contribute to the shape of the modal industry structure. It can affect the way a carrier will organize the delivery of its service spatially. The presence of density economies can affect the introduction of efficient pricing in the short term, but generally not over the long term since at some point density economies will be exhausted. This, however, will depend upon the size of the market. In the air market, for example, deregulation has allowed carriers to respond to market forces and obtain the available density economies to varying degrees.

2.1.6 Economies of Capacity Utilization

A subtle distinction exists between economies of density, which is a spatial concept, and economies of capacity utilization, which may be aspatial. As a fixed capacity is used more intensively, the fixed cost can be spread over more units or output, and we have declining average cost, economies of scale. However, as the capacity is approached, costs may rise as delays occur. This gives a u-shaped cost curve.

While economies of scale refer to declining average costs, for whatever reason, when output increases; and economies of density refer to declining costs when output increases and the network mileage is held constant; economies of capacity utilization refers to declining costs as the percentage of capacity which is used increases, where capacity may be spatial or aspatial.

While density refers to how much space is occupied, capacity refers to how much a capacitated server (e.g. a bottleneck, the number of seats on a plane) is occupied, and may incorporate economies of density if the link is capacitated, such as a congesting roadway. However if a link has unlimited (or virtually unlimited) capacity, such as intercity passenger trains on a dedicated right-of-way at low levels of traffic, then economy of density is a more appropriate concept. Another way of viewing the difference is that economies of density refers to linear miles, while economies of utilization refer to lane miles.

2.1.7 Economies of Scope

Typically, the transport firm produces a large number of conceptually distinct products from a common production facility. In addition, the products of most transportation carriers are differentiated by time, space and quality. Because a number of distinct non-homogeneous outputs are being produced from a common production facility, joint and common costs arise. The presence of joint and common costs give rise to economies of scope. There has been some confusion in the multi-product literature among the concepts of sub additivity of the cost function, trans-ray convexity, inter-product complementarity and economies of scope. Sub additivity is the most general concept and refers to a cost function which exhibits the characteristic that it is less costly to produce different amounts of any number of goods in one plant or firm than to sub divide the products or service in any proportion among two or more plants. Trans-ray convexity is a somewhat narrower concept. It refers to a cost function which exhibits the characteristic that for any <u>given set</u> of output vectors, the costs of producing a weighted average of the given output vectors is no greater than the weighted average of producing them on a stand alone basis. Economies of scope refers to the cost characteristic that a single firm multi-product technology is less costly than a single product multi-firm technology. It, therefore, is addressing the issue of the cost of adding another <u>product</u> to the product line. Inter-product complementarity is a weak test of scope economies. It refers to the effect on the marginal cost of one product when the output of some other product changes. It, therefore, is changing the <u>amount of output</u> of two or more products and not the <u>number of products</u>. Whether scope economies exist and the extent to which they exist depend upon both the number of products and the level of each output. There have not been definitive empirical estimates of economies of scope for transportation modes which are based on reliable data and undertaken in a theoretically consistently fashion.

2.2. CARRIER COSTS

How do the long run concepts of economies of scale and economies of scope and the short run concepts of economies of density and economies of capacity utilization influence costs? Why are they important to our discussion of transport infrastructure pricing? These questions will be addressed in the following section.

2.2.1 Air Carriers

A considerable number of studies, Douglas and Miller (1974), Keeler (1974), Caves, Christensen and Tretheway (1984), Caves, Christensen, Tretheway and Windle (1985), McShan and Windle (1989), and Gillen, Oum, and Tretheway (1985, 1990), have been directed at determining the functional relationship between total per-unit operating costs and firm size in airlines. All studies have shown that economies to scale are roughly constant; thus, size does not generate lower per-unit costs. However, generally, the measures of economies of density illustrate that unit cost would decrease for all carriers if they carried more traffic within their given network. In other words, the industry experienced increasing returns to density. The results also indicated that the unexploited economies of density are larger for low density carriers.

Caves, Christensen, and Tretheway (1984) have shown that it is important when measuring costs to include a network size variable in the cost function, along with output, which would allow for the distinction between economies of scale and economies of density. McShan and Windle (1989) utilize the same data set as that used by Caves et al., and explicitly account for the hub and spoke configuration that has developed in the US since deregulation in 1978. They estimate a long run cost function which employs all the variables included in Caves et. al., and found economies to density of about 1.35. The hubbing variable indicates that, ceteris paribus, a carrier with 1% more of its traffic handled at hub airports expects to enjoy 0.11% lower cost than other similar carriers.

2.2.2 Intercity Buses

Gillen and Oum (1984) found that the hypothesis of no economies of scale can be rejected for the intercity bus industry in Canada; there are diseconomies of scale at the mean of the sample (0.91). Large firms were found to exhibit strong diseconomies of scale, and small and medium sized firms exhibit slight departures from constant returns. No cost complementarities are found to exist between the three outputs, namely, number of scheduled passengers, revenue vehicle miles of charter, tour and contract services, and real revenue from freight. These results, however, may be biased since no network measure was included in the estimating equations. The scale economy measure will, therefore, contain some of the influence of available density economies.

Since deregulation of the intercity bus industries in the US and the UK., the number of firms has been significantly reduced. In the absence of scale economies, the forces leading to this industry structure would include density economies. We have, for example, observed route reorganization to approximate hub-and-spoke systems and the use of smaller feeder buses on some rural routes.

The industry reorganization is similar to what occurred in the airline industry. The consolidation of firms was driven by density and not scale economies. One significant difference between these two industries, however, is airline demand has been growing while intercity bus demand is declining.

2.2.3 Railway Services

The structure of railway costs is generally characterized by high fixed costs and low variable costs per unit of output. The essential production facilities in the railway industry exhibit a significant degree of indivisibility. As with other modes, the production of railway services give rise to economies of scope over some output ranges. For example, track and terminals used to produce freight services are also used to produce passenger services.

Caves, Christensen and Tretheway (1980) have found that the US railway industry is characterized by no economies of scale over the relevant range of outputs. However, their sample does not include relatively small railroads, firms with less than 500 miles of track. Griliches (1972) and Charney, Sidhu and Due (1977) have found economies scale for such small US railroads. Friedlaender and Spady (1981) suggested that there may be very small economies of scale with respect to firm size. Keeler (1974), Harris (1977), Friedlaender and Spady (1981) and Levin (1981) have all shown that there are large economies of traffic density in the US railroad industry. They show that, allowing all factors of production except route mileage to vary, a railway producing 10 million revenue ton-miles per mile of road, for example, will have substantially lower average costs than will a railway producing only 5 million revenue ton-miles per mile of road. Harris (1977) estimated that approximately one-third of density economies were due to declining average capital costs, and two-thirds due to declining fixed operating costs, such as maintenance, and administration. Friedlaender and Spady (1981) estimate a short run cost function with five variable inputs, one quasi-fixed factor (structures) and two outputs which take the form of hedonic functions, accounting for factors such as low density route miles and traffic mixes. The study found no economies of scale. Caves, Christensen, Tretheway and Windle (1985) have examined economies of scale and density in the US railroads. Their basic result demonstrates that there are substantial economies of density in the US railway operations. The economies of traffic density and economies of scale estimated by various studies are compared in Table 2. 2-1.

2. 2-1: Economies of Density and Scale in US Railways

Study	Density	Scale
Friedlaender and Spady (1981)	1.16	.88-1.08
Caves Christensen and Swanson (1981)	-	1.01
Harmatuck (1979)	1.92	0.93
Harris (1977)	1.72	1.03
Keeler (1974)	1.79	1.01
Caves et. al. (1985)	1.76	0.98

Source: Caves et. al. (1985).

2.3. INFRASTRUCTURE COSTS

As early as 1962, Mohring and Harwitz demonstrated that the financial viability of an infrastructure facility, under optimal pricing and investment, will depend largely upon the characteristics of its cost function. To quote Winston (1991): " If capacity and durability costs are jointly characterized by constant returns to scale, then the facility's revenue from marginal cost pricing will fully cover its capital and operating costs. If costs are characterized by increasing returns to scale, then marginal cost pricing will not cover costs; conversely, if costs are characterized by decreasing returns to scale, marginal cost pricing will provide excess revenue."

The objective of this section is to provide a summary of the theoretical and empirical literature on the cost characteristics of modal infrastructure. The discussion will deal with the following types of infrastructure: airports, highways, and railways.

In developing a set of socially efficient prices for modes of intercity transport, it is not just the carrier's cost structure which is important. Airports, roadways and harbors all represent public capital which is used by the carriers in the different modes to produce and deliver their modal services. This capital must also be priced in an efficient way to achieve the economic welfare gains available from economically efficient pricing. As with the carriers, the ability to apply first best pricing principles to infrastructure and still satisfy cost recovery constraints will depend upon the cost characteristics of building and maintaining the infrastructure.

As with carriers, the cost characteristics for infrastructure providers include scale economies, scope economies, density economies and utilization economies. Scale economies refer to the size of a facility; for example, is it cheaper to build three runways than it is to provide two runways? If so, there are economies of scale in the provision of runways. Scope economies encompass similar concepts as with carriers. Small, Winston and Evans (1989) refer to scope economies in highways when both capacity and durability are supplied. Capacity refers to the number of lanes while durability refers to the ability to carry heavier vehicles. A similar concept would apply to airports: small and large aircraft, VFR and IFR traffic, and to harbors: large ships and small ships. Although rail infrastructure is currently supplied by the same firms operating the trains, there have been moves to separate infrastructure and carrier services. This separation will mean the track and terminals will have to be priced separately from carrier services.

Density economies should also, in principle, be evident in the provision of infrastructure. It is, for example, possible to expand outputs and all inputs for highways while holding the size of the network fixed.

Utilization economies refer to the short run cost function. They describe how quickly average and marginal costs will fall as capacity utilization approaches capacity. Although not of direct interest, they are important to consider in any cost estimation since failure to consider capacity utilization can bias upward the measures of both long run average and marginal costs.

2.3.1 Airports

Economists have typically assumed that capacity expansion is divisible. Morrison (1983), in his analysis of the optimal pricing and investment in airport runways, has shown that airport capacity construction is characterized by no economies of scale, and, therefore, under perfect divisibility of capacity expansion, the revenue from tolls will be exactly equal to the capital cost of capacity investment (Mohring and Harwitz, 1962). Morrison's results, however, were based on a sample of 22 of the busiest airports in the US and did not include any small airports. In the literature, there is no empirical evidence on the cost characteristics of capacity construction of new small airports or capacity expansion of existing small airports (e.g. one runway).

2.3.2 Highways

In general, highways produce two outputs: traffic volume which requires capacity in terms of the number of lanes, and standard axle loading which require durability in terms of the thickness of the pavement. Prior to determining economies of scale in this multi-product case, the measure of economies of scale for each output, or the product specific economies of scale, must be examined. Small, Winston, and Evans (1989) reported the existence of significant economies of scale associated with the durability output of roads, the ability to handle axle loads. This is because the pavement's ability to sustain traffic increases proportionally more than its thickness. They also found evidence that there are slight economies of scale in the provision of road capacity; i.e. the capacity to handle traffic volume. However, they reported diseconomies of scope from the joint production of durability and capacity because as the road is made wider to accommodate more traffic, the cost of any additional thickness rises since all the lanes must be built to the same standard of thickness. They conclude that these three factors together result in highway production having approximately constant returns to scale. In other words, the output-specific scale economies are offset by the diseconomies of scope in producing them jointly.

2.3.3 Railways

An important difference between rail and other modes of transportation is that most railroads provide the infrastructure themselves and the pricing is undertaken jointly for carrier services and infrastructure. However, in a few cases, ownership and/or management of the trackage has been separated from carriers. Sweden is a good example but even in the US there have been joint running rights on tracks. This creates a situation whereby one firm may be responsible for the provision of trackage and another for carrier services. It is, therefore, legitimate to ask if there are any scale economies in the provision of railway infrastructure. There are no empirical estimates but it may be possible to use some of the Small, Winston and Evans (1988) work for roads to shed some light on the issue.

Small et. al argue road infrastructure produces two outputs, durability and capacity. The former refers to the thickness of roads and the latter to their width. They found economies with respect to durability, but this is less likely to occur with a rail line since there would be a relatively broad range of rail car axle loading for a given level of durability of rail, ballast and ties. Thus, there may be some minor economies. The authors found diseconomies of scope from the joint production of durability and capacity for highways. These diseconomies are less likely to be evident in rail due to the broad range of durability noted above <u>and</u> the ability to restrict usage to specific tracks. On balance, it may be there are generally constant or minor economies in the provision of rail line infrastructure. The output specific scale economies seem to be minor as do the diseconomies of producing them jointly.

2.4. SUMMARY OF THE COST STRUCTURE FOR CARRIERS AND INFRASTRUCTURE

The full costs of a mode are the sum of infrastructure costs and modal services costs. Since the choice of a particular basis for infrastructure pricing will influence the modal choices of the end users, optimal pricing strategies and cost recovery should consider the combined cost of infrastructure provision and carrier (or user) costs in order to maximize social welfare. If markets for carrier services are competitive and there are no economies in the provision of infrastructure for the mode, marginal [social] cost pricing will yield a socially efficient outcome and full cost recovery. If there are economies, from whatever source in the provision of infrastructure, efficient pricing may result in a deficit while constraining prices to recover costs may lower social welfare.

2.4.1 Air

For the airline industry, a number of studies have been directed at determining the behavior of an airline's cost function with respect to changes in the level and composition of output. The studies have shown that the long run average cost curve is relatively constant over a wide range of output; that is, there are no economies of scale in the airline industry. This means that the size of a carrier does not generate lower per-unit costs. In particular, Gillen, Oum, and Tretheway (1985, 1990) found that the airline industry experienced economies of traffic density; that is, the unit cost would decrease for all carriers if they carried more traffic within their given network. This result has been corroborated by other authors.

Studies also concluded that airport capacity construction is as well characterized by no economies of scale. This implies that the combined cost of carriers and infrastructure is also characterized by no economies of scale.

2.4.2 Road

There are somewhat different results for intercity bus and truck. Several empirical studies of the trucking industry have found no economies of scale in the industry while studies on the intercity bus industry have found that the hypothesis of no economies of scale is rejected in favor of diseconomies of scale. The research has also found there to be no economies of scope between the three outputs, namely, scheduled passenger, charter, and contract services. There is no empirical evidence on density economies, however, observing the parallel mergers which have occurred in the US and UK. bus industry after deregulation, one might hypothesize there are density economies.

Road infrastructure yields two outputs, namely, traffic volume which requires capacity (measured in number of lanes), and standard axle loading which requires durability (measured in thickness of pavement). Small, Winston, and Evans (1989), reported the existence of significant economies of scale with respect to the durability of road, and mild economies of scale with respect to traffic volume. However, they reported diseconomies of scope from the production of both durability and traffic volume because as the road is made wider to accommodate more traffic, the cost of any additional thickness rises, since all the lanes must be built to the same standard of thickness. The final outcome of these three factors at work is that highway capacity construction will be characterized by approximately no economies of scale. In other words, the output-specific economies of scale are offset by the diseconomies of scope for having to produce them jointly. Since they included both infrastructure costs and the costs incurred by road users (individual drivers and transportation carriers) in the total cost of highway modes, their result is that overall there are no economies of scale for the combined cost of highways and users.

2.4.3 Rail

An important difference, currently, between the railway mode and other modes is that rail infrastructure is provided by carriers and thus the infrastructure cost is reflected in the freight rates and passenger fares. Since railway companies provide their own infrastructure (with some exceptional cases such as VIA Rail in Canada and Amtrak in the US), the carrier's cost structure represents those of the combined carrier and infrastructure costs.

For the railway industry, several studies in the US have shown that the railway industry is characterized by no economies of scale over the relevant range of output. However, for firms of small sizes, studies have indicated that economies of scale are present. On the other hand, all studies have shown that there are large and significant economies of traffic density in railway services.

2.5. SOME INTERNATIONAL ESTIMATES OF FULL COST

There has been considerable research undertaken in Europe on intercity modes whereas the US research has paid much more attention to the full costs of motor vehicle travel in urban areas. It is also true that the American studies have also included a broader range of impacts mostly due to the urban focus. At the same time there is less research on the use of pricing strategies as a means of internalizing these externalities.

There is debate as to what should legitimately be included in the calculation of ‘full costs’. Part of the debate focuses upon what impacts to include. This issue is discussed at some length in Chapter 3. The other part of the debate focuses on ‘where’ the impact occurs. Lee (1995), for example, argues that those externalities which are internal to the users of the mode (such as congestion) should not be included in full cost calculation since their expenses have already been included in user costs. There is still debate in this point. The move to ‘internalize’ the environmental costs of the different modes of transportation is evident in a number of countries around the world. One need only examine the large difference in gasoline taxes between the US and Europe, Japan and even Canada to recognize the difference in perception of private and social costs in the US and elsewhere. One must be careful, however, in making these comparisons since in many countries governments use fuel taxes as a source of general tax revenue rather than as a method of pricing externalities.

A recent comprehensive study undertaken in Canada measured the full [unit] costs of the alternative intercity modes of transportation. These are illustrated in Table 2. 5-1 in which the costs per passenger-kilometer are represented. Although calculated on a unit or average basis they provide some important information. First, they indicate the distribution of costs across cost categories and how this varies by mode. Secondly, they provide a measure of the relative burden of who is paying and who is benefiting, again for each mode. They, therefore, permit the identification of which mode is subsidized, by how much, and in which category of cost they are subsidized.

2. 5-1: System-Wide Annual Costs of Intercity Domestic Travel

			Automobile				Bus	
Type of Cost		Users	Others	Total		Users	Others	Total
Infrastructure		0.0	1.7	1.7		0.0	0.3	0.3
Environmental		0.0	0.5	0.5		0.0	0.2	0.2
Accident		3.7	0.1	3.1		0.3	0.0	0.3
Special transportation tax or fee		1.0	-1.0	0.0		0.3	-0.3	0.0
Vehicle/Carrier		8.7	0.0	8.7		6.7	0.2	6.9
Total		12.6	1.4	14.0		7.2	0.4	7.7

			Airplane				Train	
Type of Cost		Users	Others	Total		Users	Others	Total
Infrastructure		1.9	2.7	4.6		2.3	0.0	2.3
Environmental		0.0	0.8	0.8		0.0	0.5	0.5
Accident		0.1	0.0	0.1		0.2	0.0	0.2
Special transportation tax or fee		0.6	-0.5	0.0		0.3	-0.3	0.0
Vehicle/Carrier		11.5	0.1	11.6		5.9	26.2	32.1
Total		13.9	3.1	17.0		8.5	26.4	34.9

			Ferry				All Intercity Travel	
Type of Cost		Users	Others	Total		Users	Others	Total
Infrastructure		0.0	3.8	3.8		0.2	1.8	2.0
Environmental		0.0	1.6	1.6		0.0	0.5	0.5
Accident		0.1	0.0	0.1		2.6	0.2	2.8
Special transportation tax or fee		0.9	-0.7	0.0		0.9	-0.9	0.0
Vehicle/Carrier		24.1	9.2	28.6		9.0	0.2	9.2
Total		25.1	13.9	34.1		12.5	1.6	14.5

Note: average costs, cents per passenger kilometer traveled (1994 Dollars US)
Source: Report of the Royal Commission on National Passenger Transportation, 6 Volumes

2.6. ANALYTICAL FRAMEWORK FOR COST MODELING

Our objectives in the study are to estimate the full long run cost of providing intercity passenger transportation services by high speed rail, and compare that with the highway and air modes. The cost calculation is to include the cost of building, operating, and maintaining infrastructure, as well as carrier, user, and social costs. Social costs include noise, air pollution, and accident costs, as well as congestion costs. User costs include the cost of purchasing, maintaining and operating a vehicle such as a car, and the cost of travel time.

We begin by developing a taxonomy for representing the full costs of transportation, independent of mode:

Infrastructure Costs - including capital costs of construction and debt service (ICC), and costs of maintenance and operating costs as well as service costs to government or private sector (IOC);

Carrier Costs - aggregate of all payments by carriers in capital costs to purchase a vehicle fleet (CCC), and maintain and operate a vehicle fleet (COC), minus those costs (such as usage charges) which are transfers to infrastructure, which we label **Carrier Transfers (CT).**

User Money Costs - aggregate of all fees, fares and tariffs paid by users in capital costs (UCC) to purchase a vehicle, and money spent to maintain and operate the vehicle or to ride on a carrier (UOC); less those costs (such as fares) which are transfers to carriers or infrastructure, and accident insurance, which is considered under social costs, which we label **User Transfers** (UT).

User Travel Time Costs (UTC) - the amount of time spent traveling under uncongested conditions multiplied by the monetary value of time.

User Congestion Costs (UCC)- the amount of time spent traveling under congested conditions minus the amount of time spent traveling in uncongested conditions multiplied by the monetary value of time.

Social Costs - additional net external costs to society due to emissions (SEC), accidents (SAC), and noise (SNC) and are true resource costs used in making and using transportation services;

The method used to estimate the full cost (FC) of intercity travel will combine elements from a number of sources. Adding and subtracting the above factors, thereby avoiding double-counting, we have the following equation, the components of which will be dealt with in turn in the paper:

$$FC = ICC + IOC + CCC + COC - CT + UCC + UOC - UT + UTC + UCC + SEC + SNC + SAC$$

Each of these cost elements is a function of a number of parameters. Except for the fixed cost components, these elements are dependent on the level of output. In this study, we estimate flow dependent cost functions whenever possible. We also estimate point estimates of full cost for the California corridor using available forecasts of traffic flow on each of the three modes considered. In the case of high speed rail, we use designs and alignments that have been proposed by previous studies for the California Corridor.

CHAPTER THREE: SOCIAL COSTS

3.1. DEFINITIONS

There has been a great deal of recent interest in the issue of the social or external costs of transportation (see for instance: Keeler et al. 1974, Fuller et al. 1983, Mackenzie et al. 1992, INRETS 1993, Miller and Moffet 1993, IWW/INFRAS 1995, IBI 1995). The passions surrounding social costs and transportation, in particular those related to the environment, have evoked far more shadow than light. At the center of this debate is the question of whether various modes of transportation are implicitly subsidized because they generate externalities, and to what extent this biases investment and usage decisions. On the one hand, exaggerations of environmental damages as well as environmental standards formulated without consideration of costs and benefits are used to stop new infrastructure. On the other hand, the real social costs are typically ignored in financing projects or charging for their use.

Associated with the interest in social and external cost has been a continual definition and re-definition of externalities in transportation systems. Verhoef (1994) states "An external effect exists when an actor's (the receptor's) utility (or profit) function contains a real variable whose actual value depends on the behavior of another actor (the supplier) who does not take these effects of his behavior into account in this decision making process." This definition eliminates pecuniary externalities (for instance, an increase in consumer surplus), and does not include criminal activities or altruism as producers of external benefits or costs. Rothengatter (1994), cites DeSerpa with a similar definition: "an externality is a relevant cost or benefit that individuals fail to consider when making rational decisions." Verhoef (1994) divides external cost into social, ecological, and intra-sectoral categories, which are caused by vehicles (in-motion or non-in-motion) and infrastructure. To the externalities we consider (noise, congestion, accidents, pollution), he adds the use of space (e.g. parking) and the use of matter and energy (e.g. the production and disposal of vehicles and facilities). Button (1994) classes externalities spatially, considering them to be local (noise, lead, pollution), transboundary (acid rain, oil spills), and global (greenhouse gases, ozone depletion). Gwilliam (1994) combines Verhoef's and Button's schemes, looking at a Global, Local, Quality of Life (Social), and Resource Utilization (air, land, water, space, materials) classification.

Rothengatter (1994) views externalities as occurring at three levels: individual, partial market, total market, and argues that only the total market level is relevant for checking the need of public interventions. This excludes pecuniary effects (consumer and producer surplus), activities concerning risk management, activities concerning transaction costs. Externalities are thus public goods and effects that cannot be internalized by private arrangements.

Rietveld (1994) identifies temporary effects and non-temporary effects occurring at the demand side and supply side. Maggi (1994) divides the world by mode (road and rail) and medium (air, water, land) and considers noise, accidents, and community and ecosystem severance. Though not mentioned among the effects above, to all of this might be added the heat output of transportation. This leads to the "urban heat island" effect -- with its own inestimable damage rate and difficulty of prevention.

Coase (1992) argues that the problem is that of actions of firms (and individuals) which have harmful effects on others. His theorem is restated from Stigler (1966) as "... under perfect competition, private and social costs will be equal." This analysis extends and controverts the argument of Pigou (1920), who argued that the creator of the externality should pay a tax or be liable. Coase suggests the problem is lack of property rights, and notes that the externality is caused by both parties, the polluter and the receiver of pollution. In this reciprocal relationship, there would be no noise pollution externality if no-one was around to hear. This theory echoes the Zen question "If a tree falls in the woods and no-one is around to hear, does it make a sound?". Moreover, the allocation of property rights to either the polluter or pollutee results in a socially optimal level of production, because in theory the individuals or firms could merge and the external cost would become internal. However, this analysis assumes zero transaction costs. If the transaction costs exceed the gains from a rearrangement of activities to maximize production value, then the switch in behavior won't be made.

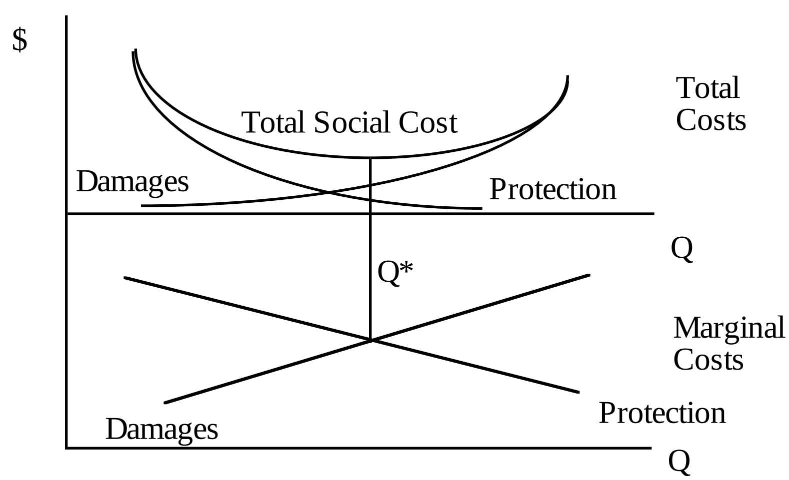
There are several means for internalizing these external costs. Pigou identifies the imposition of taxes and transfers, Coase suggests assigning property rights, while our government most frequently uses regulation. To some extent all have been tried in various places and times. In dealing with air pollution, transferable pollution rights have been created for some pollutants. Fuel taxes are used in some countries to deter the amount of travel, with an added rationale being compensation for the air pollution created by cars. The US government establishes pollution and noise standards for vehicles, and requires noise walls be installed along highways in some areas.

Therefore, a consensus definition might be "Externalities are costs or benefits generated by a system (in this case transportation, including infrastructure and vehicle/carrier operations,) and borne in part or in whole by parties outside the system."

3.1.1 Economic Tradeoffs

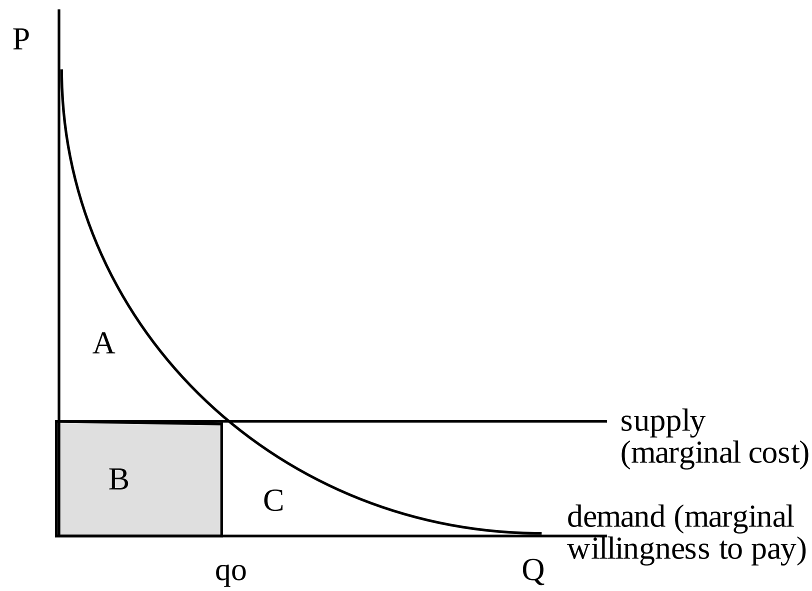
The tradeoff between benefits and costs is central to most economic analyses. Costs and benefits are both measurable and immeasurable, and a complete analysis must consider transaction and information costs as well as market costs. Individuals strive to maximize net benefits (benefits after considering costs), society might apply this to social costs as well. Reducing damages requires increasing protection (defense, abatement, or mitigation) to attenuate the damage. At some point, the cost of protection outweighs the benefit of reducing residual damages. This is illustrated in Figure 3.1-1 below. Whether this point is at zero damages (no damage is acceptable), zero protection (the damage is so insignificant as to be irrelevant), or somewhere in between is an empirical question. The concept is illustrated in the following Figure. Total social costs are minimized where the marginal cost of additional damages equals the cost of additional protection. This research will attempt to identify the full cost curves of both damage and of protection over the range of externalities caused by intercity transportation in California. Whether the marginal costs of damage and of protection are fixed, rising or declining with output, and by how much will be another important empirical question.

Figure 3.1-1: Social Costs: Damages vs. Protection



The notion of damages and protection is compatible with the idea of supply and demand, as illustrated in Figure 3.1-2. Here, the change in damages with output (dD/dQ) is the demand curve (the marginal willingness to pay to avoid damage), and the change in protection (attenuation) with output is the supply curve (marginal cost) and represented as (dA/dQ). Again, the slopes of the curves are speculative:

Figure 3.1-2



In Figure 3.1-2, area A represents the consumer surplus, or the benefit which the community receives from production, and is maximized by producing at qo (marginal cost of protection or attenuation equals the marginal cost of defense). The shaded area B represents production costs, and is the amount of social cost at the optimal level of production. Area C is non-satisfied demand, and does not result in any social costs so long as production remains at qo.

3.1.2 Systems Approach

Central to the definition and valuation of exernalities is the definition of the system in question. The intercity transportation system is open, dynamic, and constantly changing. Some of the more permanent elements include airports, intercity highways , and railroad tracks within the state. The system also includes the vehicles using those tracks (roads, rails, or airways) at any given time. Other components are less clear cut - are the roads which access the airports, freeways, or train stations part of the system? The energy to propel vehicles is part of the system, but is the extraction of resources from the ground (e.g. oil wells) part of the system? DeLuchi (1991) analyzes them as part of his life-cycle analysis, but should we? Where in the energy production cycle does it enter the transportation system?

Any open system influences the world in many ways. Some influences are direct, some are indirect. The transportation system is no exception. Three examples may illustrate the point:

a) Cars on roads create noise—this we consider a direct effect.

b) Roads reduce the travel time between two places, which increases the amount of land development along the corridor—this is a less direct effect, not as immediate or obvious as the first. Other factors may intervene to cause or prevent this consequence.

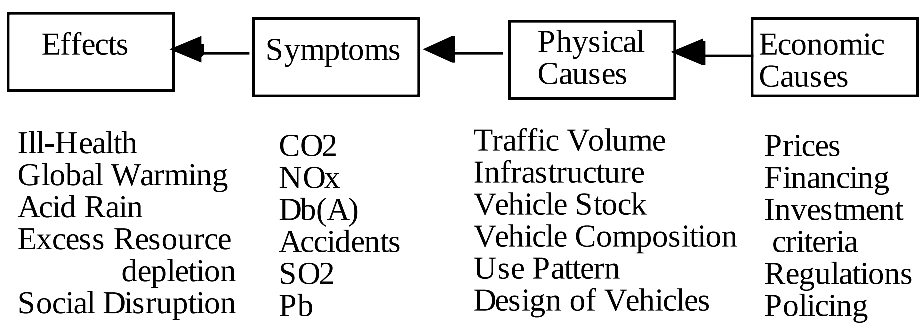
c) The new land development along the corridor results in increased demand for public schools and libraries—this is clearly an indirect effect of transportation.

As can be seen almost immediately, there is no end to the number or extent of indirect effects. While recognizing that the economy is dynamic and interlinked in an enormous number of ways, we also recognize that it is almost impossible to quantify anything other than proximate, first order, direct effects of the transportation system. If the degree to which "cause" (transportation) and "effect" (negative externality) are correlated is sufficiently high, then we consider the effect direct; the lower the probability of effect following from cause, the less direct is the effect. The question of degree of correlation is fundamentally empirical.

On the other hand, this raises some problems. Automobiles burn fuel that causes pollution directly. Electric powered high speed rail uses energy from fuel burned in a remote power plant. If the electricity is fully priced, including social costs, then there is no problem in excluding the power plant. But, if the social costs of burning fuel in a power plant are not properly priced, then to ignore these costs would be biased. This is the problem of the "first best" and "second best". The idea of the first best solution suggests that we optimize the system under question as if all other sectors were optimal. The second best solution recognizes that other systems are also suboptimal. Clearly, other systems are suboptimal to some extent or another. However, if we make our system suboptimal in response, we lessen the pressure to change the other systems. In so doing we effectively condemn all other solutions to being second best.

Button (1994) develops a model relating ultimate economic causes to negative externalities and their consequences as summarized in the following graphic. Users and suppliers do not take full account of environmental impacts, leading to excessive use of transport. Button argues that policy tools are best aimed at economic causes, but in reality measures are aimed at any of four stages. Here we are considering the middle stage, physical causes and symptoms, and are ignoring feedback effects.

Figure 3.1-3: Causes and Effects after Button (1994)



Another view has the "externalities" as inputs to the production of transportation, along with typical inputs as construction of transportation and the operation and maintenance of the system. There are multiple outputs, simplified to person trips and freight trips, although of course each person trip is in some respects a different commodity. This view comports with Becker's (1965) view that households use time in the production of commodities -- of which travel might be one.

3.1.3 Classifying Externalities

In this analysis, we have divided these direct external costs (inputs) into four main categories: Congestion (Time), Accidents (Life and Health), Environmental (Clean Air, Water, and Land, Ecosystem Continuity, Heat, Ozone Layer, Acid Rain, Greenhouse

Gases) and Noise and Vibration (Peace and Quiet). These categories will be discussed in depth in later chapters. The purpose of the following sections is to develop, to the extent possible, a common methodology for estimating these costs as a function of transportation system outputs for each mode: air, highway, and high speed rail.

3.2. MEASURING THE COST OF EXTERNALITIES

The cost of an externality is a function of two equations. The first relates the physical production of the externality to the amount of transportation output. The second computes the economic cost per unit of externality. The amount of an externality produced by transportation is the result of the technology of the transportation, as well as the amount of defense and abatement measures undertaken. There are several issues of general concern in the physical production of externalities. They are classified as: fungibility, geography, life cycle, technology, and point of view. Each are addressed in turn.

◊ **Fungibility**

"Is the externality fungible?" In other words, does the externality which is physically produced by the system under question have to be eliminated or paid for, or can something substitute for it. For example, a car may produce X amount of Carbon Dioxide. If carbon dioxide were not fungible, then that X would need to be eliminated, or a tax assessed based on the damage that X causes. However, if it were fungible, then an equivalent amount X could be eliminated through some other means (for instance, by installing pollution control on a factory or by planting trees). The second option may be cheaper, and this may influence the economic effects of the pollution generated.

◊ **Geography**

"Over what area are the externalities considered?" "Is a cost generated by a project in California which is borne by those outside California relevant?" This is particularly important in estimating environmental costs, many of which are global in nature. If we try to estimate damages (rather than the protection costs of defense, abatement, and mitigation), this becomes particularly slippery. However, if we can assume fungibility, and use the cost of mitigation techniques, the measurement problem becomes much simpler. Ideally, we would obtain estimates for both protection and damages in order to determine the tradeoffs.

◊ **Life Cycle**

In some respects we would like to view the life-cycle of the transportation system. But it becomes more difficult to consider the life-cycle of every input to the transportation system. The stages which may be considered include: Pre-production, construction, utilization, refurbishing, destruction, and disposal. Ignoring the life-cycle of all inputs may create some difficulties. Electric power will produce pollution externalities at production in a power plant, before it enters the transportation system. Thus, modes using electric power (rail, electric cars), would be at an advantage using this decision rule over modes which burn fuel during the transport process (airplanes, gasoline powered cars, diesel trains). This is true, though to a lesser extent, with other inputs as well.

◊ **Technology**

The technology involved in transportation is constantly changing. The automobile fleet on the ground in 2000 will have very different characteristic than that in the year 1900 regarding the number of externalities produced. Hopefully, cars will be safer, cleaner, and quieter. Similar progress will no doubt be made in aircraft and trains. While the analysis will initially assume current technology, sensitivity tests should consider the effect that an improved fleet will have on minimizing externality production.

◊ **Macro vs. Micro Analysis Scale**

Estimates for externalities typically come in two forms macro and micro levels of analysis. Macroscopic analysis uses national (or global) estimates of costs as share of gross domestic product (GDP), such as Kanafani (1983), Quinet (1990), and Button (1994). The data for microscopic analysis is far more dispersed. It relies on numerous engineering and empirical cost-benefit and micro-economic studies. By and large, this study is a microscopic analysis, though, on occasion, the macroscopic numbers will be used as benchmarks for comparison and estimates of data where not otherwise available. This will be true for both the physical production of externalities as well as their economic costs through damages borne or protection/attenuation measures.

Once cost estimates are produced, they can be expanded to estimate the state-wide social costs of transport as a share of state product (California GDP), which can be compared with other national estimates.

3.2.1 Issues Concerning the Economic Cost of Externalities

Two important issues of concern in measuring the economic cost of externalities are: the basis over which the output is measured and the consistency of the measurement . When estimating the full cost of externalities, the amount of externality is not simply the amount of traffic on the road multiplied by some externality rate. Rather, it must be measured as the difference between what is generated systemwide with and without the facility. For instance, a new freeway lane will have several effects: diverting existing traffic from current facilities, inducing new traffic on the new facility, and inducing new/different traffic on the old facility. The amount of this change must be accurately determined with a general equilibrium approach to estimate demand. In a general equilibrium approach, the travel time/cost used to estimate the amount of demand is equal to the travel time/cost resulting from that demand. Switching traffic from an older facility to a newer facility may in fact reduce the amount of negative externalities generated. For instance, the number of accidents or their severity may decline if the new facility is safer than the old. On the other hand, the induced traffic, while certainly a benefit in that it increases commerce, also imposes new additional costs, more accidents, pollution and noise. It is the net change which must be considered.

When addressing the costs of externalities, the estimates used across all externalities should be consistent. Cost estimates contain implicit assumptions, particularly concerning the value of time, life, and safety. Key questions can be asked of any study:

- Is the value of life and health used in estimating the cost of accidents the same as used in estimating the human effects of pollution?

- Is the value of time used consistent between congestion costs and accidents? With congestion, many are delayed a small time, accidents (ignoring congestion implications), a few are delayed a long time.

3.2.2 Cost-Function Estimation Methods

Many approaches have been undertaken to estimate the costs of externalities. The first class of approaches we call "Damage" based methods, the second can be called "Protection" based methods. The damage based methods begin with the presumption that there is an externality and it causes X amount of damage through lower property values, quality of life, and health levels.

The protection methods estimate the cost to protect against a certain amount of the externality through abatement, defense, or mitigation. One example of a defense measure is thicker windows in a house to reduce noise from the road. An abatement measure would have the highway authority construct noise walls to reduce noise or require better mufflers on vehicles. A mitigation measure may only be applicable for certain types of externalities; e.g. increased safety measures that reduce accidents on one facility also offset the increased number of accidents on another facility.

Rising marginal costs are expected of protection measures. The first quantity of externality abated /defended/mitigated is cheaper than the second and so on because the most cost-effective measures are undertaken first. This is not to say there are no economies of scale in mitigating externalities within a given mitigation technology. It merely suggests that between technologies, costs will probably rise.

The mitigation approach can be applied if we consider the externality fungible. Air pollution from the road may cause as much damage as an equivalent amount of pollution from nearby factories. The most cost effective approach to eliminating the amount of pollution produced by the road may come from additional scrubbers on the factory. While it may be prohibitively expensive to eliminate 100% of roadway pollution from the roadway alone, it may be quite reasonable to eliminate the same amount of pollution from the system. Determining the most effective method of mitigating each system-wide externality requires understanding the nature of its fungibility.

Neither of these two approaches (Damages or Protection) will necessarily produce a single value for the cost of a facility. It is more likely that each approach will produce a number of different cost estimates based on how it is undertaken and what assumptions are made. This reinforces the need for sensitivity analyses and a well-defined “systems” approach.

We divide the techniques of costing into three main categories: revealed preference, stated preference, and implied preference. Revealed preference is based on observed conditions and how individuals subject to the externality behave, stated preference comes from surveys of individuals in hypothetical situations, while implied preference looks at the cost which is implied based on legislative, executive, or judicial decisions.

◊ Revealed Preference

The revealed preference approach attempts to determine the cost of an externality by determining how much damage reduces the price of a good.

Revealed preference can also be used to estimate the price people pay for various protection (defense/ abatement) measures and the effectiveness of those measures. For instance, insulation costs a certain amount of money and provides a certain amount of effectiveness in reducing noise. The extent to which individuals then purchase insulation or double-glazed windows may suggest how much they value quiet. However, individuals may be willing to spend some money (but less than the cost of insulation) if they could ensure quiet by some other means which they do not control - but which may be technically feasible.

- Hedonic Models: The most widely used estimates of the cost of noise are derived from hedonic models. These assume that the price of a good (for instance a home) is composed of a number of factors: square footage, accessibility, lot area, age of home, pollution, noise, etc. Using a regression analysis, the parameters for each of these factors are estimated. From this, the decline in the value of housing with the increase in the amount of noise can be estimated. This has been done widely for estimating the social cost of road noise and airport noise on individual homes.

In theory, the value of commercial real estate may be similarly influenced by noise. In our literature review thus far, no study of this sort has been found. Furthermore, although noise impacts public buildings, this method cannot be used as a measure since public buildings are not sold.

Similarly, when determining some of the costs of noise, one could investigate how much individuals might be willing to pay for vehicles which are quieter. Like a home, a hedonic model of vehicle attributes could be estimated. A vehicle is a bundle of attributes (room, acceleration, MPG, smooth ride, quiet, quality of workmanship, accessories) which influence its price, also an attribute.

- Unit/Cost Approach: A simple method, the "unit cost (Rate) approach" is used often for allocating costs in transit. This method assigns each cost element, somewhat arbitrarily, to a single output measure or cost center (for instance, Vehicle Miles Travel, Vehicle Hours Travel, Number of Vehicles, Number of Passengers) based on the highest statistical correlation of the cost with output.

- Wage/Risk Study: A means for determining the economic cost of risk to life or health or general discomfort is by analyzing wage/salary differentials based on job characteristics, including risk as a factor.

- Time Use Study: This approach measures the time used to reduce some risk by a certain amount. For instance, seatbelts reduce the risk of injury or using pedestrian overpass may reduce the risk of being hit by a car. The time saved has a value, which may inform estimates of risk aversion.

- Years Lost plus Direct Cost: This method estimates the number of years lost to an accident due to death and years lost from non-fatal injuries. It also the monetary costs of non-life damages. However, it defines life in monetary terms. While it may have some humanistic advantages in that it does not place a dollar value on life, defining life through dollars and sense may have some practical value. Defining life through dollars and sense may help us assess whether an improvement, with a certain construction cost and life-saving potential, is economically worthwhile.

- Comprehensive : This accident costing method extends the Years Lost plus Direct Cost method by placing a value on human life. The value is assessed looking at the tradeoffs people make when choosing to conduct an activity a certain risk level versus another activity at a different risk, but different cost/time. Studies are based both on what people actually pay and what are willing to pay, and use a variety of revealed preference techniques. This is the preferred method of the US Federal Highway Administration.

- Human Capital: The Human Capital approach is an accounting approach which focuses on the accident victim's productive capacity or potential output, using the discounted present value of future earnings. To this are added costs such as property damage and medical costs. Pain and suffering can added as well. The Human Capital approach can be used for accidents, environmental health, and possibly congestion costs . It is used in the Australian study Social Cost of Road Accidents (1990). However, Miller (1991) and others discount the method because the only effect of injury that counts is the out-of-pocket cost plus lost work and housework. By extension, it places low value on children and perhaps even a negative value on the elderly. While measuring human capital is a necessary input to the costs of accidents, it cannot be the only input.

◊ Stated Preference

Stated preference involves using hypothetical questions to determine individual preferences regarding the economic costs of a facility. There are two primary classes of stated preference studies: Contingent Valuation and Conjoint Analysis.

- Contingent Valuation: Perhaps the most straight-forward way of determining the cost of an externality is asking the hypothetical questions, "How much you would a person pay to reduce externality by a certain amount" or "How would a person pay to avoid the imposition of a certain increment of externality". Jones-Lee (1990) has been the foremost investigator into this method for determining the cost of noise. This method can, in theory, be applied to any recipient of noise, although it has generally been asked of the neighbors (or potential neighbors) of a transportation facility.There are several difficulties with this approach. The first difficulty with any stated preference approach is that people give hypothetical answers to hypothetical questions. Therefore, the method should be calibrated to a revealed preference approach (with actual results for similar situations) before being relied upon as a sole source of information. The second regards the question of “rights”. For instance, someone who believes he has the right to quiet will not answer this question in the same way as someone who doesn’t. The third involves individuals who may claim infinite value to some commodity, which imposes difficulties for economic analysis.

- Conjoint Analysis: To overcome the problems with contingent valuation, conjoint analysis has been used. Conjoint analysis requires individuals to tradeoffs between one good (e.g. quiet) and another (e.g. accessibility) has been used to better measure the cost of noise, as in Toronto by Gillen (1990).

◊ **Implied Preference**

There are methods for measuring the costs of externalities which are neither revealed from individual decisions nor stated by individuals on a survey. These are called implied preference because they are derived from regulatory or court-derived costs.

- Regulatory Cost : Through government regulation, costs are imposed society with the aim of reducing the amount of noise or pollution or hazard is produced. These regulations include vehicle standards (e.g. mufflers) roadway abatement measures such as noise walls, as well as the many environmental regulations. By determining the costs and benefits of these regulations, the implicit cost of each externality can be estimated. This measure assumes that government is behaving consistently and rationally when imposing various standards or undertaking different projects.

- Judicial Opinion and Negotiated Compensation: Similar to the implicit cost measure, one can look at how courts (judges and juries) weigh costs and benefits in cases which come before them. The cost per unit of noise or life from these judgments can be determined. This method is probably more viable in accident cases.

3.2.3 Incidence, Cost Allocation and Compensation

This final set of topics deal with incidence (who causes the externality), cost allocation (who suffers from the externality), and compensation (how can the costs be appropriated and compensation paid fairly).

◊ **Incidence**

The general model is that the costs can be generated by one of several parties and fall on one of several parties. The parties in this case are: the vehicle operators and carriers; the road, track, and airport operators; and the rest of society.

- Vehicle Operators and Carriers: bus company, truck company, driver of a car, railroad, airline

- Road/Track/Airport Operator: Department of Transportation, railroad, airport authority

- Society: the citizenry, government, citizens of other states/countries, the environment

This conceptual model is not concerned with anything smaller than the level of a vehicle. How costs on a vehicle are attributed to passengers in the vehicle, or the costs of freight carriage to the shipper, is not our concern. Similarly, ownership is not an issue, the operator of a vehicle may not be the owner, in the case, for instance, of a rented car. Obviously there is some overlap here between vehicle operators and road and track operators. In the case of American railroads, the firm which operates trains usually owns the track, although often a train will ride on tracks owned by a different railroad. Moreover, for some means of transportation, but not those considered here, there may be no vehicles (for example pipelines and conveyor belts.)

Costs can be imposed in any cell of this matrix:

Generator \ Recipient		Vehicle Operators: Self	Vehicle Operators: Others	Road & Track Operators: Self	Road & Track Operators: Others	Society: Local	Society: Global
Vehicle Operators	Self						
	Others						
Road & Track Operators	Self						
	Others						
Society	Local						
	Global						

As an illustration of how this model works, we look at noise. Transportation noise is generated by vehicles in motion, and can affect any of the following classes: self, other vehicle users, and local society. There is noise generated by the roadway or the rail during construction, but this is ignored, and the noise does not actually hurt the road and track operators (except indirectly where they are held responsible for noise generated by vehicles and must build noise walls or other abatement measures.) A similar situation occurs with airports. Technically the planes make almost all of the noise, but the airport is held responsible. That noise is generated by wheels on pavement and thus depends in some respects on the roadway operator is also ignored.

• Vehicle operator on self, on other vehicles. For instance, one of the attributes of a vehicle (an auto say) is its quietness, this is reflected in the price of the vehicle. Quietness has two aspects: insulation, which protects the cab from noise generated by the car and other vehicles; and noise generation, which is how noisy the car is to itself and others. The noise generated by the vehicle and heard within the cab are internal costs, while those generated by the vehicle and heard by others is external to the vehicle operator, but internal to the transportation system.

• Vehicle operator on society. The noise generated by a vehicle negatively impacts the usefulness and flexibility of land uses nearby, where the impact declines with distance. The decline in utility is reflected in land values. The costs are clearly external to both the operator and the transportation system.

◊ Cost Allocation

Clearly there are external costs, but it is not always clear who should bear them. This issue brings about questions of cost allocation. These include: objectives - for what reason are we allocating costs, methodology - how are we allocating costs, structure - how do we break down costs, and problems - how do we deal with the thorny issues of common and joint costs and cross-subsidies.

The first question that must be asked is what are the objectives of cost allocation. There are several contenders, which unfortunately are not entirely compatible. These include equity, efficiency, effectiveness, and acceptability.

The first consideration is equity or fairness. This concept raises a series of question summarized as “equity for whom”. Depending on how you slice it, different “fair” solutions are possible. The classic divisions are vertical vs. horizontal equity. Horizontal equity is a fair allocation of costs between users in the same sector, vertical equity is fairness across sectors. Are the costs allocated “fairly” between users, between facilities, between modes, between economic sectors? Is the burden for the project shared fairly between the economy and the environment?

The second consideration is efficiency. Somewhat clearer than equity, efficiency still raises the same questions of “for whom.” Is the allocation efficient for the user, the operator, the state, the country? Does it consider inefficiencies, subsidies and taxes in other sectors of the economy, or other components of the transportation system?

Efficiency can also be stratified into two categories: theoretical and practical.. The first ignores implementation (information and transaction) costs that rise with the number of charges imposed. Moreover, economists identify three kinds of efficiency: Allocative, which aims for the optimal mix of goods; Productive, which attempts to attain the minimum average cost; and Dynamic, which seeks long term optimal investment or capital rationing. Allocative efficiency may be thought of as congestion pricing, to ensure the optimal use of a transportation facility. Productive efficiency will attempt to raise enough money to operate and maintain the physical plant at the lowest cost. Dynamic efficiency will attempt to raise money to finance the facility, proactively or retroactively. To what extent these goals coincide is unclear.

Contrasted with efficiency is effectiveness. While the test of efficiency asks if the system is achieving its goals with minimum effort, the test of effectiveness asks if the system's goals or output measures are consistent with broader societal goals. For instance, an efficient road may move traffic through a neighborhood at a high rate of speed, but this may be ineffective in meeting the broader social goal of a higher quality of life in the neighborhood, which the traffic disrupts. Costs can be allocated which achieve an efficient use of resources, but result in an ineffective or counter-productive system.

Added to this, we will consider the profit motive. If the facility is constructed by a profit seeking firm, prices will reflect an attempt at profit maximization in either a competitive, monopolistic, or oligopolistic environment.

A last consideration is acceptability. A system, which may have desirable attributes, if unimplemented, serves no-one. In the political world, tradeoffs and compromises must be made to achieve progress.

Costs can be allocated based on who causes them or by who receives benefit from them. There are pricing schemes reflecting both. There is a dichotomy between the methods of cost allocation suggested by economists and the approaches taken by engineers (as well as the official policy of the US government through modal cost allocation studies).

At least three economic approaches can be taken for allocating costs. The economic top-down approaches take equations of cost and allocate the results to users, these are: average total cost per user, average variable cost per user, and marginal cost (short run and long run), the last of which is favored by economists.

On the other hand, engineers working from the bottom-up break the system into components, which are assigned to users. Each mode or carrier has somewhat different methods for cost allocation. These are summarized below:

- Fixed Allocation - a set fee is charged based on some previous study

- Industry Agreed Upon (e.g. General Managers Associations Rules - rules allocating costs of freight cars on foreign rails, a pre-established agreement)

- Zero Allocation - user gets free ride on common costs and pays only attributable costs

- Proportional (New Investment/Long Range Pricing) - divides variable and fixed costs to users in proportion to use

- Minimum Cost of Service: Avoidable Cost Allocation (hierarchy costs/avoidable costs/separable costs/remaining benefits) - assigns to a beneficiary only the costs which could be avoided if the beneficiary did not use the service

- Minimum Cost of Service: Attributable Cost Allocation - assigns as cost allocation + share of common costs based on use.

- Minimum Cost of Service: Priority of Use Cost Allocation - assigns attributable cost allocation, but charges extra if priority is given to user or discounts if priority is taken from user (e.g. queue jumping)

In addition to the centralized cost allocation methods described above, there are other methods of allocation to users:

- Negotiated contracts - the parties negotiate the charge based on individual circumstances. This is often used in the rail industry where the trains of one carrier use the tracks of another.

- Arbitration - like a negotiated contract, but where a third party makes ultimate decision on the charge.

- Regulatory finding - A regulatory agency such as the former Interstate Commerce Commission gathers information and makes a decision as to appropriate rate. This is now most widely used in cases of monopoly oligopoly practice.

- Legislative finding - A legislature assumes the role of regulatory agency and prices and/or conditions of the cost allocation. An example of this is the adoption of taxes supporting the highway system, where gas taxes, vehicle licenses, and truck charges as well as tolls have to be approved by the state legislature.

- Judicial finding - After some dispute between parties (carrier vs. carrier, carrier vs. government or government vs. government) a court may be called on to make a final decision.

- Ramsey Pricing Rule - This rule would charge based on the customer's elasticity of demand. The more elastic the customer (the more options he has the lower his price. So long as the short run marginal cost is covered, it may worthwhile for one firm to use this pricing rule to keep customers using their service rather than a competitors.

- Discriminating Monopolist/Oligopolist An unregulated monopoly discriminate among customers to obtain higher revenues (capture the consumer surplus). There are three classes of monopolistic discrimination: (1st degree, degree, 3rd degree).

The engineering and economic cost allocation discussed above allocate the costs to users. But there are alternative approaches:

- General Revenue: If transportation is to be subsidized, then the general public (including both users and non-users) can be charged a certain percentage of costs. This is seen when using general tax revenue for transportation.

- Value Capture: Similarly, another transfer occasionally used is a "value capture" approach, whereby nearby landowners are taxed based on the increase property value owing to a new transportation facility, this has been used in Angeles around new transit stations. In practice, some of each approach may be used.

◊ Compensation

If individuals and organizations who cause externalities are to be charged, those who receive the unwanted noise, pollution, etc. should be compensated. To the extent that the recipients are amorphous, such as "the environment", the collected funds should be expended in that sector for remediation of damages or their mitigation ahead of time. Also, the health damages from environmental damage are typically diffuse. On the other hand, it is fairly clear who suffers from noise. But the externality gets buried in the land price immediately after the opening (or perhaps announcement) of a facility. Therefore only the land owner at that time should receive compensation.

Accidents result in damages to several classes of parties: those involved in accidents (and their families and insurance companies), commuters delayed by accidents (though this may be better treated in the congestion section), and society at large. Those involved are largely covered privately through the insurance sector, and care must be taken to avoid double-counting.

Congestion is typically divided into two classes: recurring and non-recurring. Non-recurring congestion is most often caused by incidents (traffic accidents, inclement weather). The value of time for these may be different, as recurring congestion probably entails less schedule delay since it is already accounted for by most commuters. Money raised from congestion pricing, in addition to reducing traffic volumes, can be used to expand capacity further to alleviate congestion. But this does not compensate those who now take a slower (but cheaper mode of transport) after road pricing is in effect. A question arises as to whether those individuals have some right to free travel which is being eliminated through pricing, or whether some general subsidies for travel are warranted. Congestion has further issues concerning pricing, for instance the peak vs. off-peak. When there is more traffic, each additional vehicle has more and more impact, suggesting higher tolls in the peak. However, the tolls will reduce demand, so an equilibrium solution to the problem is essential.

Social severance and visual impact are also amorphous. They will be difficult to price. To some extent for visual impact, the neighbors of a project can be identified and damages defined in terms of lower property values. In terms of the aesthetic quality of a trip, it may be conceptually possible to compare to parallel routes (a parkway vs. a freeway), one “prettier” than the other, and see if there is a difference in traffic volumes other than that explained by a route choice model. The difference in volume gives an implied choice of the value of the route in terms of additional time (and thus money), which may be significant in tourist areas. There is also a risk aspect to travel, drivers may choose certain roads which are through “good areas”, because they do not want to break down in isolated areas or perceived bad neighborhoods.

The social aspects of disruption of community (after taking into account net change in property value before and after infrastructure accounting for all of accessibility (increase or decrease), noise, and visual impact) is extremely difficult to determine. A political solution may need to be found to pricing and arranging for compensation.

3.3. NOISE

3.3.1 Measuring Noise

Noise is usually defined as unwanted sound. Physically, sound is perceived by a sensation in the ear as a result of fluctuations in air pressure. The size and rate of those fluctuations determine the magnitude and frequency of the sound. Sound can be measured in several ways: as a flow of energy (power), as energy flow per unit area (intensity), or by fluctuations in air pressure (pressure). The measurements are usually translated using a reference value. For instance, the most common measure, the decibel (dB) is defined as follows (Starkie and Johnson 1975):

(3.3.1) $$dB = 10 \log_{10} (P^2 / P_{ref})$$

where:

P = pressure in Newtons/m^2

P_{ref} = 0.00002 Newtons/ m^2, which is the quietest audible sound.

Similarly, the decibel can be measured using intensity (I) with the following equation:

(3.3.2) $$dB = 10 \log_{10} (I / I_{ref})$$

where:

I = intercity in Watts/ m^2

I_{ref} = 10-12 Watts/ m^2

The frequency of sound is measured in cycles per second (Hertz), the range from 20 - 16,000 is that which can be heard by the human ear. Generally, sound measures are weighted to reflect what is perceived as “loudness.” The most common weight, the A scale, gives the measure dB(A), where the number of decibels is weighted by sound at various frequencies to give equivalent loudness.

When performing noise-cost studies, sound, which varies over the course of time, must be averaged to give an equivalent loudness, which is the continuous energy mean equivalent of the noise level measured over a specific period. This is further translated into an index, in the United States the Noise Exposure Forecast (NEF) is used, which is defined as follows:

(3.3.3) $$NEF = 10 \log_{10} 10^{Lepn/10} + 10 \log_{10} N - 88$$

where:

Lepn = Effective perceived noise level (loudness)

N = number of events

It is important to note that due to the logarithmic scale of noise measurement the amount of noise measured is not linearly additive with the number of vehicles. One truck may generate 80 db(A) noise, but two trucks will only generate 83 db(A).

3.3.2 Noise Generation

3.3.2.1 Highway Noise

Essential to determining the cost of noise of a specific facility is a determination of the amount of noise generated by that facility, or the traffic on that facility. Factors which influence this include: traffic flow, percentage of heavy vehicles, traffic speed, road gradient, and the materials of the road surface. In addition, the propagation of the noise over distance is influenced by ground cover, obstruction, barriers, and buildings. For this exercise, it will be assumed that propagation is simple, over an unobstructed plain. The basic noise level measured is L10, the amount of noise exceeded 10% of the time. The equations in this section come from the U.K. D.O.T. (1988). The 1 hour basic noise level is given by:

(3.3.4) $L_{10} = 42.2 + 10 \log_{10} q$ dB(A)

where:

q= hourly traffic flow at 75 km/hr,

percentage of heavy vehicles = 0,

flat grade

For the 18 hour basic noise level, the equation is

(3.3.5) $L_{10} = 29.1 + 10 \log_{10} Q$ dB(A)

where:

Q = thousand vehicles per 18 hour day

The correction (Cpv) for mean traffic speed and heavy vehicles is given as

(3.3.6) $Cpv = 33 \log_{10}(V + 40 + 500/V) + 10 \log_{10} (1 + 5p/V) - 68.8$ dB(A)

where:

V = mean traffic speed in km/hr

p = percentage of heavy vehicles

The impact of noise declines with distance from the edge of the roadway. This correction (Cd) is given as follows:

(3.3.7) $Cd = - 10 \log_{10} (d/13.5)$ dB(A)

where:

d = shortest slant distance from the effective source (meters)

Given the land use density, the number of houses at each distance from the roadway can be computed for a given square kilometer. The cost of the noise can be computed, this is done in the application of the model discussed in a subsequent chapter.

3.3.2.2 High Speed Rail Noise

Noise levels for high speed rail depend on the technology chosen. High speed rail can be compared to existing systems to provide a baseline. Rail noise differs from highway noise in one key respect. Highway noise is a relatively continuous drone, while rail noise is a punctuated event, which occurs for the few moments when a train passes.

In conventional diesel powered train, rail noise is made up of two primary sources: the locomotive engine and wheel-rail interaction (Wayson and Bowlby 1989). For diesel, the maximum A-weighted sound level has been measured and an equation developed:

(3.3.8) $$L_A = 11.09 \log 0.6V + 70.8$$

where:

L_A = maximum A weighted sound level, dB(A)

V = speed in kph

For General Electric E-60CP engines, and ASEA RC4 engines, passby noise results (measured at 15 meters) have been estimated for the two sources: Drift, and Power. These are given below:

Drift

(3.3.9) $$L_A = 30 \log 0.6V + 32$$

(3.3.10) $$L_A = 27 \log 0.6V + 37$$

Power

(3.3.11) $$L_A = 27.5 \log 0.6V + 35.4$$

(3.3.12) $$L_A = 34.5 \log 0.6V + 23$$

HSR noise emanates from two principal sources: wheel-rail noise, which is proportional to 30 log Speed; and aerodynamic noise which is proportional to 60 log Speed (Hanson 1990). A third source due to electrification has been found to be significant though. Measurements have been made for noise levels of different high speed train technologies:

Table 3.3-1: Train Noise Levels (dB(A)) for Various Technologies

Train	60 MPH 96 KPH	100 MPH 160 KPH	120 MPH 192 KPH	200 MPH 320 KPH
Maglev		72	75	85
ICE	72	75	78	92
Shinkansen	79	80	82	
Amtrak	79	82	89	
TGV*				97
Turbotrain		~100		

*source: Hanson (1990), except * from Wayson and Bowlby 1989; note: at 25 m.*

Hanson (1990) has calculated that in order to maintain 55 dB(A) background Ldn at 180 mph (288 kph), one needs about a 480 ft (146 m) corridor. In order to provide a comparison between highways and rail, L10 was taken to be a function of speed. We estimated a simple model from the data in the above Table, giving the following equation

(3.3.13) $L_A = 19.94 + 29.72 \log 0.6V$

[r-squared = 0.81]

For the Shinkansen, Wayson and Bowlby (1989) report that:

- The noise level does not decrease linearly for each doubling of distance as would be expected (probably due to ground impedance)
- Geometric spreading has much more effect on the noise levels at high speed than does changes in speed (noise levels are more influenced more by distance changes in speed)
- The noise level measurements are correlated with the logarithm of speed.

To account for that, a distance decay relationship from data provided from a Matsuhisa and Shibata study was estimated by us:

(3.3.14) $Noise_{@Dist(D)} = Noise_{@25m} - 6.01 \ln(D)$

where: D = Distance in meters

[r-squared = 0.98]

The noise production and distance decay models were applied using the same adjustments as used for autos.

3.3.2.3 Aircraft Noise

Noise due to aircraft can be associated with airports and with aircraft flying overhead not in the process of takeoff or landing. Most research in this domain has dealt with noise around airports. Obviously, it is the aircraft that actually generate the noise. However, it is the airport, the most convenient point of complaint, that is held responsible.

Table 3.3-2: Population Impacted by Noise at Selected California Airports

Airport	Moderate Impact Zone	High Impact Zone
Los Angeles	292,400	51,100
San Diego	77,300	24,000
San Francisco	124,100	11,400

source: Gillen 1990 after Transportation Research Circular # 286.

The annoyance caused by noise is due to a number of unique factors, including individual preferences, socio-economics, environmental conditions, local topography, and number of flights. Assuming that noise annoyance is capitalized in land prices (discussed in the next section), we need only determine the noise coming from aircraft. Aircraft noise production is tied to the "stage" of the aircraft. Aircraft stage is its level of technology, which is related to its age and size. The technology determines total engine thrust needed, and is thus an influence in noise production.

A Noise Exposure Forecast (NEF) is used to estimate the equivalent amount of noise produced by aircraft (Levesque, 1994). The following equation is used to estimate the NEF produced by aircraft i on flight path j.

$$NEF(i,j) = Lepn(i,j) + 10 \log[Nd + 16.67\ Nn] - 88 \tag{3.3.15}$$

where:

Lepn = the effective perceived noise level at the location.

Nd = number of daytime flights (0700 - 2200)

Nn = number of nighttime flights (2200 - 0700)

The same discount factor for distance as used for the automobile model (described above) is assumed.

3.3.3 Noise Damage and Protection Costs

The damages caused by noise include the loss of sleep, lower productivity, psychological discomfort and annoyance. These are hard to quantify, but because they are associated with a place, the quantity of damage is often viewed as resulting in lower property values. A number of studies have been performed over the years to measure the decline in residential property value due to noise and its associated vibration. This has not been done for non-residential (commercial and public) buildings, however, where abatement measures are more cost-effective.

The following are empirical findings from hedonic models of housing collected by Modra and Bennett (1985), Nelson (1982), and from other studies. Damages can be estimated in other ways, but in large part, the property value loss should incorporate other estimates of damage (such as loss of sleep).

These studies use a noise depreciation index (NDI) which is the percentage reduction of house price per dB(A) above some base. To determine the amount of noise damage produced by a facility, one must know the noise produced on that facility (as a function of traffic volume) and the location of residences near the facility. Also the house value must be known because the impact of noise is generally found to be a percentage reduction in house price rather than a fixed value.

These property value impact studies have been performed for areas around highways, Table 3.3-3, and airports, Table 3.3-4. The average NDSI for all of the airport noise surveys since 1967 (excluding the first three) is 0.62, the same value as for highways. Few, if any, studies have been performed for railroads. For that reason, the depreciation of property values around rail lines will be assumed to be the same as near highways. However further research should investigate the effect of high intensity noise (produced more often by trains) vs. high frequency noise (produced by cars).

Pennington et al. (1990) studied the Manchester-Stockport area, and found that after accounting for what they call "neighborhood effects, "that the effect of noise was smaller. But the extent to which noise and neighborhood quality interact is unclear. Does a neighborhood become "bad" because of negative noise externalities reducing the quality of life, or does a "bad" neighborhood attract noisy elements (highways, airports, industry)?

Further estimates of noise cost as a percentage of GNP are available at the national level (Kanafani 1983). These could be allocated to give an estimate of noise damages per unit of VMT, but these are likely to be less reliable for a specific project.

An alternative means for determining the cost of noise is to estimate how much it would cost to protect against some amount of noise. If it is cheaper to eliminate noise through protection measures than to correct the damage that the noise would do, then the best estimate of the cost of noise is the protection cost rather than the damage cost. Of course those protection measures should be undertaken if one were otherwise considering paying compensation for damages. A number of protection measures exist, which can be applied at the level of the vehicle, the roadway, or building.

At the vehicle level, there are already regulations in place to quiet vehicles, the most significant of these is mufflers. One could estimate the implied preference cost of noise by calculating the cost of mufflers and the amount of noise reduced, however, we have not found such a calculation. Similarly, from the point of view of the driver, luxury cars are quieter than less expensive cars, part of the additional expense can be attributed to their quietness. However a brief review of the literature on automobile noise did not turn up any studies pricing quiet as an attribute of cars using an hedonic model.

Another means of noise prevention can occur at the vehicle and roadway level together. If the roadway is controlled, such as a toll facility, it is conceivable that noise could be measured for each vehicle entering the roadway. If it can be measured, a charge proportionate to the production of noise, or a simple regulation prohibiting noise above some threshold could be imposed. The first would clearly reduce the demand for noisy vehicles on the facility by making travel more expensive, and would recover money from others to be used as compensation for damages. Both would move noisier vehicles onto other routes.

Roadway barriers represent another measure of noise prevention. These barriers include noise walls and berms. Noise walls use less land, but are expensive and generally only used in urbanized areas. Hall and Willard (1987) when costing noise, found that noise barriers were a negative in terms of visual amenity, that there were linear and non-linear cost functions, so that the cost per unit of noise depends on the quantity of noise, and that the data with barriers were consistent with the data for places without barriers.

Lastly, protection can be undertaken at the level of the individual building. Homes and commercial buildings can be more heavily insulated, and windows can be glazed. These reduce the sounds from the nearby transportation facility (road, rail, airport) at least while individuals are inside their buildings, and thereby reduce some of the costs. However, as with all of these measures, their effectiveness depends on volume and frequency of the service as well as a number of site specific factors. For that reason, no general estimate of the cost of protection can be provided, though at the time of design of the facility, protection costs should be estimated in a thorough engineering study and compared with damage compensation costs.

Table 3.3-3: Noise Depreciation Near Highways

Researcher	Site	NDI	NDSI - Leq, Adj.	Year	Average House Value
Towne	Seattle, WA	negligible		1968	
Diffey	London	0		1971	
Gamble et al.	all 4 areas	0.26		1970	
	N. Springfield VA	0.21	0.26	1970	$33,600
	Bogata NJ	2.22		1970	$29,100
	Rosedale, MD	0.42		1970	$25,100
	Towson, MD	0.26		1970	$31,100
Anderson and Wise	all 4 areas	0.25	0.31	1970	
	N. Springfield VA	0.14	0.18	1970	$33,600
	Towson, MD	0.43	0.54	1970	$31,100
Hammar	Stockholm	1.4		1972	
Vaughn, Huckins	Chicago	0.65	0.65	1974	
Nelson,	Washington DC	0.87	0.88	1975	
Langley	No. Springfield VA	0.32	0.40	1977	
Bailey	No. Springfield VA	0.30	0.38	1977	
Abelson	Sydney, NSW	0.56		1977	
Hall et al.	Toronto, ON	1.05	1.05	1977	
Langley	No. Springfield VA	0.40	0.50	1980	
Palmquist	Kingsgate, WA	0.48	0.48	1980	
	N. King Co. WA	0.30	0.30	1980	
	Spokane, WA	0.08	0.08	1980	
Allen	No. Virginia	0.15	0.15	1980	
	Tidewater	0.14	0.14	1980	
Taylor et al	Southern Ontario	0.5		1982	
Holsman, Bradley	Sydney, NSW	0.72		1982	
Pommerehne	Berlin	1.2		1985	
Hall and Willard	Totonto/Vic. Park	0.335		1987	
	Toronto/Leslie St.	2.10		1987	
	Toronto/Etobicoke	0.39		1987	
	pooled	0.70		1987	
Soguel	Neuchatel	0.91		1989	
Streeting	Canberra	0.90		1989	
Swiss (X)	Basle, SWITZ	1.26			
	AVERAGE	0.62			

Table 3.3-4: Noise Depreciation Near Airports

Researcher	Study Area	Range of noise level	Range of NDI	Best NDSI (NEF)	Year	Average House Value
			(%)	(%)		
Paik	New York	20-40	1.9-2.0	1.9	1960	$16,656
Paik	Los Angeles	20-40	1.8-2.0	1.8	1960	$19,772
Paik	Dallas	20-40	2.3-2.6	2.3	1960	$18,011
Emerson	Minneapolis	20-50	0.4	0.58	1967	$19,683
Dygert	San Francisco	25-45	0.5-2.0	0.50	1970	$27,600
Dygert	San Jose	25-45	0.1-1.5	0.70	1970	$21,000
Price	Boston	25-45	0.6	0.83	1970	$13,000
Mieszkowski	Toronto/ Etobicoke	20-35	0.3-1.3	0.50	1969-73	
De Vany	Dallas	20-55	0.2-0.8	0.58		
Nelson	Washington, DC	20-35	1.0-1.1	1.10	1970	$32,724
	Rochester		0.55	0.55	1980	in Nelson
	Sydney/ Marrickville		0.50	0.50	1980	in Nelson
	Edmonton		0.50	0.50	1980	in Nelson
	London		0.68	0.68	1980	in Nelson
O'Byrne	Atlanta					
Pennington	Manchester	27-40		0.47	1990	£30,886
Gillen, Levesque	Toronto	0-40		0.18	1990	C195,809
	AVERAGE			**0.62**		

3.3.4 Integrated Noise Model

In order to translate noise production rates into economic damage costs the following model is developed. This model extimates total residential property damage costs per linear kilometer of a roadway or railway. The model was run through a number of scenarios to develop simplified average and marginal cost functions. The model variables are shown in Table 3.3-5 and are grouped grouped into Assumptions (inputs) and Results (outputs):

Table 3.3-5: Assumptions (Inputs):

Variable	Definition
Interest	Discount Rate to convert total home depreciation into a annual value
Years	Number of Years over which depreciation occurs
Flow (Qh)	# of Vehicles per Hour (highway model)
Trains (Qt)	# Trains per hour (rail model)
Speed	Speed in km/hr (highway, rail models)
heavy	% trucks, heavy vehicles (highway)
peak	% daily traffic in peak hour (highway)
Cost/dB(A)	noise depreciation index
HouseValue	Average Home Price
Density	houses/square kilometer
Base NEF	Background NEF (20 - 30 for highway model; 0 for airport, rail models)
Pax/train	Passenger per train (rail model)
height	Height off ground of highway, railway (highway, rail models

Table 3.3-6: Results (Outputs)

Variable	Definition
Total Cost	Total Home Depreciation Value
Annual Cost	Annual $ Value of Total Cost
$/vkt	Cost per vehicle kilometer traveled(highway model)
$/pkt	Cost per passenger kilometer traveled(rail model)

3.3.4.1 High Speed Rail

Application of the noise model under certain assumptions, gives us an average cost curve for the noise damage associated with each passenger kilometer traveled depending on the number of trains per hour (Qt). We perform this analysis for two train speeds: 200 kph and 320 kph, and under the following assumptions: a discount rate of 7.5%, trains in service 18 hours per day, each train with a capacity of 350 passengers and a 75% load factor, a noise depreciation index of 0.62, an average home value of $250,000 and a density of 360 household per square kilometer. The damage caused by the new service is determined by comparing the noise before and after the service is deployed, in our analysis we assume a baseline of zero background noise.

The model is solved by dividing the area on each side of the tracks into 10 meter strips (s) parallel to the tracks. Each 10 meter by one kilometer strip has a number of housing units (Hs) depending on the density. The total damage for each strip is computed based on multiplying the homes by the value (HV) of each home by the noise depreciation index (NDI) by the net increase in the NEF (after (NEFa) - before (NEFb)). The total damage as a present cost (P) is summed over all the ten meter strips for a one kilometer stretch.

(3. 3.16) $$P = \sum_{s} (H_s)(HV)(NDI)(NEF_a - NEF_b)$$

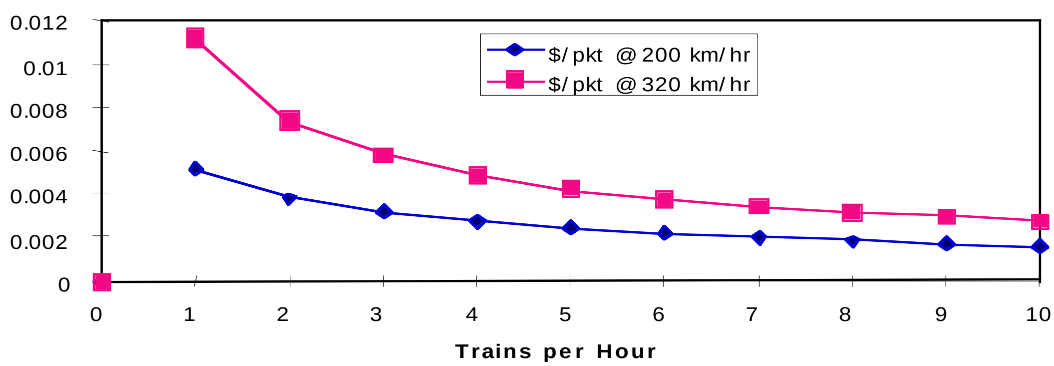
Because of the logarithmic shape of the noise curves, the higher the level of background noise, the less damage each additional unit of noise production causes. The costs are linear with respect to density, home value, noise depreciation index, and the number of passengers (as determined by capacity and load factor). It is non-linear with respect to speed and number of trains per hour. Under the assumptions identified above, social average costs of noise (SNAC) are given by the following equations (r-squared = 0.99, 0.96 respectively), these are graphed in Figure 3.

(3. 3.17) SNAC@200kph = 0.0050 -0.0015 ln (Qt)

(3. 3.18) SNAC@320kph = 0.0103 -0.0035 ln (Qt)

At 200 kph, our best estimate of the expected cost of noise is $0.0025/pkt; at 320 kph it is $0.0043/pkt, assuming 5 trains per hour, though clearly these costs depend on local conditions as described above.

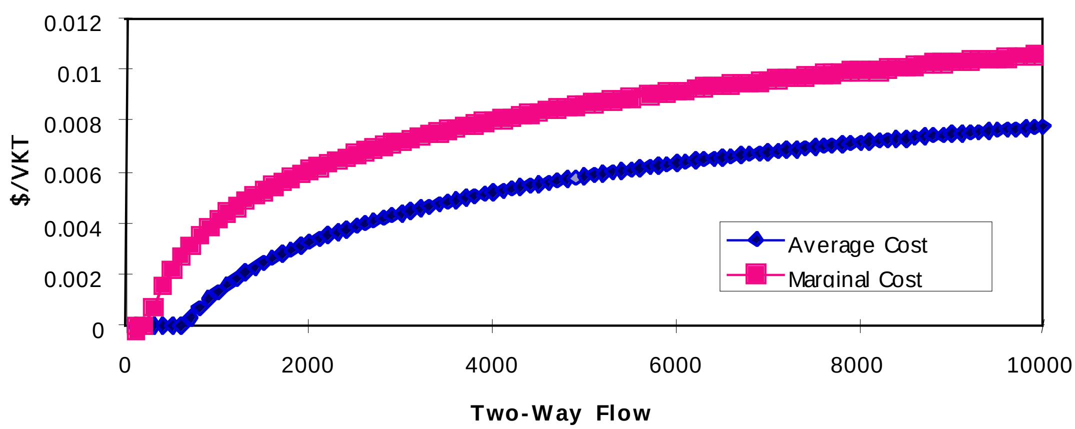
Figure 3.3-1: Average Noise Cost of High Speed Rail



3.3.4.2 Highway

For automobile travel the integrated highway noise model gives a range of between \$0.0001/vkt and \$0.0060/vkt average cost, depending on flow, given the assumptions of Interest Rate = 7%, Years = 30, Home Value = \$250 K, Density = 360HH/sqkm, Cost/dB(A) = 0.0062, a speed of 100 km/hr, 10% heavy vehicles, and a maximum range of 500 m on each side of the highway. A graph of \$/vkt vs. flow is shown on figure 3.2.1. However this value is extremely sensitive to assumptions. At an auto occupancy of 1.5 and flow of 6,000 vehicles per hour, this converts to \$0.0045/pkt.

Figure 3.3-2: Highway Noise: Average and Marginal Costs



INFRAS/IWW (1995) gives noise estimates from Europe of \$0.0058/pkt for automobiles, about the same for buses (\$0.0054/pkt) and \$0.0163/tkt (tonne km traveled) by truck. This study calculated an estimated noise cost per exposed person, mostly derived from willingness to pay studies, and the estimated number of exposed persons at various levels of exposure. Based on macroscopic mode shares, and adjusting for the noisiness of modes, the total costs were allocated. It is notable that the results are on the same order of magnitude as our own with such widely diverging methodologies.

For cars, NRDC (Miller and Moffet 1993) reports a range from \$0.0008/pkt to \$0.0013/pkt urban based on studies by Keeler (1975) and Hokanson (1981), in 1990 U.S. dollars. For buses, they take \$0.0003/pkt as an acceptable value.

The complete model is complex, requiring the combination of a number of equations. For analytical purposes, this was converted to a simpler average cost ($/vkt) model. A regression was performed after fixing the assumption noted above, with the independent variable being the natural log of highway flow (Qh), and the dependent variable being $/vkt . The regression was performed over 15 different values of flow: Some of the variables can be re-incorporated into the model through the use of multiplicative adjustment factors for density (fD), House Value (fH), and the Cost per decibel deflator (fC).

(3.3.19) $$ACh_n = fD * fH * fC\,(-0.018 + 0.0028 \ln(Q_h))$$

[N = 15, r-squared = 0.92, all variables significant at 99% level]

The total cost function is the Average cost multiplied by the number of units:

(3. 3.20) $$TCh_n = Q_h * ACh_n = fD * fH * fC\,(-0.018\,Q_h + 0.0028\,Q_h \ln(Q_h))$$

From this, we derive the marginal cost function:

(3. 3.21) $$MCh_n = \partial TC/\partial Q_h = fD * fH * fC\,(-0.018 + 0.0028 * (1 + \ln(Q_h)))$$

where:

fD = Density/360 (default = 1)

fH = House Value/$250,000 (default = 1)

fC = Cost per dB(A)/0.0062 (default = 1)

3.3.4.3 Air

Table 3.3-7 shows the estimated noise costs per passenger kilometer traveled generated by air travel in eight countries. The average value for these results is $0.0043/pkt which is used here.

Table 3.3-7: Noise Costs Generated by Air Travel

Country	Average Cost/pkt
Canada	0.0039
Germany	0.0049
Italy	0.0079
Holland	0.0099
Sweden	0.0014
Switzerland	0.0017
France	0.0030
United Kingdom	0.0018
Average	0.0043

source: Quinet 1990, IBI 1995
note: all values converted to $US, 1995

An alternative approach would require conducting engineering studies around the airports in California. In principle the methodology would be similar to that used for highway and high speed rail modes. However specific details about the noise generation of aircraft using each airport, flight paths, airline schedules, land uses, and topography would be required. This would provide the effective perceived noise level and noise exposure forecast for specific geographical zones. For each zone, a hedonic model could be applied to estimate the reduction in property value due to air traffic noise. This capitalized value would need to be allocated to specific aircraft, and then to passengers and passenger kilometers based on flight lenghts.

A third approach would use the implied value of noise damage resulting from damages awarded by courts settling law suits. A given award would be taken to be damages, which again would need to be allocated to aircraft, passengers, and passenger kilometers.

3.4. CONGESTION AND TIME

The time which a trip takes can be divided into two components, uncongested and congested times. The uncongested time is a simple function of distance and uncongested speed. Congested time depends on the number of other vehicles on the road. While the uncongested time is clearly an internal cost, congestion, like accidents, but unlike the other externalities, is both internal and external to the transportation system. As the system approaches "capacity", a vehicle imposes an increasing amount of delay on all other vehicles in the system, which has ramifications both within and outside the transport sector. The increased cost of transportation has costs in the productive sectors of the economy, reducing the amount of time and money that can be spent in other activities and on other goods. Some argue that congestion is external to the vehicle but internal to the transport system (Nijkamp, 1994). In our analysis, congestion is considered an externality on the basis of the proposition that it is external to the vehicle or carrier. In this section, both congested and uncongested travel times are considered.

In this study, two modes: highway and air transportation, are considered subject to congestion effects. It is assumed that the high speed rail system has been designed to a capacity level to avoid congestion at both stations and along the lines. It is important to recognize that volume-delay relationships are non-linear, so the marginal congestion cost imposed by each vehicle depends on the number of vehicles. For limited access highways, the point of maximum throughput typically has a speed which is one-half of the freeflow speed. For signalized highways, the relationships are much more complex, and must consider delay at intersections caused by traffic on other links. Most of the congestion delay associated with air travel occurs at and around airports. In both cases, for highways and airports, the amount of delay depends on both supply and demand.

This section deals with several topics. The first is the production of congestion (or travel time) which depends on the technology of the infrastructure and vehicles as well as the flows on the facility. This therefore requires estimates of demand to calculate the cost of congestion (which in turn influences the amount of demand). Second, we look at the value of time of the users (passenger and freight) on the facility. Third, we consider marginal congestion cost functions, these can be thought of as the cost pf congestion or of the protection mechanism to prevent congestion.

3.4.1 Delay

3.4.1.1 Highways

The exact relationship between volume and delay can be best determined by a detailed, site specific, engineering study. For highways, the Highway Capacity Manual (TRB 1985) provides some estimates. For a segment with a 70 MPH design speed, under ideal conditions the capacity is taken to be 2000 passenger cars per hour per lane (pc/hp/l).

Table 3.4-1: Levels of Service for Basic Freeway Segments

LOS	Density (PC/MI/LN)	Speed (MPH)	Volume/ Capacity	Maximum Flow (PC/H/L)
A	≤ 12	≥ 60	0.35	700
B	≤ 20	≥ 57	0.54	1100
C	≤ 30	≥ 54	0.77	1550
D	≤ 42	≥ 46	0.93	1850
E	≤ 67	≥ 30	1.00	2000
F	> 67	< 30	unstable	unstable

source: Highway Capacity manual, TRB 1985

The following is an equation for limited access freeways from the previous table:

(3.4.1) $$Thd = 0.54 * (Qh/Qho)^{10}$$

where:

Thd = Time highway delay per mile per vehicle
Qh = Flow per unit time (e.g. vehicles/hour)
Qho = Capacity per unit time (typically 2000 vehicles per hour per lane)

The incremental delay caused by an additional vehicle, at capacity (moving from 1999 to 2000 vehicles per hour) is given in the following Table 3.4-2, where one car causes almost six minutes of total delay on a single one-mile segment.

Table 3.4-2: Example of Rising Average Delay

	Average Delay/mile (min./veh)	Total Delay (min/mile)	Average Delay/km (min/veh)	Total Delay (min/km)
at 1999 vph	0.5359	1071.27	0.3215	642.76
at 2000 vph	0.5386	1077.18	0.3231	646.31
Difference	0.0027	5.91	0.0016	3.55

Of course, any estimates of the amount of delay depend on estimates of volume, and vice versa, so the problems will need to be treated together before a definitive answer can be determined.

3.4.1.2 Air Transportation

For air travel, there have been some studies of airport delay. Drake (1978), Maniser (1985), and Kanafani and Ghobrial (1985) have estimated congestion models for airports. Perhaps the most widely used approach is that of the FAA (1983). Using a methodology similar to the highway capacity manual, each airport, based on runway designs and other physical factors, has a rated capacity (annual service volume). Delay per aircraft depends on the usage (in operations) of the airport relative to its capacity. The following average delay per aircraft (in minutes) was estimated using the FAA graphs:

(3.4.2) $$Tad = 0.19 + 2.33\,(Qa/Qao)^6$$

where:

Tad = Time in delay per aircraft

Qa = Aircraft Operations per year

Qao = Annual Service Volume

3.4.2 Value of Time

The value of time depends on a number of factors (Hensher 1995). Among them are the mode of travel, the time of day, the purpose (business, non-business) of the trip, the quality or level of service of the trip (including speed), and the specific characteristics of the trip-maker, including income. Furthermore, the value of time saved probably depends on the amount of time saved - 60 people saving 1 minute may not be worth the same as 1 person saving 60 minutes. Time in motion is valued differently than time spent waiting. Similarly schedule delay, the amount of time between when one wants to depart and the next scheduled service (bus, train, plane) also has a value associated with it. Unexpected delays are more costly than the expected, since those are built into decisions. All of these factors need to be considered in a detailed operational analysis of the costs of travel time and congestion. But for our analysis, we will consider only the value of time in motion, comparing uncongested (freeflow) and congested (delay) time.

Table 3.4-3: Major Airports in California, Utilization, Capacity, Delay.

ID	Airport Name	Enpl. ('000) 1991	Ops ('000) 1991	Capacity (ASV) ('000) 1991	Average Delay (min)
LAX	Los Angeles	22520	661	675	2.24
SFO	San Francisco	15187	435	393	4.47
SAN	San Diego/ Lindbergh Field	5617	260	225	5.73
SJC	San Jose	3443	337	385	1.23
OAK	Metropolitan Oakland	3013	414	625	0.39
ONT	Ontario	2873	156	355	0.21
SNA	John Wayne/ Orange County	2636	551	355	32.74
SMF	Sacramento Metropolitan	2176	152	370	0.20
BUR	Burbank/ Glendale/ Pasadena	1843	229	230	2.46

There are a number of approaches for valuing travel time, ranging from utility theory to theories of marginal productivity (FAA 1989). Economic theory in competitive markets holds a firm in a competitive market will be in equilibrium when the marginal revenue product of a factor of production equals its price. In other words, the last good which is produced still earns money, but the next one won't. If labor is taken to be an input to the firm, the firm will pay salaries up to the point that the worker adds profits to the firm, this is his earning rate. Given those assumptions, the value of time for the business traveler is the wage rate, since he is traveling instead of working. Of course, this ignores any differences in the quality of the trip, the fact that work can be done while traveling, that much business travel occurs on the employee's rather than the employer's time, and a number of other factors. It also creates problems for valuing the time of non-business travel.

The extension to non-business travel assumes that the consumer values non-business activities the same at equilibrium, (otherwise they would expend more time on the activity with the higher value). Since one of those equilibrium activities to which the consumer is indifferent is work, it is plausible to value non-business travel at the wage rate as well. Extending the household production theories of Becker (1965), it can be assumed that households perform activities which maximize utility, including expenditures of both time and money. Since travel itself is an intermediate activity, and thus provides no utility, the time saved in travel (for instance, due to an improvement) can be spent either consuming leisure activities or earning income. Therefore the value of the in travel must be compared with its time at work and at home. Thus, the value of time saved can be greater or less than the wage rate depending on the value of time in travel (is it positive or negative?), as well as the valuation of work, and the wage rate cannot be assumed to be the only factor used in estimating the value of time.

A large number of studies have estimated the value of travel time. These studies use several approaches, often grouped under the willingness to pay rubric. A number of studies calculate elasticity of demand to estimate how much money people pay to save time. Early studies were based on regression analysis, more recently multinomial logit has been used.

Miller and Fan (1992) have collected estimates of value of time from a variety of studies of inter-city transportation, including several high speed rail studies. These are shown in Tables 3.4-4 and 3.4-5. The FAA (1989) has collected estimates for the value of time from a number of aviation studies, these are reproduced in Table 3.4-6. The FAA's recommended values of time, based on type of trip, are reproduced in Table 3.4-7.

Table 3.4-4: Value of Time: Business Trips

STUDY	Air	Rail	Car	Bus	Currency
Ridout-Miller	$3-$28	$1-$10	X	$1-$10	CAN69
Wilson	$11	$11	$11	$11	CAN84
Koppelman	$20-$60	$20-$60	$20-$60	$20-$60	US77
Compass/ Tri-State	$65-$67	$39-$48	$37-$47	$25	US90
RPI/ Cole Sherman New York	$51	$26	$26	X	US90
Consumer Contract/ ColeSherman (Horizons) Ontario-Quebec	$58	$25	$25	$17	US90
British Rail/ Illinois	$54	$28	$23	X	US90
CRA Texas (linehaul, access)	$35,$24	X	$20,$13	X	US90

source: Miller and Fan, 1992

Table 3.4-5: Value of Time: Non-Business Trips

STUDY	Air	Rail	Car	Bus	Currency
Ridout-Miller	$0.03 - $0.30	$0.05-$0.44	X	$0.05-$0.44	CAN69
Wilson	$0.003	$0.003	$0.003	$0.003	CAN84
Koppelman	$15-$45	$15-$45	$15-$45	$15-$45	US77
Compass/ Tri-State	$34-$42	$20-$37	$16-$37	$15-$34	US90
RPI/ ColeSherman New York	$32	$21	$26	$32	US90
Consumer Contract/ ColeSherman (Horizons) Ontario-Quebec	$32	$19	$18	$12	US90
British Rail/ Illinois	$19	$13	$13	X	US90
CRA Texas (linehaul, access)	$28,$19	X	$9,$6	X	US90

source: Miller and Fan, 1991

Table 3.4-6: Applied Values of Time in Air Travel

Study	Year	Value of Time in Business Travel	Value of Time in Non-business Travel
Systems Analysis and Research Corp.	1964	1.0 x Income	1.0 x Income
Systems Analysis and Research Corp.	1966	2.5 - 3.0 x Earnings Rate	"Not Feasible"
McDonnell Aircraft Corp	1966	1.0 x Earnings Rate	$1.00 / Hour
American Aviation	1966	2.5 x Earnings Rate	Not Noted
Boeing - SST (FAA 1967)	1966	1.0 x Income	1.0 x Income
Lockheed - SST (FAA 1967)	1966	2.0 x Earnings Rate	1.0 x Income
Institute for Defense Analysis - SST	1966	1.0 x Earnings Rate	1.0 x Earnings Rate
FAA - SST	1967	1.5 x Earnings Rate	1.0 x Earnings Rate
Boeing - V/STOL	1967	1.0 x Income	1.0 x Income
Reuben Gronau Ph.D. Dissertation	1967	0.40 - 0.45 x Earnings Rate	No Systematic Relationship
Charles River Associates - SST	1969	1.5 x Earnings Rate	1.5 x Earnings Rate
Reuben Gronau	1970	1.15 - 1.25 x Earnings Rate	No Systematic Relationship
Arthur DeVany	1971	1.0 x Earnings Rate	1.0 x Earnings Rate
Various FAA Facilities and Equipment	1974-88	1.0 x Earnings Rate	1.0 x Earnings Rate
Alan Grayson	1981	0.61 x Earnings Rate	2.14 x Earnings Rate
Morrison and Winston	1985	0.85 x Earnings Rate	1.49 x Earnings Rate
Pickrell	1987	1.64 x Earnings Rate	0.21 x Earnings Rate

source: FAA 1989 p. 5

Table 3.4-7: Recommended Values of Travel Time Saved

User Group	Business Trips	% of All Business Trips	Non-business Trips	% of all Non-business Trips	Average for all Trips	% of all Trips
Air Carrier - Domestic	$25.00	70.8%	$26.97	78.5%	$26.20	75.4%
Air Carrier - International	37.22	1.1%	55.83	7.7%	$50.34	4.8%
Commuter	25.00	4.8%	26.97	5.3%	26.20	5.1%
GA Piston	38.00	11.8%	57.00	8.4%	47.52	9.6%
GA Turbine	140.47	7.6%	210.71	0.03%	140.96	3.2%
Rotorcraft	75.00	2.4%	112.50	0.1%	78.34	1.1%
Air Taxi	52.65	1.5%	0.00	0.0%	52.65	0.6%
Government	25.00	0.0%	0.00	0.0%	25.00	0.0%
Military	20.00	0.0%	0.00	0.0%	20.00	0.0%
Weighted Average	**37.06**	**100.0%**	**31.86**	**100.0%**	**33.85**	**100.0%**

source: FAA 1989 p. 11

3.4.3 Marginal Cost Functions

There are several methods to protect against, or optimize congestion. These include supply-based measures and demand-based measures. Supply measures include the expansion of capacity, demand-based measures involve reducing demand, one of the more effective means of which would be a pricing mechanism. The cost of expanding an airport or highway, or constructing a high speed rail line will be addressed in the chapter on capital and operating costs. In the final analysis, the optimal pricing strategy depends on optimizing the trade-off between expanding supply (capacity) and constricting demand, through pricing or some other mechanism, and potentially accepting some amount of delay as being less costly than mechanisms to reduce it.

Estimates of the average delay depending on the use (demand) of highway and airport facilities were derived in earlier sections. Microeconomics theory suggests that in an efficient and competitive system, prices are at marginal cost, as this maximizes profits and consumer benefits, and thus total welfare for society. The marginal cost is that which is charged to the last consumer, the price where serving the last consumer still results in positive net revenue or

3.4.3.1 Highway

Recall the delay expression from above, this average delay is the average cost in minutes per mile or minutes per kilometer, composed of two parts, a fixed portion reflecting the uncongested time to travel, which is a private cost, and the variable portion which is a function of volume, which is the result of an externality from other drivers.

(3.4.3) $ACht = L/Vf + 0.54 * (Qh/Qho)^{10}$ [English]

(3.4.4) $ACht = L/Vf + 0.32 * (Qh/Qho)^{10}$ [Metric]

The total costs are simply the average cost multiplied by the total number of users (Q).

(3.4.5) $TCht = QhL/Vf + 0.54 * (Qh)^{11}/(Qho)^{10}$ [English]

(3.4.6) $TCht = QhL/Vf + 0.32 * (Qh)^{11}/(Qho)^{10}$ [Metric]

The marginal cost (delay) per unit output is simply the derivative of the total cost, or:

(3.4.7) $MCht = \partial TC/\partial Q = L/Vf + 5.9 * (Qh/Qho)^{10}$ [English]

(3.4.8) $MCht = \partial TC/\partial Q = L/Vf + 3.5 * (Qh/Qho)^{10}$ [Metric]

where:

L = Length (miles or kilometers)

Vf = freeflow speed (mph or kph)

Qh = highway flow in vehicles per hour per lane

Qho = highway maximum flow (capacity), (2000 vehicles per hour per lane)

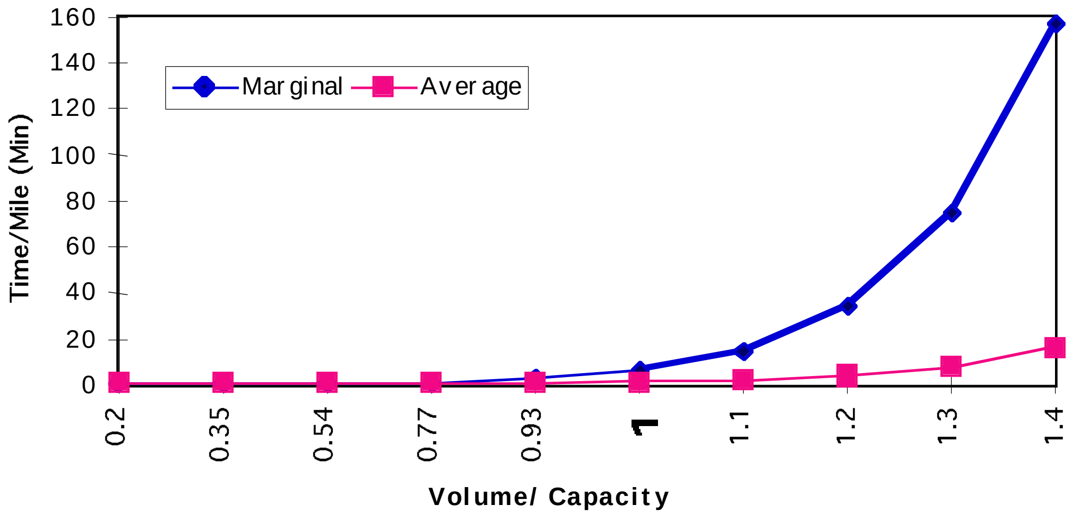
Table 3.4-8: A Comparison of Highway Average, Marginal, and Total Costs

Flow	Marginal Delay (min/vmt)	Marginal Cost ($/vmt)	Average Delay (min/vmt)	Average Cost ($/vmt)	Total Delay (min/vmt)	Total Cost ($/vmt)
0	0	0	0	0	0	0
1000	0.00576	0.00096	0.00053	0.000088	0.53	0.088
1500	0.3322	0.055	0.0304	0.00506	45.60	7.60
2000	5.9	0.98	0.54	0.09	1080	180.

note: assumes value of time is $10/hour.

The above equations can be monetized by multiplying the cost, which is given above in minutes per mile by a value of time. To illustrate, some examples are given below, and graphed in the Figure 3.4-1 below.

Figure 3.4-1: Congestion: Average vs. Marginal Costs of Highway Travel



We have to avoid double counting. If we are to use congestion tolls as a measure of the cost of social cost of econgestion, then these costs should be calculated at a particular level of demand. The appropriate toll needs to be solved simultaneously with the demand in order to make an accurate estimate.

To compare, NRDC (1993), while recognizing the problematic nature of a general cost, estimates a national average of \$0.0035/pmt spread across all drivers. This is within our broad range (three orders of magnitude) of \$0.0018 - \$0.90/pmt, or \$0.00102 - \$0.54/pkt. For comparison purposes, we select a value \$0.005/pkt. This estimate is consistent with the idea of approximately free flow travel for five of the seven hour automobile trip between San Francisco - Los Angeles and a 10 kph reduction in speed for the other two hours.

3.4.3.2 Air

For airport delay, we can undertake a similar exercise. Again, the average delay equation is simply the average cost in units of minutes, as a function of operations and capacity (annual service volume):

(3.4.9) $ACat = 0.19 + 2.33\ (Qa/Qao)^6$

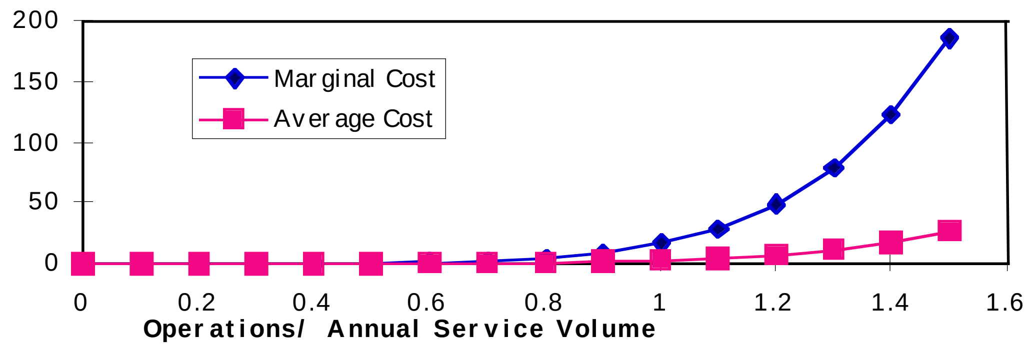
The total cost is simply the average cost per unit multiplied by the number of units.

(3.4.10) $TCat = ACat * Qa = 0.19\ Qa + 2.33\ (Qa/Qao)^7$

The marginal cost (the derivative of the total cost with respect to output Qa) is thus:

(3.4.11) $MCat = \partial TCa/\partial Qa = 0.19 + 16.31\ (Qa/Qao)^6$

Figure 3.4-2: Congestion: Average vs. Marginal Costs of Airport Delay



Again the issue of double counting needs to be addressed. Because congestion costs depend on volume, and volume depends on fares (and thus costs), the two should be solved simultaneously. Again, the above delay measures can be monetized by multiplying by a value of time. For comparison with other modes, we use a n average congestion cost of $0.0017, which is good on the San Francisco - Los Angeles trip.

3.4.4 High Speed Train

Because we are assuming the rail system to be uncongested, the average cost of time by train is simply the freeflow time

(3.4.12) $ACtt = L/Vf$

The total costs are simply the average cost multiplied by the total number of users (Qt).

(3.4.13) $TCtt = Qt\, L/Vf$

The marginal cost of time per unit output here is the same as the average cost, and is simply the derivative of the total cost, or:

(3.4.14) $MCtt = \partial TCtt/\partial Qt = L/Vf$

where:

L = Length (miles or kilometers)

Vf = freeflow speed (mph or kph)

Qt = highway flow in vehicles per hour per lane

These costs can be monetized by multiplying through by a value of time.

3.5. ACCIDENTS

3.5.1 Accident Rates

3.5.1.1 Highway

There are a number of sources recording highway accidents. The National Highway Traffic Safety Administration has two databases: NASS - the National Accident Sampling System and FARS, the Fatal Accident Reporting System. In addition, each state keeps records, as does the insurance industry with its National Council on Compensation Insurance DCI (Detailed Claims Information) database. Injuries are typically classified according to the following scheme, along with the percentage of crashes associated with each category. Only a small proportion of accidents result in death or incapacitating injury as shown in Table 3.5-2

Table 3.5-1: Fatality Rates by Passenger Mode

Mode	1991 Passenger Deaths	1991 Passenger Miles (billions)	1991 Deaths per 100 M Passenger Miles	1989-91 Average Death Rate
Passenger Automobile	22215	2300.5	0.97	1.05
Buses	25	128.1	0.02	0.03
- School Bus	9	83.3	0.01	0.02
- Transit Bus	2	21.3	0.01	0.01
- Intercity Bus	6	23.5	0.03	0.01
Railroad Passenger Train	8	13.6	0.06	0.05
Scheduled Airline	104	338.1	0.03	0.02

source: National Safety Council 1993 (p.95)

Table 3.5-2: Accidents by Classification

	Classification	Percent of Crashes	Percent of People
K	Killed/Fatal Injury	0.3	0.1
A	Incapacitating Injury	2.9	1.5
B	Non incapacitating/ Evident Injury	5.6	3.0
C	Possible Injury	7.6	4.8
O	Property Damage	31.2	36.2
	Unreported	52.4	54.4

note: the number of unreported accidents was estimated from surveys. The total number of crashes was computed for the years 1982-85 and was 14,800,000 affecting 38,146,000 people. source: Miller 1991

The actual rates of accidents are also not immediately apparent. Many crashes, particularly minor accidents without loss of life or major injury, are not reported to the police or insurance industry for obvious reasons. However, we proceed with reported accidents on California freeways, shown in Table 3.5-3.

Table 3.5-3: Number of Accidents on California Freeways

	Road Miles	Travel (MVM)	Accident Total	Property Damage Only	Injury	Fatal	Killed
Rural Freeway	1935	19592	8901	4942	3692	267	338
Urban Freeway	2190	92315	79459	53493	25463	503	562

source: Caltrans 1993

Using the following equations to compute accident and fatality rates, California-specific rates can be computed:

(3.5.1) Accident Rate (AR) = (# Accidents x 1,000,000) / Vehicle Miles Traveled

(3.5.2) Fatality Rate (FR) = (# Victims x 100,000,000) / Vehicle Miles Traveled

The following Table shows accident rates by automobile on rural and urban highways in California. There is a general trend toward a reduction in the rate of accidents, and in their fatality. Safety features such as seat belt usage, air bags, anti-lock brakes, and better design, as well as lower speeds due to congestion in urban areas may be factors. On the other hand, higher speed limits in rural areas may have a safety cost. To what extent technology continues to improve safety in the future remains an unsettled question.

Table 3.5-4: Accident Rates in California

Year	Accidents Total/ /MVM	RURAL (Injured + Fatal/ MVM	Fatal/ 100MVM	Accidents Total /MVM	URBAN (Injured + Fatal) /MVM	Fatal /100MVM
1989	.50	.20	2.08	.92	.34	.87
1990	.47	.23	1.85	.91	.33	.80
1991	.45	.22	1.60	.90	.32	.74
1992	.43	.20	1.35	.88	.31	.62
1993	.45	.20	1.73	.86	.28	.61

source: Caltrans 1993
Note: MVM = Million Vehicle Miles

It should be noted that while there are more accidents proportionately in urban areas, the share of fatal accidents is much less than in rural areas, as urban accidents tend to be at lower speed.

While accidents are often assumed to be a fixed rate, this “linearity” conjecture should not be assumed to be true. Some work has been attempted to estimate the rate of accidents as a function of traffic. The most relevant for California was conducted by Sullivan and Hsu (1988). They estimate the model of freeway accidents given below:

Table 3.5-5: Square Root of Total Annual Accidents During Peak Periods

Independent Variables	Total Annual Accidents During Peak Periods Coefficient	T-Statistic	Total Annual Non-Injury Accidents During Peak Periods Coefficient	T-Statistic
L*N	0.19	3.90	0.13	3.26
IRAMP	1.92	6.63	1.56	6.27
ARAMP	-0.098	-4.10	-0.72	-3.52
Qh	0.000143	3.90	0.000137	4.36
NONE	-0.017	-3.38	-0.019	-4.30
N	62		62	
R-Squared	0.95		0.95	

Variable	Description
Dependent Variable	The square root of the total number of annual accidents in the section during the peak periods 5:00 - 9:30 a.m. or 3:00 -7:30 p.m. (If both periods are congested, the result should be multiplied by two.
L*N	The section length (L) in miles times the number of travel lanes (N) (excluding auxiliary lanes)
IRAMP	The average number on-ramps per mile
ARAMP	= IRAMP if there are auxiliary lanes = 0 if there are no auxiliary lanes in the section,
Qh	The average hourly traffic volume in all lanes during the peak period
NONE	The average percentage of time during the peak period when no queue exists in the freeway section.

source: Sullivan and Hsu 1988

This model is a total accident rate (TARh) model. We square the model above to get the total number of accidents expected during the peak period over the course of the year, given in equation 3.4.3. It can be converted to a marginal accident rate (MARh) model by taking the first derivative with respect to Qh. We define the variable "a" as a constant reflecting all the variables multiplied by their respective coefficients other than Qh. (The variable NONE in theory may depend on Qh, but we will assume for now that the section has been designed sufficiently with no queueing, so that NONE equals zero. Again recall that in this project we are concerned with intercity travel, and that access to any intercity mode (airport, highway, or rail station) will occur on similarly congested urban roads, so that the net difference will not be measurable).

(3.5.3) $$TARh = (a + 0.000143\ Qh)^2$$

$$= a^2 + (0.000286)(a)\ Qh + 0.000143^2\ Qh^2$$

(3.5.4) $$AARh = TARh/Qh$$

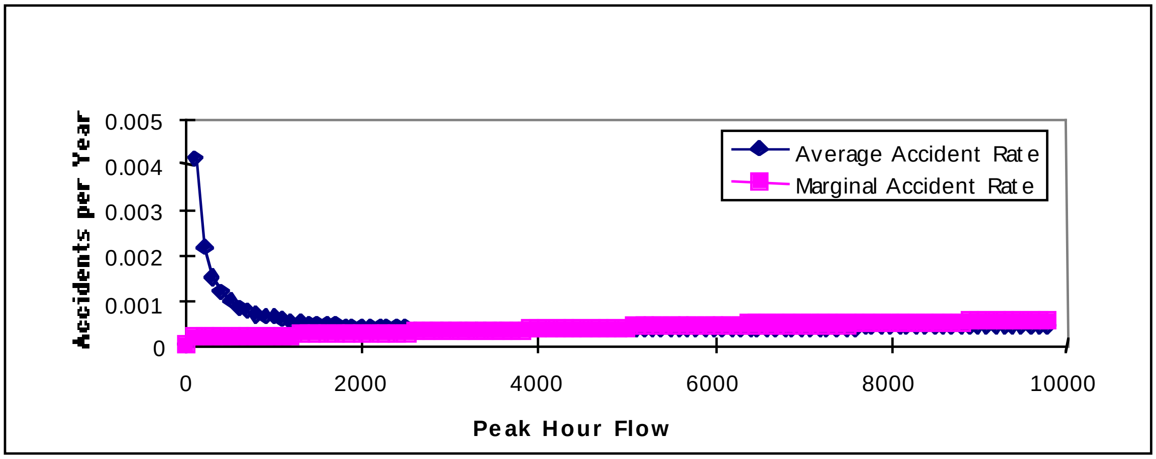
$$= (a + 0.000143\ Qh)^2 = a^2/Qh + (0.000286)(a) + 0.000143^2\ Qh$$

(3.5.5) $$MARh = \partial TARh/\partial Qh = (0.000286)(a) + (2)0.000143^2\ Qh$$

(3.5.6) $$a = 0.19\ L^*N + 1.92\ IRAMP - 0.98\ ARAMP - 0.017\ NONE$$

The cost functions can be graphed and are shown in Figure 3.5-1:

Figure 3.5-1: Marginal and Average Highway Accident Rates



Note: (Accidents per Year on a one km segment (4 lane highway, 0.12 ramps per km) vs. Peak Hour Flow)

Table 3.5-6: U.S. Civil Aviation Accidents, Deaths, and Death Rates

	Accidents		Death	Rate/ MVH		Rate/ MVM	
Year	Total	Fatal	#	Total	Fatal	Total	Fatal
Large Airlines							
1988	29	3	285	0.0251	0.0018	0.0062	0.0004
1989	28	11	278	0.0248	0.0098	0.0061	0.0024
1990	26	6	39	0.0214	0.0049	0.0052	0.0012
1991	27	4	50	.0.0227	0.0034	0.0056	0.0008
1992	19	4	53	0.0155	0.0033	0.0038	0.0008
Commuter Airlines							
1988	19	2	21	0.0908	0.0096	0.050	0.005
1989	18	5	31	0.0803	00.223	0.046	0.013
1990	15	3	6	0.0642	0.0128	0.033	0.007
1991	22	8	77	0.1013	0.0368	0.058	0.021
1992	23	7	21	0.1055	0.0321	0.056	0.017
On-Demand Air Taxis							
1988	101	28	59	0.384	0.106	-	-
1989	111	25	83	0.368	0.083	-	-
1990	108	28	49	0.482	0.125	-	-
1991	88	26	73	0.393	0.116	-	-
1992	74	24	66	0.332	0.108	-	-
General Aviation							
1988	2368	460	800	0.869	0.168	-	-
1989	2233	432	768	0.798	0.153	-	-
1990	2218	445	763	0.778	0.156	-	-
1991	2143	414	746	0.787	0.152	-	-
1992	1956	408	812	0.719	0.150	-	-

source: National Safety Council 1993 (p.96)
note:MVH: Million Aircraft Hours Flown; MVM: Million Vehicle Miles.

3.5.1.2 Air

Aviation accident statistics are collected by the National Transportation Safety Board. Table 3.5-6 compares accident rates for large airlines, commuter airlines, air-taxis, and general aviation, which are in descending order of safety. There are no clear trends over time for the years 1988-92.

Fatalities, though dominant, are not the only cost of an air accident. For scheduled major carriers (14 CFR 121), the following statistics are given for 1992:

Table 3.5-7: Major Air Carrier Accidents Injury Classification

Degree of Injury	Number of Persons
Fatal	31
Serious	19
Minor	29
None	1825
Total	1904

source: National Transportation Safety Board 1992

Table 3.5-8: Accident and Death Rates for Large and Commuter Airlines

		ACCIDENTS			RATE/ MVH		RATE/ MVM	
		Total	Fatal	Deaths		Fatal		Fatal
Large Airlines	English	19	4	53	0.0155	0.033	0.0038	0.0008
	Metric						0.0023	0.00048
Commuter Airlines	English	23	7	21	0.1055	0.321	0.056	0.017
	Metric						0.034	0.010

Note: MVH = Million Aircraft Hours, MVM (MVK) = Million Vehicle Miles (Kilometers)

3.5.2 Value of Life and Injury

The principal means for estimating the cost of accidents is to estimate their damage costs. The method presented here uses a comprehensive approach which includes valuing years lost to the accident as well as direct costs. Several steps must be undertaken: converting injuries to years of life, developing a value of life, and estimating other costs. Placing a value on injury requires measuring its severity. Miller (1993) describes a year of functional capacity (365 days/year, 24 hours/day) as consisting of several dimensions: Mobility, Cognitive, Self Care, Sensory, Cosmetic, Pain, Ability to perform household responsibilities, and Ability to perform wage work. The following Tables (3.5-8 and 3.5-9) show the percent of hours lost by degree of injury, and the functional years lost by degree of injury.

Central to the estimation of costs is an estimate of the value of life. Numerous studies have approached this question from various angles. Jones-Lee (1988) provides one summary, with an emphasis on British values from revealed and stated preference studies. The FAA (1989) provides another summary. He finds the range of value of life to vary by up to two orders of magnitude (a factor of 100). Miller's (1991) summary is reproduced below, with numbers updated to 1995 dollars.

Table 3.5-9: Percentage of Hours Lost to Injuries by Degree of Injury

Type of Activity	Modest	Major	Fatal	Total
Functioning	18.0	40.7	41.3	100.0
HH Production	25.2	22.1	52.7	100.0
Work	21.7	19.1	59.2	100.0

source Miller (1991) p.26

Table 3.5-10: Functional Years lost by Degree of Injury

Degree of Injury	Per Injury	Percent of Lifespan	Per Year	Percent of Annual Total
1. Minor	0.07	0.15	316,600	10.7
2. Moderate	1.1	2.3	587,700	20.0
3.Serious	6.5	13.8	1,176,700	40.0
4. Severe	16.5	35.0	446,700	15.2
5. Critical	33.1	70.0	413,800	14.1
Avg. Nonfatal	0.7	1.5	2,941,500	100.0
Fatal	42.7	100.0	2.007,000	

source Miller (1991) p29
note: expected lifespan for nonfatally injured averages 47.2 years

Table 3.5-11: Estimated Value of Life by Type of Study

Type of Study	Value of Life ($) (1988 dollars)	Value of Life ($) (1995 dollars)
Average of 49 studies	2.2 M	2.9 M
Average of 11 auto safety studies	2.1 M	2.7 M
Study Type		
Extra wages for risky jobs (30 studies)	1.9-3.4 M	2.5 - 4.4 M
Market demand vs. price		
safer cars	2.6 M	3.4 M
smoke detectors	1.2 M	1.6 M
houses in less polluted areas	2.6 M	3.4 M
life insurance	3.0 M	3.9 M
wages	2.1 M	2.7 M
Safety behavior		
pedestrian tunnel use	2.1 M	2.7 M
safety belt use (2 studies)	2.0 - 3.1 M	2.6 - 4.0 M
speed choice (2 studies)	1.3 -2.2 M	1.7 - 2.9 M
smoking	1.0 M	1.3 M
Surveys		
Auto safety (5 studies)	1.2-2.8 M	1.6 - 3.6 M
Cancer	2.6 M	3.4 M
Safer Job	2.2 M	2.9 M
Fire Safety	3.6 M	4.7 M

Source: Miller (1990),
*Note: in millions (M) of after-tax dollars ($1995 = $1988 * 1.3).*

3.5.3 Comprehensive Costs

After converting injuries to functional years lost, combining with fatality rates, and value of life, a substantial portion of accident costs have been captured. But this data must be supplemented by other costs, including hospitalization, rehabilitation, and emergency services.

Table 3.5-12: Costs per Person in Accidents by Component Category:

Cost Component Category	All Reported Accidents (1988 dollars)	All Reported Accidents (1995 dollars)
Hospital/Medical	$588	$764
Vocation/Rehabilitation	7	9.1
Household Production	503	654
Wages	1993	2591
Insurance Administration	379	493
Workplace Costs	117	152
Emergency Services	50	65
Travel Delay	100	130
Legal/Court	429	558
Property Damage	1351	1756
Human Capital Subtotal	5517	7172
Pain and Suffering	11788	15324
Comprehensive Subtotal	17305	22496
Direct Costs	3021	3927
Years Lost	0.13	0.13

Source: Miller (1991) p 42
*Note: ($1995 = $1988 * 1.3)*

Table 3.5-13: Comprehensive Costs by Severity of Accident

Accident Severity	Cost Per Person (1988 dollars)	Cost Per Person (1995 dollars)	Cost Per Crash (1988 dollars)	Cost Per Crash (1995 dollars)
K-Fatal	$2,392,742	$3,110,564	$2,722,548	$3,529,312
A-Incapacitating	169,506	220,357	228,568	297,138
B-Evident	33,227	43,195	48,333	62,832
C-Possible	17,029	22,138	25,288	32,874
O-Property Damage	1,734	2,254	4,489	5,835
Unreported	1,601	2,081	4,144	5,387
A-B-C reported nonfatal	46,355	60,261	69,592	90,469
K-A-B-C reported injury	77,153	100,298	115,767	150,497

*note: assuming 4% discount rate ($1995 = $1988 * 1.3)*
source: Miller 1991 (p39)

Taking the above comprehensive costs, they can be allocated to the various accident categories by severity. These costs are in general higher than estimates previously used by NHTSA (1983), Miller discusses the differences in depth.

Costs vary by location, and are given in the following Tables, converted to 1995 U.S. dollars.

Table 3.5-14: Cost Per Crash by Location

Type of Crash	Cost Per Crash (~1995 Dollars)
rural	111,000
rural interstate	120,000
urban	42,000
urban interstate	70,000

3.5.4 The Full Cost of Accidents

3.5.4.1 Highway

Combining costs of $120,000 for an rural crash and $70,000 as the cost of an urban crash with California accident rates for 1993, we have the following estimated cost per million vehicle miles (first row) and per million vehicle kilometers (second row).

Table 3.5-15: Cost of Highway Accidents

	Rural Rate /MVM (/MVK)	Rural Cost (1995 dollars)	Rural Cost /VMT (/VKT)	Urban Rate /MVM (/MVK)	Urban Cost (1995 dollars)	Urban Cost /VMT (/VKT)
English	.45	$120,000	$0.054	.86	$70,000	$0.060
Metric	.27	$120,000	$0.032	.52	$70,000	$0.036

Source: Rural and Urban Interstates (1995)

The NRDC (1993) estimates auto accident costs at about $0.043/pmt ($0.026/pkt) for urban and $0.03/pmt ($0.018/pkt) for rural travel.

Application of the accident model developed above gives similar results. The average annual total accident rate per hour at a level Qh = 6000 vph and a = 0.63 (1 km section, 4 lanes wide, 0.12 intersections per km, no queueing) is 2.214. Dividing by 365 (days per year) , and then multiplying by 33% (the proportion of four and half hour peak period traffic in the peak hour), and dividing by the number of vehicles, we get the probability of an accident per hour per vehicle is 0.000 000 34. Multiplying this by the cost of an accident, we get $0.040/vkt for rural travel or $0.023/vkt for urban travel. Clearly the value resulting depends upon the assumptions made. Taking the rural travel cost and converting from vkt to pkt (at 1.5 person per vehicle) gives .026pkt while the urban cost is 0.015/pkt. A compromise value is around $0.020/pkt. Previous estimates are given in the following Table: 3.5-15:

Table 3.5-16: Previous Estimates of Accident Costs

Study	$/PMT	$/PKT
U.S. DOT (1975)	$0.024	$0.014
Keeler et al (1975)	$0.022 rural $0.027 urban	$0.013 rural $0.016 urban
Erickson (1982)	$0.0033	$0.002
Gordon (1990)	$0.034	$0.02
Jones-Lee (1990)	$0.03	$0.018
Vernbergg and Jagger (1990)	$0.023	$0.014
U.S. Dept. of Commerce (1990)	$0.06	$0.036
Konheim and Ketcham (1991)	$0.048 rural $0.092 urban	$0.028 rural $0.0552 urban

Source: NRDC (1993)

These results are consistent with, though not identical to international studies, which give the following costs of accidents by mode (Canadian cents per Pkm or Tkm).

Table 3.5-17: Cost of Accidents by Surface Transportation Mode, International Data

Country	Year	Car pkm	Bus pkm	Pass. Rail pkm	Truck tkm	Freight Rail tkm	Inland Water tkm
Germany	1990	2.83	0.51	0.44	1.62	0.01	0.01
France	1985				1.04	0.004	
Belgium	1985				0.48	0.19	
Switzerland	1991	4.20	1.02	0.57	4.96	0.04	
Sweden urban	1987	7.06	1.77	0.18	1.77		
Sweden interurban	1987	12.36	0.18		0.18		
USA	1990	2.83	0.60	0.51			

Source: IBI Group (1995); Note: in 1994 Canadian cents,

Australian data (ABTC 1992) shows an average cost per accident of $AU 10,378. This result is significantly lower than American figures, principally due to a lower value of life in the Australian method, which is not as comprehensive as in the United States.

IWW/INFRAS (1995) compute costs of accidents using a macroscopic methodology, computing national estimates of fatality and injury costs. Their European average was in European Currency Units, E0.032/pkt for cars, E0.009/pkt for buses, E0.022/tkt for trucks, E0.0019/pkt for passenger rail, and E0.0009/tkt for freight rail. Given the variation of exchange rates, these figures are consistent with our estimate.

3.5.4.2 Air

A similar calculation could be performed for air travel. However, because the accidents are fewer, and vary a great deal in magnitude, accident rates are not stable on a yearly basis. Similarly, it is difficult to establish with confidence any costs beyond loss of life using the value of life idea discussed above. Some estimates for accident rates are provided in Table 3.5-8.

If, for large airlines we have 0.0008 fatal accidents per million aircraft miles, an average number of passengers per flight of 100, an average of 13 deaths per fatal crash, and a value of life of $2.4 million, then the cost for accidents on large aircraft is $0.00025/PMT ($0.00042/ PKT) . Taking more conservative values of life and including non-life costs (injury and medical, accident cleanup, etc.), and assuming a higher number of fatalities could quadruple the estimate to $0.001/PMT ($0.0017/ PKT) .

This range of estimates is consistent with Canadian estimates of accident costs ($0.001/PKT 1994 Canadian cents) (IBI 1995). Australian data (ABTC 1992) show an estimate of $1,259,000 (AU88) total cost per fatal accident, multiplied by the U.S. accident rate of 0.0008 fatal accidents per million aircraft miles gives a cost of $AU 0.001/PMT, which is also within the same order of magnitude as our estimates. However, given the experience with Australia's highway estimates, their estimate is probably better seen as a lower bound.

For commuter airlines, the estimate is somewhat higher: 0.017 fatal accidents, 25 passengers per flight, 3 deaths per fatal crash, and the same value of life gives the cost for accidents of $0.005/PMT ($0.0083/PKT) . Again taking more conservative values, we get $0.02/PMT ($0.033/PKT) as a higher cost estimate per passenger mile (kilometer) on commuter aircraft.

3.6. AIR QUALITY

3.6.1 The Nature of Air Pollution

Probably the most difficult cost to establish in this project is that of air pollution. Determining the quantity of pollutants emitted from an automobile, airplane, or train is in principle a relatively straight-forward engineering task, though it depends on vehicle type, model year, vehicle deterioration, fuel type, speed, acceleration and deceleration, and other factors. However, emission rates are determined by tests in laboratory, rather than actual conditions. So to some extent, these rates probably underestimate the amount of actual emissions (Small and Kazimi 1995).

Determining the damage done is more difficult still. For a variety of reasons, pollution is generally considered a negative externality, the polluter involuntarily imposes a cost on the recipient. Studies have looked at various aspects of air pollution and its costs. This chapter will attempt a synthesis to provide useful information.

As used here, the costs of air pollution fall into four main categories: Photo-chemical Smog, Acid Deposition, Ozone Depletion, and Global Warming; though it is only the first and last for which significant research into transportation costs have been undertaken. There is considerable scientific controversy surrounding all of these categories, and there is no direct translation from pollutant emitted to damage inflicted. The amount of damage depends on a number of environmental factors including the place and time of emission. Furthermore, there are significant issues regarding the life-cycle of energy production. While the pollution from a car occurs where the car is, for an electrically powered system such as a train, the pollution occurs at the generating plant. Should that pollution be considered in this study - or is it assumed that the electricity from the generating plant is properly priced, reflecting either implicitly or explicitly that cost of pollution?

How are the costs of pollution calculated?

First are damages: Calculations of the health effects of pollution have been attempted. However, as with many numbers related to estimates of externalities, the accuracy of health estimates is open to question. To some extent, the damage cost of pollution is capitalized in real estate values, but unlike noise, it is difficult to extract this information. Studies have attempted to calculate damage losses due to global warming, and from that estimate an appropriate carbon tax, or price which would be charged on an activity based on the amount of carbon produced.

Second are protection measures, which include defense, abatement, and mitigation approaches to preventing or counter-acting a decision creating pollution. Some analyses use 100% cost of mitigation. An example of a mitigation measure is the cost of the number of trees planted to soak up the CO_2 pollution generated. However, with some pollutants there may be no abatement measures, and the only prevention measure would be to avoid production.

Third, estimates can be made of how much would people pay to avoid (or to be compensated) for a certain level of air pollution. Methods for this include stated preference surveys and analyses of the implied cost due to preventative regulations. However, stated preference methods are suspect for a variety of reasons, including their hypothetical nature, which allows individuals to answer unrealistically, or perhaps even "strategically game" to influence the outcome of the study and thus influence policy.

What are the main pollution problems?

- Photo-chemical Smog - Photochemical Smog is a regional problem occurring low in the atmosphere and at ground level. Seasonal in nature, it tends to peak in the summertime in most areas. A principal cause is tailpipe emissions from automobiles. The Clean Air Act Amendments of 1990 were primarily aimed at smog. Ozone, is formed in the atmosphere by a reaction between volatile organic compounds (VOCs), nitrogen oxides (NOx) and water in the presence of sunlight, is the main cause of smog.

- Acidic Deposition (Acid Rain) - This problem, most prevalent in eastern North America and Europe, is found in the troposphere. Acid rain is formed when sulfur dioxide (SO_2) and nitrogen dioxide (NO_2) reach with H_2O to form sulfuric and nitric acid. The principal source of SO_2 is fixed source burning of fuels, particularly coal, such as in electricity generation.

- Global Warming (Greenhouse Effect) - Global warming is, as the name implies, a potential problem of international proportions. Several trace gases in the troposphere absorb heat emitted by the earth and radiate some of it back, thus warming the global atmosphere. Without any greenhouse effect, the earth would be extremely cold as heat would not be retained with the atmosphere acting as a greenhouse. The conclusion of many scientists is that manmade pollutants are increasing the amount of heat retained by the earth. In the long term this may raise the average planetary temperature, resulting in a slight melting of polar ice-caps and a consequent rise in the sea-level. The impacts on global weather patterns are not well understood, some areas may benefit, but others are sure to lose. There is considerable dispute in the scientific community on the magnitude of changes caused by man-made pollution. In particular, little is understood about feedbacks within the environmental system, for instance a rise in temperature may increase cloud cover, which will cause more sunlight to be reflected rather than reaching the earth, thereby mitigating the temperature rise. Other feedbacks may make the problem worse. The trace gases which are thought to cause global warming fall into three categories (Barakat and Chamberlin, 1990): direct: radiatively active gases such as CO_2 (49%), O_3 (18%), CH_4 (14%) , N_2O (6%), and CFCs and others (13%). The percentage indicates contribution of manmade sources to global warming; indirect: chemically/photochemically active gases such as CO, NOx, SO_2 which effect atmospheric concentration of OH, CH_4, and O_3; aerosol emissions. The principal pollutant is CO_2. While 96% of CO_2 production is natural, it is the 4% which is manmade (burning fossil fuel and converting land use) which is of concern. A doubling of CO_2 is expected to raise the global mean equilibrium surface temperature by 1.3 - 4.5 degrees Celsius (2.2 - 7.6 degrees Fahrenheit). The economic and ecological effects of such a change are unknowable with certainty, although attempts have been made at estimating these costs. As of 1986, the concentration of CO_2 in the atmosphere was 346 ppm, and increasing at 0.4 percent per year (1.38 ppm) - at this rate the concentration will double in about 250 years. However, other pollutants may also raise global temperature. There is considerable uncertainty about the magnitude of each pollutant, and their interactions. Attempts have been made to translate other pollutants into CO_2 equivalents.

- Stratospheric Ozone Depletion - Ozone (O_3) is formed when oxygen molecules (O_2) are combined with oxygen atoms photodissociated from other oxygen molecules. The layer of ozone in the atmosphere reflects ultraviolet radiation bombarding the earth. While the creation of ozone is independent of human activity, its destruction is not. Due to some manmade pollutants, particularly CFCs, the layer is thought to become thinner over time. Holes in the ozone layer have appeared over the polar ice caps. The Montreal Protocol is an international treaty which requires the phasing out of damaging CFCs. CFCs are used principally in refrigerants, such as air conditioners. Overall, the transportation sector's impact is relatively small.

Air pollution emissions come primarily from the excess byproduct of burning of a fuel, though there are other sources, including evaporation and leakage of feedstocks and finished energy resources, and venting, leaking, and flaring of gas mixtures. There are a number of stages in the fuel-cycle (DeLuchi, 1991). Though transportation changes will obviously influence all of the stages in the fuel cycle, we are making the assumption in this paper that aside from the "end use" transportation stage, all other stages are in functioning markets for which pollution externalities have already been captured. This question is particularly relevant for a comparison of gasoline powered modes with electrical powered modes. If the electricity sector does not fully account for its externalities, such an accounting should be made here, but if it does, we need to avoid double counting.

Table 3.6-1: Impact of Pollutants on Type of Pollution

Pollutant	Smog	Acid Rain	Global Warming	Ozone Layer
Carbon monoxide (CO)	x,t			
Carbon dioxide (CO_2)			X,T	X,t
Chlorofluorocarbons (CFC)			x,t	x
Methane (CH_4)			x	
Nitrogen Oxides (NO_x)	T	X,T	T	x
Nitrous Oxide (N_2O)			x	
Ozone (O_3)	X,T		x,T	
Sulfur Oxides (SO_x)		X		
Volatile Organic Compounds (VOC)	T		T	

Notes: X: Contaminant is a major (> 25%) manmade source of the pollution problem, x: contaminant is a minor (<25%) manmade source of the pollution problem, T: transportation is a major manmade source (> 25%) emissions of the contaminant, t: transportation sector is a minor (<25%) manmade source of emissions of the contaminant

Source: Barakat & Chamberlin, 1990.

Does the electricity sector count its "full costs" as we are proposing to do for transportation in this analysis?

There is a movement in electricity planning towards so-called "Least Cost Planning" which considers both the cost of supply expansion or "Megawatts" as well as demand reduction, so-called "Negawatts", short for negative watts, when studying future needs. This approach often accounts for environmental externalities.

Also, the electricity industry, like the transportation sector, is subject to the Clean Air Act, and specific pollution standards must be met. This implies that any capacity (or production) expansions in areas not meeting standards (for instance, most of urban California) which result in additional pollution must be offset. While existing pollution is not taxed per se, all new pollution is effectively taxed to the point where it is 100% mitigated (or more, with new generation required to produce offsets greater than production). Assuming electricity is priced reflecting costs, pollution regulations should be reflected in the price of electricity.

To what extent is electricity properly priced already? While electricity generation is now a heavily regulated industry, there is a movement to deregulate production within California - which will favor low cost producers, selling at marginal cost in an efficient market. Thus we conclude that the marginal additional electrical requirements for high speed rail or the electric vehicles will not generate additional pollution which is not already accounted for implicitly in the price of electricity. However, this also suggests that the price of electricity will rise to cover pollution mitigation costs.

We have not yet addressed the question of incidence, who bears the pollution control costs, and whether that is an equitable distribution. A deregulated network market will result likely result in a single price for electricity at any given point, analogous to DeVany and Walls (1994) who identified the operation of “The Law of One Price in a Network” for deregulated natural gas. Whether it is appropriate to charge old and new users alike, or whether there is some inherent right to lower prices for those who were around first, is an interesting equity question, but which cannot be addressed here. The failure of one price though would result in incorrect price signals and inefficient allocation, opening opportunities for arbitrage.

3.6.2 Emission rates by Mode

3.6.2.1 Trains

Data are available concerning the diesel trains principally used throughout California. Very few lines in California are electrified presently. With electric powered trains, the emission quantities would clearly be different. Table 3.6-2 summarizes emission factors for all types of rail operations in California in six basins (Bay Area, Central Coast, South Coast, San Diego, San Joaquin, and Sacramento).

Table 3.6-2: Pounds of Pollution per Ton-mile of Freight, Diesel Trains

Pollutant	lb/1000 gallons of fuel (4-11)	Annual Emissions Tons/Yr (4-19), (4-20)	1000 Gallons per Year (calc)	lb per mile	lb per ton mile (freight)
HC	22	1550	140909	.225	.000057
CO	68.4	4816	140818	.70	.000179
NOx	512	36171	141292	5.25	.001346
SOx	37.1	2630	141779	.38	.000097
PM-10	11.1	789	142162	.11	.000028

Source: Locomotive Emissions Study, 1992 exhibit 4-11,4-19,4-20 , where: Miles per train = 90, Trains per year = 152,660, Miles per year = 13,739,400, and miles per 1000 gallons = 97.5

Here each freight train averages 3900 tons, and each passenger train averages 495 tons trailing. The Table can be broken out for freight and passenger, and by basin if necessary, also by engine and locomotive type. The numbers above are averages of all six basins and all train types. While additional precision is possible, it is doubtful if accuracy can be improved significantly.

Overall, trains are a small share of total emissions produced in all six basins. Most pollutants are less than 0.12%. However, train NOx amounts to up to 3.4% of all NOx, and train SOx is 1.6% of the total. The share of mobile source is somewhat higher.

Table 3.6-3: Emissions by Train Type per Day (tons, 1987)

Train Type	HC	CO	NOx	SOx	PM-10
Mixed Freight	1.51	4.85	37.3	2.76	0.81
Intermodal Freight	1.13	3.68	27.8	2.04	0.61
Local Trains	0.96	3.06	21.3	1.59	0.46
Yard Operations	0.55	1.38	9.42	0.51	0.21
Passenger Trains	0.095	0.22	3.24	0.30	0.07
All Operations	4.2	13.2	99.1	7.2	2.2

Source: Locomotive Emission Study ES-3

Information is available on air pollution from some of the high speed rail systems in Europe and Japan by multiplying fuel use (whether diesel or electric) by the amount of pollution generated by its burning. It is important to note that if the train uses electricity, the social cost of that pollution is probably best attributed to the energy sector. The data is provided here for information purposes. As a point of comparison, Hirota and Nehashi (1995) report the Shinkansen as producing 2.30 tons of CO per billion passenger kilometers, 0.18 tons of Sox and 0.31 tons of NO, generated by burning 136 kcal of energy per passenger kilometer.

3.6.2.2 Aircraft

By and large, estimates of pollution from aircraft are significantly smaller than from cars;

Table 3.6-4: Air Pollutants Emitted from Transportation Systems

System	Fuel	Fuel	Pounds of Emissions x 10^3					
	Type	Amount	Uncontrolled				With Controls	
		Reqd.	PM	CO	HC	NO_2	PM	NO_2
Conventional Diesel	# 2 diesel	0.0462 gal	1.16	6.02	4.39	17.28		
Conventional Electric	Coal (bit.)	0.472 lb	16.9	0.472	0.236	3.54	0.169	3.01
	Nat. Gas	5.6 cu ft	0.056	0.095	0.0056	3.92		3.33
	Fuel Oil	0.039 gal	0.39	0.195	0.039	4.10	0.0039	3.48
Japanese Shinkansen	Coal (bit.)	0.138 lb	4.95	0.138	0.069	1.037	0.050	0.881
	Nat. Gas	2.460 cu ft	0.025	0.042	0.0025	1.722		1.464
	Fuel Oil	0.0171 gal	0.171	0.086	0.017	1.801	0.0017	1.531
TGV	Coal	0.107 lb	3.844	0.107	0.054	0.805	0.0384	0.684
	Nat. Gas	1.274 cu ft	0.0127	0.0216	0.0013	0.892		0.758
	Fuel Oil	0.009 gal	0.0887	0.0444	0.0089	0.933	0.00089	0.793
TVE	Coal	0.415 lb	14.87	0.415	0.208	3.114	0.149	2.647
	Nat. Gas	4.926 cu ft	0.0493	0.084	0.0049	3.448		2.931
	Fuel Oil	0.0343 gal	0.343	0.172	0.0343	3.607	0.0034	3.066
MD-80 Aircraft	JP4	0.162 lb	0.422	0.227	0.08	3.08		

source: Wayson and Bowlby 1989 *Note: Basis: One Passenger Mile: 50% Load Factor*

Table 3.6-5: Emissions Comparison by Mode in the United States, 1989

Mode	Passenger Miles (km)	HC tons, M. (kg, M)	CO tons, M. (kg,M)	NOx tons, M. (kg, M)
Highways	3.4×10^{12} (5.4×10^{12})	5.63 (5,118)	35.96 (32,690)	6.54 (5,945)
Jets	3.5×10^{11} (5.8×10^{11})	0.06 (54)	0.18 (163)	0.08 (72.7)
Total Transport		7.05 (6,409)	43.97 (39.972)	8.71 (7,918)
Total All Sources		20.39 (18,536)	66.95 (60,863)	21.88 (19,890)

source: GAO (1992), Bureau of Transportation Statistics (1994) Annual Report
note: in million tons english, or (million kg metric)

Combining the total emissions with an estimate of passenger kilometers traveled by jets in the United States produces an estimate of pollution per unit output. However this ignores some of the joint cost aspects of air and highway travel, where freight is shipped along with passengers.

Table 3.6-6: Emissions on Highways and by Jets in the United States

Mode	HC (gm/pkt)	CO (gm/pkt)	NOx (gm/pkt)
Highways	0.95	6.053	1.11
Jets	0.093	0.28	0.13

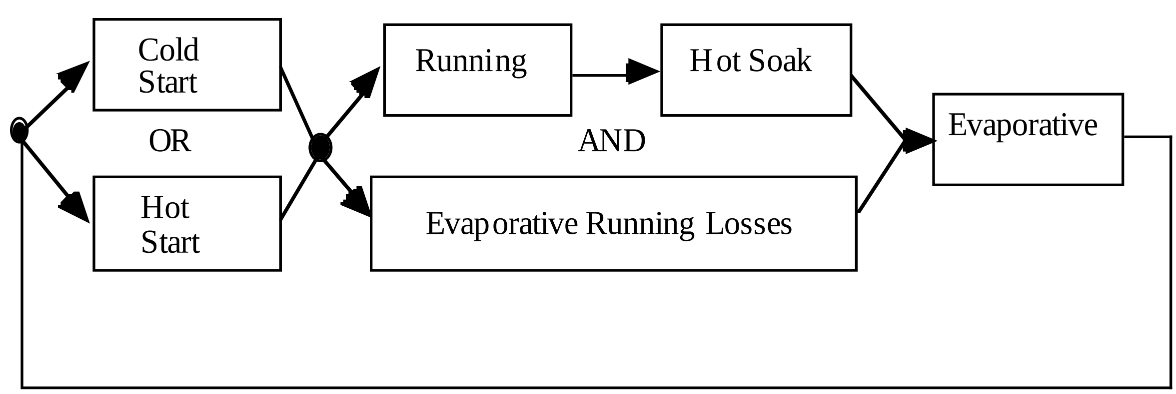
source: Authors Estimate
Note: pkt = passenger kilometer travelled

This suggests that on a per distance basis, aircraft are cleaner than automobiles by about a factor of 10. While these are clearly macroscopic estimates, the highway emissions calculated here are in the same range as those suggested by the MOBILE4 and EMFAC models after considering both running and cold start emissions and age of the fleet, as described in the next section. The more precise estimates from the MOBILE4 and EMFAC models, as adjusted for underestimation will be used for the auto mode. The consistent estimates are provided for comparison purposes only.

3.6.2.3 Automobiles

Despite the simplifications proposed in the previous section, the science of emissions estimation is an extremely complicated subject. Sophisticated models (e.g. EMFAC, MOBILE) have been developed which characterize emissions generation by a number of factors including fleet mix (size and age of vehicles), fuel usage, the environment (temperature) and travel characteristics. For each vehicle over the course of a trip and until its next trip, emissions are computed for the stages shown in the following chart:

Figure 3.6-1: Auto Emissions Process



The question arises as to which components should be considered in an analysis of intercity transportation. If parts of the cycle are common to all modes of transportation (for instance if auto access were assumed for air and high speed rail as well as highway modes), then cold starts would be common to all modes. Similarly, if the inter-city trips are assumed to displace an otherwise expected intra-city trip, for instance a daily work trip from the Bay area suburbs to downtown San Francisco is replaced by a one day trip to Los Angeles, then a number of the components (cold or hot start, hot soak, and evaporation) are common to the trips. If the trip is accessing LA via high speed rail or air travel, then the trip to the airport substitutes for another trip within the region, and the incremental difference over the amount of pollution otherwise expected is small. Though for a highway trip between the two cities running emissions are significantly greater.

Table 3.6-7: Summary of Exhaust Emission Rates

Light Duty Autos (gasoline) (w/Cat Converter)	HC (TOG, VOC)	CO	NOx
Zero Mileage Level Running Emissions (g/mi)	0.278	2.915	0.635
0-50 K Mile Deterioration Rate (g/mi/10K miles)	0.056	0.748	0.034
50+ K Miles Deterioration Rate (g/mi/10K miles)	0.076	0.939	0.034
Incremental Cold Start (g/trip)	4.84	48.47	2.85
Incremental Hot Start (g/trip)	0.60	9.80	1.59
Hot Soak (g/trip)	0.77	N/A	N/A
Diurnal Emissions (g/Hour)	0.75	N/A	N/A

source: EMFAC 7F, MOBILE 4.1
Note: 1992 model year vehicle characteristics, summertime 75%, 55 MPH running speed

It should be noted that light duty trucks pollute about 20% more than autos, that medium duty trucks (with catalytic converters) pollute about two times as much as autos on HC and NOx and the same on CO. Heavy duty trucks are also about two times auto pollution rates for HC and CO, and five times for NOx. Furthermore, older cars pollute more than newer, a 1972 model year is about ten times more noxious than a 1992 car, though most improvements came from standard implemented between 1972 and 1982.

It has been noted from studies of pollution in more realistic situations, that the rates proposed above may err on the low side. Small and Kazimi (1995) after reviewing considerable technical research, developed corrected emission factors, which will be used in the final analysis here.

Table 3.6-8: Corrected Emission Factors

Pollutant	Gasoline Car	Light duty diesel truck	Heavy duty diesel truck
CO	13.000	1.607	9.326
VOC	3.757	0.362	2.356
NOx	1.260	1.492	15.683
SOx	0.038	0.122	0.576
PM10	0.011	0.395	2.359

Source: Small and Kazimi (1995)
Note: 1992 Fleet Average, (gm/mile) from EMFAC7F, updated for VOC underestimate by 2.1.

3.6.2.4 Greenhouse Emissions for Cars and Airplanes

EMFAC and MOBILE only provide data on criteria pollutants, that is pollutants for which standards have been set for health reasons. Greenhouse gases (principally carbon dioxide and methane) do not have such standards.

The Energy Information Agency has developed emission factors on greenhouse gases. The following is extracted from that report and other sources.

Table 3.6-9: Motor and Jet Fuel Carbon Emissions Factors

Fuel Type	Million Metric Tons Carbon (1992)	Passenger Kilometer Travel	1bC / PMT	gmC / PKT
Motor Fuel	263.2	$2.4x10^{12}$	0.17	46
Jet Fuel	59.2	$5.8x10^{11}$	0.37	100

Source: Energy Information Agency, page 102 (1994); Bureau of Transportation Statistics (1994)

Pickrell (1995) reports carbon emissions of 6.2 lbs/gallon of gasoline, which at 22 miles per gallon and 1.2 person per vehicle works out to an emissions rate 0.23 lb/pmt, which is of the same order of magnitude as the above macroscopic estimate of 0.17 lb/pmt (46 9m/pkt).

British researchers have produced estimates which can be compared for our purposes. Wootton and Poulton (1993) convert fuel litres of gasoline to CO2 by multiplying by a factor of 23.51 accounting for fuel density and the molecular weight of CO2. Their estimates of CO2 emissions in g/km range from 162 to 228 depending on the size of the vehicle. Taking the medium size car value of 186 g/km, converting into grams of carbon (dividing by 3.6667 or 12/44) gives 50.72 grams of carbon per km or 81.15 g/mi or 0.178 lb/mi. These are consistent with our estimates.

3.6.2.5 Health Damages

Lave and Seskin (1977) performed a regression to estimate the mortality rate in various metropolitan areas in 1969 as a result of a variety of factors, including sulfate readings and suspended particulates.

Table 3.6-10: Mortality Rate Regression Analysis

Variable	Coefficient	T-Statistic
Minimum Sulfate Reading	0.774	2.11
Annual Arithmetic Mean Suspended Particulate Reading	0.818	3.39
Population Density	0.131	2.54
Percentage of SMSA Population 65+	6.568	18.09
Percentage of the SMSA Population that is non-white	0.204	2.27
Percentage of the SMSA Population with incomes below the poverty level	0.557	2.29
the logarithm of the SMSA Population	-0.365	-1.94
Constant	330.647	
R-Squared	0.805	

source: Lave and Seskin (1977)

This provides an elasticity (with respect to mortality rate) of sulfates and particulates of 0.0297 and 0.0866 respectively (0.1163 in total). This assumes a linear relationship between pollutants and mortality, which is not in consonance with dose-response literature, but may be acceptable in a small range. Fuller et al (1983) apply this along with data from Cooper and Rice (1976) to estimate total health damage due to pollution as $21,982 million in 1977 $21,982 = 0.1163 * $258,920 * 73% (where 73% reflects percent of US population in SMSA).

Table 3.6-11: Cost of Illness

Category	1972	1977
Direct	$75,231	$114,918
Morbidity	$45,323	$ 61,127
Mortality	$57,380	$82,874
Total	$174,934	$258,920

source: Cooper and Rice (1976), Fuller et al (1983)
Note: In millions of 1977 dollars

Using the methodology summarized in the following Table, they provide an estimate for damage costs from the various pollutants. Taking a tolerance factor based on health estimates at the time, this is converted to a severity factor relative to CO. Total tons are converted to CO equivalents, and then the costs are allocated to each pollutant based on their relative severity. This is multiplied by total costs to estimate total cost per pollutant, and thus cost per unit of emissions.

Table 3.6-12: Macroscopic Estimates of Cost of Pollution

	CO	HC	NOx	SOx	PM10
Tolerance Factor	7800	788	330	373	260
Severity Factor, (vs. CO)	1	10	24	21	30
Total US Emissions (million tons)	113.4	29.8	24.8	30.2	15.5
Severity Tonnage	113.4	298.0	595.2	634.2	465
Cost Allocation, $\Sigma = 1$	0.0539	0.1414	0.2826	0.3012	0.2208
Cost ($ million)	1,184	3,110	6,212	6,621	4,853
Cost per ton ($/ton)	$10	$104	$250	$219	$313
Cost per kilogram ($/kg)	$0.012	$0.12	$0.28	$0.24	$0.35

sources: Small (1977) and Fuller et al (1983)
Note: 1977 dollars

Ottinger (1990) provides separate estimates of environmental and health damages per pollutant from a variety of synthesized methods. The results are reproduced below.

Table 3.6-13: Starting Point Costs of Environmental Damages by Pollutant

Damage	Effect	SO_2	NOx and Ozone	Acid Deposit	PM10	CO_2
Health	Mortality	$4.48	$0.89	na	$0.86	na
	Morbidity	$0.13	$0.76	na	$0.08	na
	Total	$4.61	$1.64	$0.00	$0.94	na
Materials	Corrosion/ Soiling	$0.31	$0.03	na	$0.00	na
Vegetation	Crops Ornamental Forests	$0.00	$0.03	na	$0.00	na
Visibility		$0.36	$0.44	na	$0.00	na
Ecosystems		na	na	na	$0.00	na
Historical Monuments		na	na	na	$0.00	na
	TOTAL	$5.29	$2.14	$0.00	$3.10	$0.018

Source: Ottinger et al 1990
Note 1989 $CAN/kg; na = not available

Some recent work on the costs of air pollution from cars comes from Small and Kazimi analyzing the Los Angeles region. They update factors from EMFAC and MOBILE 4 to correct for reported underestimation of pollution. They then review recent evidence on mortality and morbidity and its association with pollutants (VOC, PM10, SOx, NOx). Using work from Hall et al (1992) and Krupnik and Portney (1991), they combine various exposure models of the Los Angeles region with health costs Their findings suggest that particulate matter is a primary cause of mortality and morbidity costs, followed by morbidity due to ozone. Of course, costs in densely populated areas, such as the Los Angeles basin, should be higher than in rural areas as the exposure rate is far higher. They also assume a value of life of $4.87 million in their baseline assumptions, though they test other scenarios, we report their estimate using a $2.1 million value of life (Vl) for consistent comparison with other studies.

The health cost estimates from Fuller et al (1983) differ from the more recent effects estimated by Ottinger et al (1990), and even more so from the Small and Kazimi

(1995) estimates for the Los Angeles basin. The estimates are most similar on the ozone producing NOx and HC, and vary widest for the particulate problems due to PM10 and SOx :

Table 3.6-14: A Comparison of Estimates of Health Effects ($/kg)

	Fuller et al	Ottinger	Small (1995) @4.87M VoL	Small (1995) @2.1 M VoL
SOx	$0.84	$4.61	$24.97	$10.76
NOx + HC	$1.22	$1.64	$3.09	$1.33
PM10	$1.20	$0.94	$23.19	$10.00

note: Fuller et al. (1983) updated to 1995 U.S. dollars using medical care inflation rates, Ottinger (1990) updated from 1990 Can to 1995 U.S. dollars, Small and Kazimi (1995) in 1995 U.S. dollars, Los Angeles region

Fuller et al (1983) also apply methods developed by Salmon (1970), Small (1977) and Schwing et al (1980) to estimate materials damage, again the numbers vary, this time Fuller's estimates are significantly higher. Finally, Fuller et al. update the results from a 1964 study (Benedict et al 1971) to estimate vegetation damage from air pollution. Both Fuller and Ottinger agree in general that NOx is the primary source of vegetation damage, and their estimates of $0.02 - $0.03/kg are close.

Table 3.6-15: Estimates of Materials and Vegetation Damage ($/kg)

	Materials Damage		Vegetation Damage	
	Fuller et al.	Ottinger	Fuller et al.	Ottinger
CO	$0.0063	na	na	na
HC	$0.19	na	$0.0019	na
NOx	$1.00	$0.03	$0.023	$0.03
SOx	$1.60	$0.31	$0.0019	$0.00
Particulates	$1.03	$0.00	na	$0.00

Source: Fuller et al (1985), Ottinger (1990)
Note: Converted to 1995 U.S. dollars

3.6.2.6 Macro-economic Models

The use of a macro-economic/global climate model to estimate a “carbon tax” which would be the price of damages from pollution has been attempted by Nordhaus (1994). He used a model which would estimate the appropriate tax at a given point of time to optimize the amount of pollution, trading off economic costs of damages due to greenhouse gases and the damages due to imposing the tax. The taxes are in tons of Carbon equivalent. The taxes and rate of control of greenhouse gases are given in the Table below:

Table 3.6-16: Carbon Tax to Optimize Rate of Greenhouse Damage

Decade Centered on Year	Rate of Control of GHG (as percent of uncontrolled emissions)	Carbon Tax Equivalent (1989 $/ton C)
1965	0.0	$0.00
1975	0.0	0.00
1985	0.0	0.00
1995	8.8	5.29
2005	9.6	6.77
2025	11.1	10.03
2075	13.4	17.75

source Nordhaus (1994) p. 94

However, others propose much higher Carbon taxes, in Europe proposals range from $52.80/tonne to $123.20/tonne and in the United States from $82.80/tonne to $179.40/tonne (IBI, 1995). These values are significantly higher than that recommended by Nordhaus, which we use. Nordhaus’s results already factor in the optimization required to compare the costs of damages to that of prevention, developing an equilibrium solution, while the other estimates consider only the cost of damage, not the economic burden imposed by the new tax or the changes in behavior required to obtain equilibrium.

3.6.3 Cost of Prevention and Mitigation

3.6.3.1 Reduced Emissions from Diesel Trains

There are some recommendations in terms of measures to reduce emissions from trains. The cost effectiveness of these is given below: We look at two estimates of prevention strategy, those used for diesel trains, and some estimates associated with mitigating green house gases.

Table 3.6-17: Cost per Unit Reduction of NOx from diesel trains

Control Strategy	Cost per Pound	Cost per kg
Reduced Idling *	$0.29/lb	$0.63/kg
EMD High Rate Injector Retrofit	$1.34/lb	$2.95/kg
Retarded Injection Timing	$0.10/lb	$0.22/kg
Retarded Injection Timing w. High Quality Fuel	$0.93/lb	$2.05/kg

Source: Locomotive Emission Study ES-3
*Note: * would save operating costs*

The estimate of the marginal cost of emission reductions would then by the $1.34 per pound ($2.94/kg) after the more cost effective strategies have been undertaken. Moreover, these measures have limited effectiveness. In total, they only reduce about 16% of NOx emissions.

Table 3.6-18: Diesel Trains Emission Reductions (Tons/Day)

Strategy	HC	CO	NOx	SOx	PM-10
Injector Retrofit	--	.44	6.79	--	--
Reduced Idling	.34	.93	2.82	.19	0.085
Retarded Injection	Increase	Increase	6.14	--	Increase
High Quality Fuel	Nullifies Increase	Nullifies Increase	--	3.6	Nullifies Increase
TOTAL	.34	1.37	15.75	3.79	0.085
% Reduction from Baseline	8.1%	10.38%	15.86%	52%	3.86%

Source: Locomotive Emission Study, ES-6

Alternative fuels are under research. Electrification is an expensive option, which would reduce mobile source emissions (and probably total emissions). For the Los Angeles mainlines alone, the cost was estimated at $1.06 Billion.

3.6.3.2 Carbon Mitigation through Forestation and Other Means

CO_2 is a primary contributor to the possibility of global warming as suggested by a number of researchers. Controlling the amount of CO_2 emitted from power plants through scrubbers ($240 per ton of carbon) is quite costly, while technical solutions such as pumping CO_2 in liquid form to the midocean deep below sea level are not yet available. Other estimates of the cost of carbon mitigation include $23.17 per ton for reduced energy consumption in buildings, $18.11 per ton for fuel switching, and $176 per ton for increasing auto fuel efficiency to 44 MPH.

A solution of mitigation through alternative means, such as planting trees, has been proposed and used in some instances. Hodas (1990) provides the following information, summarized by us in tabular form:

Table 3.6-19: Cost per Ton of Carbon Absorption through Forestation Programs

Project name	Size of Project (tons over 40 yrs)	Cost per Ton	Analyst
Applied Energy System's Guatemala Carbon Sequestration Project	16.3 x 10^6 tons	$4.21	WRI
Conservation Foundation/ World Wildlife Fund Costa Rica Project	10.9 x 10^6 tons	$2.64 ($6.50 - $18.70)	CF/WWF (Hodas)
Costa Rican Government	4.23 x 10^5 tons	$6.30 - $23.60	Hodas
Chernick and Caverhill estimate		$40 - $200	
Tellus Inst. (Chernick & Caverhill data)		$80	
Koomey (Chernick and Caverhill data)		$84	
Schillberg for Cal. and Pacific NW		$54	
California Energy Commission		$26 (later $54)	
Marland in South Africa & Sahel		$67 - $120	
Buchanan Pacific Northwest Forestry		$19.50 ($26.23-$47.40)	Buchanan (Hodas)
Reichmuth/Robison		$6.30 - $24.70	
Conservation Reserve Program	3.46 x 10^7 tons	$53 - $58	Dudek and LeBlanc
Foresting Urban Areas		$26	Akbari

source: Hodas (1990)
note: ranges are due to uncertainties in interest rate, as well as uncertainty about program effectiveness

Hodas notes that, as yet, there is no world-wide tree-planting market. Further difficulties arise in that once the trees are burned (for fuel or through natural causes), the carbon that had been soaked up may get released. Also, this cannot be the only solution, to offset total U.S. carbon emissions would require 1,500 x 106 hectares of average forest, while the total land area is only 913 x 106 hectares. This strategy is thus more likely to be seen on a project by project basis - a notion fully compatible with estimating the full costs for a single corridor.

Table 3.6-20: Cost ($/ton) for Control (various sources)

Pollutant	PACE	OKO	Putta	Sanghi	Burrington	Wilson	*Wilson
CO_2	13.6	4.5-45	1.1	8 - 50	22		26
SO_2	4060	2268	832		1500		12500
NOx	1640	1814	1832		6500	4300	14300
PM10 (TSP)	2380	454	333		4000		8600
HC (VOC)					5300		3600
CO					870		
N_2O					3960		
CH_4					220		

*sources: Pace - Ottinger (1990); Fritsche - OKO (1990); Putta (1990); Sanghi (1990); Burrington (1990); Wilson (1990). note: * Used to estimate total social cost,not control cost; TSP= total suspended particulates, similar to PM10; VOC = volatile organic compounds, similar to Hydrocarbons (HC)*

Sanghi (1990) provides a comparison of the cost per ton for various control technologies used in scenarios in New York. Different technologies and approaches clearly have a wide range of costs.

Table 3.6-21: Cost per ton Carbon Removed, New York Scenarios

#	Measure (in order of Cost)	Levelized Real Cost of Carbon Removed (1990 $/ton)	Reduction in Carbon from 2008 "Business as Usual" million tons
1	State Facilities	-650	0.17
2	Furnaces	-417	0.42
3	SBEEP	-277	0.35
4	EASI (Boiler)	-267	0.96
5	EASI (Other)	-259	1.14
6	TFS	-219	0.18
7	Urban Trees	-9	0.05
8	CAFE Standards	0	3.35
9a	Reforest (tropical)	6	0.86
9b	Reforest (NY) upgrade	11	0.25
9c	Reforest (NY) public	13	0.48
10	Low Emissions Elec.	32	13.32
9d	Reforest (NY) private	49	0.48
11	Wind	150	0.55
12	Block #1	300	3.46
13	Block #2	375	1.17
14	Block #3	500	9.33
		AVERAGE = 156	TOTAL = 36.51

source: Sanghi (1990), notes: levelized $/ton include capital costs plus fuel savings over the life of measure, State Facilities = 20% reduction in energy use in Offices, Furnaces = improve home furnace efficiency from 81% to 91%, SBEEP, EASI, and TFS = provide info. on fuel efficiency of small business, CAFE = increase corporate average fuel economy from 28 MPH to 42 MPH by 2008, Reforestation = soak carbon through various reforestation programs, Low Emissions = switch fuel make-up in energy use, Wind = 1200 MW of wind energy production, Block #1-#3 = Assume new technology and radical restructuring of energy industry

3.6.4 Full Cost of Pollution

3.6.4.1 High Speed Rail

As noted earlier, high speed rail does not directly produce pollution, and therefore has zero direct costs. However, it does use electricity, purchased from utilities. Depending on the regulatory status of electric generation, the pollution costs may already be accounted for in that sector.

3.6.4.2 Aircraft

The cost of air pollution caused by air travel (basically the health damages from particulates, sulfur oxides, hydrocarbons, carbon monoxide, and nitrogen oxides, plus the greenhouse damages due to carbon) is $0.0009/pkt , or for a 1000 km trip, approximately 87 cents, which at $49 per trip is 1.7% of the fare.

Table 3.6-22: Air Pollution Costs of Air Travel

Pollutant	Emissions gm/pkm	Health Damage $/kg	Control Costs $/kg	Costs $/km
PM10	---	$0.94 - $10.00	$0.36 - $9.46	---
SOx	---	$0.84 - $10.76	$0.91 - $13.75	---
HC	0.09	$1.22 - $1.33	$3.96 - $5.83	$0.00012
CO	0.28	$0.0063	$0.96	$0.0000018
NOx	0.13	$1.22 - $1.33	$4.35	$0.00017
Carbon	100	$0.0058	$0.0029 - $0.132	$0.00058
TOTAL				**$0.00087**

Source: Emissions: Authors' Estimates; Damage and Control Costs: Various

3.6.4.3 Highways

For cars, we have a cost of $0.0046/vkt, ($0.0031/pkt) or $4.60 for a1000 km trip. Rates for trucks are higher based on higher emission rates. By our calculation, air travel is less environmentally damaging than car travel.

Table 3.6-23: Air Pollution & Global Change, Costs of Automobile Travel

Pollutant	Emissions gm/vkt	Damage Cost $/kg	Control Cost $/kg	Total Cost $/km
PM10	0.0066	$0.94 - $10.00	$0.36 - $9.46	$0.000066
SOx	0.0228	$0.84 - $10.76	$0.91 - $13.75	$0.00024
HC	2.254	$1.22 - $1.33	$3.96 - $5.83	$0.0030
CO	7.8	$0.0063	$0.96	$0.000049
NOx	0.756	$1.22 - $1.33	$4.35	$0.0010
Carbon	46	$0.0058	$0.0029 - $0.13	$0.00026
TOTAL				**$0.0046**

Source: Emissions: Small 1995; Damage and Control Costs: Various.

NRDC (1993) calculates car and light truck pollution costs to be about $0.04/pmt to $0.07/pmt ($0.024/pkt - $0.042/pkt). This is almost ten times higher than our estimate. Their estimates for the cost of carbon dioxide emissions is almost 20 times more than ours. Other pollutant cost estimates were higher, and more pollutants were priced, including CFCs, which are being phased out.

Our estimate of $0.0043/pkt (0.43 cents/pkt) by automobile (excluding the cost of carbon emissions and greenhouse effects) is near the low end of estimates provided by IBI (1995) in the following Table. However, our estimate of $0.0003/pkt (0.03 cents/pkt) by air travel (again excluding carbon) is lower than the lowest estimate provided.

Table 3.6-24: Costs of Air Pollution, Comparison of Studies

MODE	Hansson/ Markham	Kageson/ T&E	Planco	Swiss MoT	INFRAS/ IWW
Cars	0.43 - 1.44	0.47 - 1.86	2.26	0.15	0.35 - 1.33
Trucks	1.03 - 1.71	0.50 - 0.71	1.48	1.69	0.52 - 2.77
Pass. Rail	0.17 - 0.37	0.08	0.13	0.00	0.08 - 0.44
Freight Rail	0.22	0.08	0.20	0.00	0.03 - 0.15
Air	1.08	0.70	---	---	0.18 - 1.09
Shipping	0.20	---	0.22	---	0.15 - 0.91

Source: IBI (1995) Exhibit 3.4, note: All costs, 1995 U.S. cents per pkt or per tkt

Our estimates of costs of carbon per passenger kilometer of travel was 0.05 cents for air travel and 0.03 cents by car. The automobile estimates are significantly lower than some European and other U.S. estimates. IWW/INFRAS (1995) estimates the external cost of climate change for cars at E0.0066/pkt (ECU), E0.0027/pkt for buses, and E0.01066/tkt for trucks. Also E0.0030/pkt for passenger rail, E0.0011/tkt for freight rail, E0.0098 for passenger air, and E0.0505/tkt for air freight. The principal cause of the difference is the $52.80/tonne proposed carbon tax in Europe (with the higher year 2000 estimates using a $123.20/tonne carbon tax), as compared with the $5.80/tonne carbon tax for 1995 (based on Nordhaus, 1994) used in our study. The Miller and Moffett study assumed an even higher carbon tax, $82.80/tonne - $179.40/tonne.

Table 3.6-25: Estimates of Carbon Charge Required per pkm/tkm

MODE	Kageson 1993	Kageson 2000	Miller & Moffet Low	Miller & Moffet High
Car	0.57	0.72 - 1.40	1.29	2.81
Light Truck			1.55	3.38
Freight Truck	0.32	0.46 - 0.84		
Bus			0.76	1.65
Passenger Rail (Electric)	0.28	0.43 - 0.85	0.85	1.79
Freight Rail (Diesel)	0.24	0.37 - 0.72	0.58	1.12

Source IBI (1995) after Kageson (1993) , Miller and Moffet
Note: 1995 U.S. Cents; Kageson estimates for Europe, Miller and Moffet for U.S.

CHAPTER FOUR: HIGHWAYS

The method we use to estimate the full cost (FC) of highway travel combines elements from a number of sources, including User Costs (UC), Infrastructure Costs (IC), Environmental Costs (SEC), Noise Costs (SNC), Accident and Safety Costs (SAC), and Time Costs (TC). First, we measure costs borne by users of the system (UC). These include the cost of vehicle ownership (as measured by depreciation) and the cost of operating and maintaining the vehicle (including gas, tires, repairs and such). Costs borne by users also include the costs of taxes and insurance. Although the cost of taxes and insurance are borne by users, they are also transferred to the government. The transferred costs are not added to other cost categories, they are labeled user transfers (UT). Similarly, user insurance costs are a transfer of risk associated with the "social" cost of safety and accidents, which we account for separately.

The next category is infrastructure costs. Here we look at state level expenditures, including federal transfer payments as well as the expenditures of lower levels of government. Highway travel, like other modes, is wrought with common and joint costs. The allocation of common and joint costs between different trip classes and vehicle types will greatly influence the estimates of the full cost of highway usage. Using econometric analysis, we estimate the short and long run average as well as the marginal cost per vehicle kilometer traveled. We then develop an econometric model to associate government spending with price and usage factors.

Finally we add social costs as developed in Chapter 3 and which include: damage to the environment (SEC), which is the monetized consideration for pollution and property damage in addition to the estimated costs of global climate change; the decline in property value due to noise (SNC); are the full cost of accidents (SAC), regardless of incidence. While noise and environmental damage costs are pure externalities, in that their incidence falls on those outside the system, accident and congestion costs are inflicted by one system user on another. Time costs (TC) are divided into two components, one reflecting freeflow travel time, the other reflecting the increase in time due to congestion (other users). The full cost is then computed with the following formula:

$$FC = (UC - UT) + IC + SEC + SNC + SAC + TC$$

Each of these costs is a function of various parameters, which may include usage of the system. Thus, in many ways, full cost depends upon demand. In this chapter, we examine both the function and the range of point estimates based upon assumptions of demand and other factors.

4.1. User Costs And Transfers

The cost of operating a vehicle depends upon numerous factors, many of which are decided by the user. An important such factor is the size of the vehicle. In 1995, the most popular car size was the intermediate, and that is the type assumed in this analysis of cost. The operating costs considered in the analysis include: gas, oil, maintenance and tires; insurance costs (fire/theft, collision, and property damage/liability;) and license, registration, taxes, and depreciation depreciation. It should be noted that insurance costs as well as license registration and taxes are typically considered transfers and must not be double counted. For instance, the full cost of accidents cannot be considered a solely social cost. Neither can we consider insurance as only an operating cost . Accidents are also safety and financial costs and insurance simply transfers part of the financial incidence of accidents from drivers to an insurance pool. Similarly, license, registration, and taxes pay for part of constructing, maintaining, and operating the highway system. We can express this intricate cost accounting system as a series of equations:

(4.1.1) $UC(Y) = f(Cg, Co, Ct, Cf, Cp, Cc, Cl, Cd(A,Y), A,Y)$

(4.1.2) $Cd(A,Y) = - ß1\, A - ß2\, AY$

(4.1.3) $UC(Y) = (Cg + Co + Ct)Y + Cf + Cp + Cc + Cl + Cd(A,Y)$

(4.1.4) $UT(Y) = Cf + Cp + Cc + Cl + Cd(A,Y)$

(4.1.5) $UN(Y) = UC - UT = (Cg + Co + Ct)Y + Cd(A,Y)$

where:
UC(Y) = User Operating Cost ($/yr) as a function of output (Y)
UT(Y) = User Transfer Costs ($/yr)
UN(Y) = Net User Costs ($/yr)
Cg = Cost of Gas ($/mi or $/km)
Co = Cost of Oil ($/mi or $/km)
Ct = Cost of Tires ($/mi or $/km)
Cf = Cost of fire and theft (insured) ($/yr)
Cp = Cost of property damage and liability (insured) ($/yr)
Cc = Cost of collision (insured) ($/yr)
Cl = Cost of licenses, fees, and taxes ($/yr)
Cd(A,Y) = Cost of Depreciation ($/yr) as function of years and output
Y = Output in Distance Traveled per Year (miles or km)
A = Age (years over which car is depreciates), for purposes of our analysis A=1 when determining annual depreciation
ß1, ß2 = coefficients from price model discussed in section 4.1.2

Since we are dealing with a single output product, vehicle trips, we can apply basic economics to find the average and marginal costs per unit distance (Y) (mile, km.):

(4.1.6) $$AUC = \partial UN / \partial Y = Cg + Co + Ct - ß1A/Y - ß2A$$

(4.1.7) $$AIC = MC = \partial UN/\partial Y = Cg + Co + Ct - ß2A$$

where: AUC = Average Unit Cost

AIC = Average Incremental Cost

MC = Marginal Cost

4.1.1 A Model Of Car Price

It is known that depreciation occurs for two reasons. It is due to wear and tear on the vehicle and it is also a result of changing demand. Demand for an aging (unused) vehicle is replaced by the demand for a newer vehicle which comes equipped with more technologically advanced features. Demand is also affected by changing preferences. In order to estimate the various cost control components of depreciation, and thus to distinguish between average (stand-alone) cost or the marginal (incremental) cost, we developed a database of used car asking prices from a site on the World-Wide-Web for used car trading selecting Honda Accords and Ford Tauruses. A model with the following form was estimated using ordinary least squares regression:

(4.1.8) $$P = ß0 + ß1\,A + ß2\,AY + ß3\,M$$

where: P = asking price (current $).

A = Age of automobile = 1996 - Model Year

Y = Distance Traveled per Year (miles or km) for that particular car

M = Make 1 if the car was a Ford Taurus, 0 if it was a Honda Accord

ßx = model coefficients

Table 4. 1-1: SUMMARY OUTPUT

Statistics	
Multiple R	0.935
R Square	0.874
Adjusted R Square	0.861
Standard Error	1858
Observations	34

Table 4. 1-2: A NOVA

	df	SS	MS	F	Significance F
Regression	3	722004883	240668294	69.670115	1.272E-13
Residual	30	103631935	3454397.83		
Total	33	825636817			

Table 4. 1-3: Car Price Model Estimation

	Coefficients	Standard Error	t Stat	P-value
ß0 - const.	20053.4964	758.275741	26.4461795	2.4023E-22
ß1 - A	-1351.3415	201.914596	-6.6926388	2.0486E-07
ß2 - AY	-0.0234179	0.01522374	-1.5382506	0.13446925
ß3 - M	-2738.2386	791.029384	-3.4616142	0.00163497

The implication of this is that the car loses $0.023/vmt in value and loses $1351 in value per year . This also implies that Tauruses sell for $2740 less than Hondas, all other things being equal. The intercept term suggests that a new Honda Accord (1996) with no miles is valued at $20,053. These are not actual transaction prices, but asking prices so we can probably assume that an additional 10-20 percent markup is included in the price. For a car that is driven 10,000 miles per year, the model estimates a depreciation of $1581. For a car driven 15,000 miles per year, the model estimates a depreciation of $1702. Even considering markup, these are less than the depreciated values of $2883 given by the American Automobile Association and shown in Table 4.6 below.

Figure 4.1-1: Price vs. Age

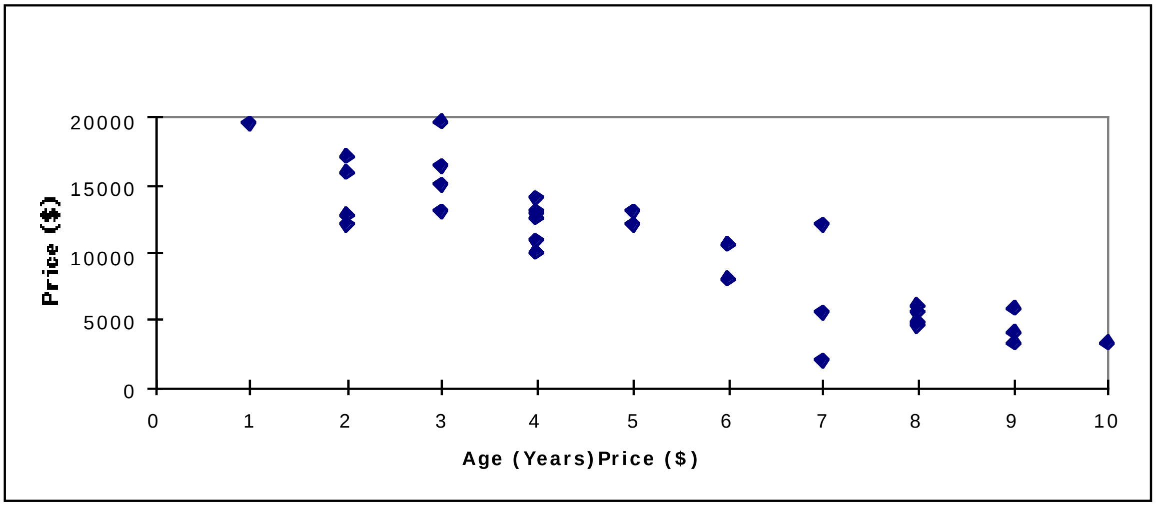
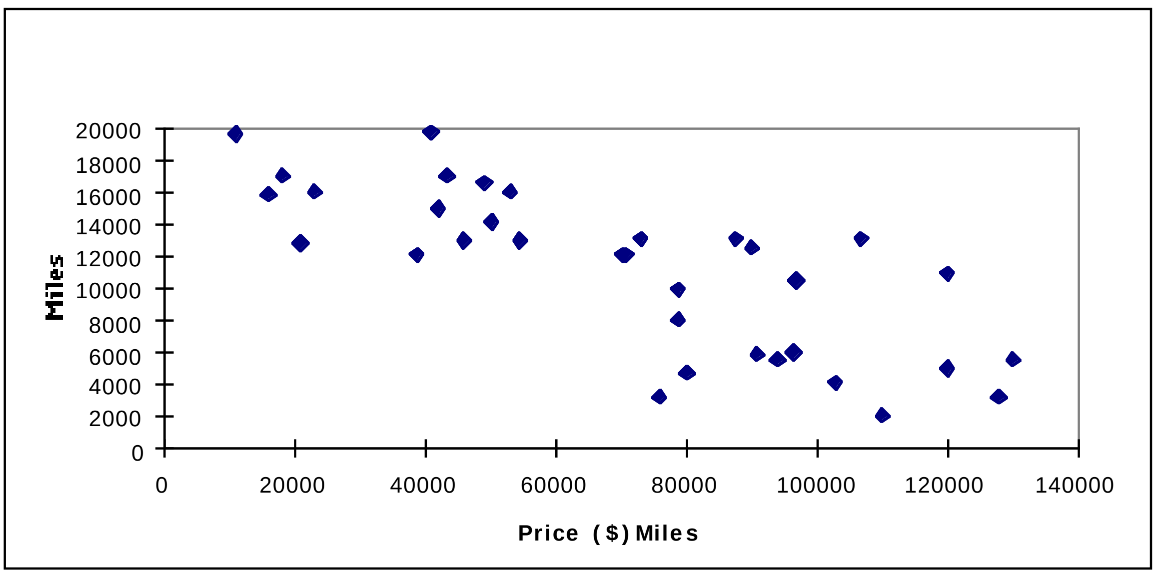


Figure 4.1-2 Price vs. Miles



4.1.2 The Average And Incremental Cost Of An Owned Car

There are two ways to estimate operating costs : Stand-alone (average) costs or incremental (marginal) costs. In our case, stand-alone costs reflect the cost of owning the car and are predicated upon the assumption that intercity travel is not only routine but that it is also one of the primary reasons for owning the car. The incremental cost assumes that the car is already owned (or leased or rented), and that only the incremental cost of making the trip (ignoring a large part of the depreciation for instance) should be counted. The efficient answer can be determined in principle by Ramsey pricing, which requires knowing the inverse elasticity of demand, and should fall between the stand-alone and incremental costs.

Applying equations 4.6 and 4.7 above, and assuming values for costs (described below) we can compute the average unit costs and average incremental or marginal cost of car ownership. These are given in table 4.4 below.

Table 4.1-4: Average Unit and Incremental Cost of Car Ownership

Variable	Value (english)	Value (metric)
Cg - Gas	\$0.025/vmt	\$0.015/vkt
Co - Oil	\$0.024 /vmt	\$0.014 /vkt
Ct - Tires	\$0.009 /vmt	\$0.0054 /vkt
ß1 - Age Depreciation	\$1351/yr	\$1351/yr
A - Age	1 yr	1 yr
Y - Distance/Year	10,000 mi	16,000 km
ß2 - Distance Depreciation	\$0.023/vmt	\$0.014/vkt
Average Unit Cost	\$0.216/vmt	\$0.130/vkt
Marginal Cost	\$0.081/vmt	\$0.049/vkt

For a 1000 km (600 mi) trip, the average cost for the automobile user is \$130, but the marginal cost is only \$49. In all likelihood, the user perceives the cost of the trip as the marginal cost, if not lower, since he is likely to disregard the cost of oil, tires and depreciation from his calculation.

4.1.3 The Cost Of A Rented Car

The cost of a highway trip can also be estimated by considering the cost of car rental. This is important not only for California residents who don’t own a car, but also for visitors who enter California via air and visit multiple cities within the state. For a single trip, the stand alone user cost of a rental is the same as the incremental cost of rental.

When a car rental company rents out a vehicle, it can amortize the fixed costs of ownership over a much larger number of miles than the typical driver would undertake. This price advantages is mitigated somewhat by overhead costs which must be covered by the firm. The cost of renting an intermediate car for a three-day weekend is about $90 - $120. If we assume that a 600 mile trip can be made over the weekend, then the rate for the car is $0.15 - $0.20 per mile ($0.09 - $0.12/vkt) in charges plus $0.025/vmt ($0.015/vkt) for gas, excluding oil, maintenance and tires. Excluding the cost of gas, the rental cost is less then the average unit cost of ownership, but more than the $0.08/vmt ($0.05/vkt) marginal cost of ownership. So the cost clearly depends on the basis over which it is taken.

4.1.4 Price Estimates

Table 4.6 shows operating costs estimated by the American Automobile Association (AAA). They include gas cost of six cents per mile, excluding tax. However, the retail price of a gallon of gas (excluding tax) at the end of 1995 is about $0.70/gallon though noticeably higher in 1996. At 28 miles per gallon (the CAFE (Corporate Average Fuel Economy)) standard for new cars which all manufacturers must achieve as a fleet average) this translates to $0.025/mile for gas. The value we use here. e.

We adopt the AAA estimates in Table 4.6 for the price of oil and maintenance and tires. As noted above, we estimated depreciation ourselves in section 4.1.2, and found a lower level than that given by AAA.

4.1.5 Comparison With Other Studies

Miller and Moffet (1993) cite estimates of the average personal automobile ownership cost as ranging from $0.25 - $0.30 per passenger mile traveled (pmt), ($0.15 - $0.18/pkt) including the fixed cost of $0.17 - $0.22/ pmt ($0.10 - $0.13/pkt) for purchase, registration, and depreciation, and the variable costs of $0.08/ pmt ($0.05/pkt) for fuel, tolls, maintenance, and depreciation. However they note that these costs are somewhat high, given that they assume new cars, while many cars are used. A Swedish study (Kageson in OECD 1994) cites internal costs to the driver costs ranging from $0.14 - $0.21/ pmt ($0.084 - $0.126/pkt). Our three estimates for average unit costs, marginal cost, and rental cost are summarized below for comparison with the other studies.

Table 4. 1-5: Cost Comparison

Cost Estimate	Value (english)	Value (metric)
Average Unit Cost	$0.216/vmt	$0.130/vkt
Marginal Cost	$0.081/vmt	$0.049/vkt
Rental Cost	$0.200/vmt	$0.120/vkt
Miller and Moffett	$0.275/pmt	$0.165/pkt
Kageson	$0.175/pmt	$0.105/pkt

Table 4. 1-6: (US) Automobile Operating Costs - Intermediate Size Automobile 1993-1977

Year	Gas/ Oil	Maint.	Tires	Fire/ Theft	Collision	Prop.Dam / Liab	Lic/ Reg/ Taxes	Deprec
	(¢/mile)	(¢/mile)	(¢/mile)	($/year)	($/year)	($/year)	($/year)	($/year)
1993	6.00	2.40	0.90	107	232	385	183	2883
1992	6.00	2.20	0.90	113	261	373	179	2780
1991	6.70	2.20	0.90	115	258	353	169	2543
1990	5.40	2.10	0.90	110	247	318	165	2357
1989	5.20	1.90	0.80	109	245	309	151	2094
1988	5.20	1.60	0.80	86	203	284	139	1784
1987	4.80	1.60	0.80	87	196	252	140	1506
1986	4.48	1.37	0.67	86	191	232	130	1320
1985	6.16	1.23	0.65	92	198	213	115	1253
1984	6.19	1.04	0.63	80	200	225	106	1207
1983	6.64	1.04	0.68	80	201	222	102	1343
1982	6.74	1.00	0.63	53	153	243	54	1356
1981	6.27	1.18	0.72	76	180	254	88	1287
1980	5.86	1.12	0.64	70	172	248	82	1038
1979	4.11	1.10	0.65	74	168	241	90	942
1978	3.89	1.10	0.66	57	138	229	74	894
1977	4.11	1.03	0.66	80	188	250	74	847

Table 4.1-7: (SI) Automobile Operating Costs - Intermediate Size Automobile 1993-1977

Year	Gas/ Oil	Maint.	Tires	Fire/ Theft	Collision	Prop.Dam/Liab	Lic/ Reg/ Taxes	Deprec
	(¢/km)	(¢/km)	(¢/km)	($/year)	($/year)	($/year)	($/year)	($/year)
1993	3.60	1.44	0.54	107	232	385	183	2883
1992	3.60	1.32	0.54	113	261	373	179	2780
1991	4.02	1.32	0.54	115	258	353	169	2543
1990	3.24	1.26	0.54	110	247	318	165	2357
1989	3.12	1.14	0.48	109	245	309	151	2094
1988	3.12	0.96	0.48	86	203	284	139	1784
1987	2.88	0.96	0.48	87	196	252	140	1506
1986	2.68	0.82	0.40	86	191	232	130	1320
1985	3.69	0.74	0.39	92	198	213	115	1253
1984	3.69	0.62	0.38	80	200	225	106	1207
1983	3.98	0.62	0.41	80	201	222	102	1343
1982	4.04	0.60	0.38	53	153	243	54	1356
1981	3.76	0.71	0.43	76	180	254	88	1287
1980	3.52	0.67	0.38	70	172	248	82	1038
1979	2.47	0.66	0.39	74	168	241	90	942
1978	4.13	0.66	0.40	57	138	229	74	894
1977	2.47	0.62	0.40	80	188	250	74	847

Source: "Your Driving Costs" by American Automobile Association, Compiled by Runzheimer International

Notes for Table 4.7:

1) Insurance figures based on: personal use vehicle, < 10 mile (16 km) commute , no young drivers
2) Depreciation Costs - difference between amount paid and projected trade in value divided by the number of years planning to keep the car (10 or 12 years)
3) National average per mile costs for an intermediate automobile (Taurus/Celebrity V6)
4) Fire and Theft - $50 deductible in '77, $100 until 1992 and $250 in 1993
5) Collision - $100 deductible in '77, $250 until 1992 and $500 in 1993
6) Property Damage and Liability Coverage - $100,000 / $300,000
7) Uncorrected US Dollars and Cents
8) 6 Cylinder (Ford Taurus/Chevy Celebrity or similar)

4.2. Infrastucture Costs

4.2.1 Theory Of Transportation Product

Transportation product of a given commodity between an origin and destination can be loosely defined as a flow of goods between those two points at varying levels of service (Bailey and Friedlaender, 1983). Transportation product for a highway network can be defined as the vector of flows of passengers and freight between the origins and destinations served by the network in each of the OD markets that it serves :

(4.2.1) $$Y = \{Y_{mnc}\}$$

where:

m = origin
n = destination
c = class of service (passenger vehicle, single unit truck, combination truck)
Y = flows of passengers (or commodities)

Other dimensions such as the period (time of day or week or season), the commodity type in freight transport, or the level of service (such as the speed of travel) can be incorporated into this measure. The incorporation of these measures would more accurately describe the situation but would also complicate the specification. For exposition, we will not include them.

The question of aggregation drives the actual specification of the vector of flows. For instance, each size of car (such as subcompact, compact, intermediate, large, wagon or utility vehicle) can be specified as a separate commodity or can be aggregated into a vehicle class (cars). The vector of flows definition can be used to model either side of the boundary between different products and product differentiation depending upon the aggregation scheme used.

Provided that the definition of transportation product is (correctly) characterized as a vector of flows, the measurement of costs using an aggregate unit times distance (UTD) measure, such as passenger kilometers or passenger miles, can lead to incorrect inferences concerning the technical properties of an industry. This section provides insight into the measurement of technical properties that results from the specification of transportation product as a single aggregate output and from a disaggregated vector of flows definition.

4.2.1.1 Aggregated Unit Output

Most of the transport costing literature has focused on the specification of transportation output using a unit times distance measure instead of a multi-product output definition. This section highlights the different measurements of technical properties that have resulted from the aggregate assumption for the different modes.

The measure of average costs (AC) is well defined for the single output case, defined simply as the total cost (C(Y)) divided by the total output (Y). This represents the per unit cost of producing an undifferentiated unit of "aggregate" output:

(4.2.2) $$AC = C(Y)/Y$$

Marginal cost can also be easily derived from any twice differential cost function C(Y) as defined by neoclassical microeconomics :

(4.2.3) $$MC = \partial C(Y)/\partial Y = MC(Y)$$

The technological property of economies of scale has been defined as "s" in the following relationship characterizing level of output to costs :

(4. 2.4) $$C(w, l^{s}Y) = l^{s}C(w,Y)$$

where:

Y = output

w = the vector of factor prices

l = the level of production (output) for the firm.

In the above formula, we have :

constant returns to scale for s = 1

increasing returns to scale for s > 1

decreasing returns to scale for s < 1

Economies of scale have been examined extensively in the literature for many passenger modes with differing results. The incorporation of a measure seeking to capture the effects of the size of the network on the cost structure has led to improved inferences. The measurement of technological properties of the industry structure has been done primarily without consideration of the true multi-product output structure that exists.

More dramatically, economies of scope cannot be compared using a cost function calculated from a completely aggregate output definition since no consideration of the network of flows has been provided. Economies of density have been captured by incorporating a proxy measure for network size in the cost functions for the case of commercial airlines (Caves, Christensen and Tretheway, 1984). Certain effects of economies of scope may have been attributed to economies of density in that formulation using the UTD aggregate output definition.

4.2.1.2 Multi-Product Output

Viewing transportation product as a multi-product output (with the multiple products being the vectors of flows produced) provides a more correctly interpretable view of the actual costs and technological properties of any transportation firm. A multi-product transportation cost function can be written as "C(Y)"

where:

$Y=\{Y_i\}$

i represents each origin to destination flow at a given level of service.

The marginal cost of production for each product (or flow) i can be calculated from any twice differentiable transport cost function :

(4. 2.5) $MC_i = \partial C(Y)/\partial Y_i = MC_i(Y)$

While the average cost of production is well defined for the single output case as illustrated above, under the definition of a vector of flows the measure of average costs becomes ambiguous :

(4. 2.6) $AC_i = C(Y)/Y$

does not uniquely exist. Unless the outputs in the vector Y are assumed to be equivalent (analogous to the UTD measure) or systematically related, the above measure of average cost has no closed form. Some type of index must be used in place of the vector Y in the calculation of an "average" cost. In this way, the calculation of average cost requires a weighting of the outputs.

The incremental cost can provide more direct insight into the problem of marginal costs of production for a transportation firm. The incremental cost of introducing the additional output (vector of flows) Yn is equal to :

(4. 2.7) $IC_n = C(Y) - C(Y_{m-n})$

where:

$Y = \{Y_1, \ldots, Y_m\}$

$Y_n = \{Y_1, \ldots, Y_n\}$

$Y_{m-n} = \{Y_{n+1}, \ldots, Y_m\}$

The loose interpretation of this concept is the amount of money that must be spent in order to introduce the remaining vector of products (or flows). Incremental cost can be thought of as the marginal cost of introducing an additional vector of flows Yn to an existing network.

In a hierarchical highway network, with smaller roads (e.g. collectors and distributors) feeding larger roads (arterials) feeding still larger roads (freeways), the size of the vector of flows is lumpy. The addition of a link from a previously unserved place feeding into a freeway will automatically create a new set of network connections, both from that place to everywhere else, and from everywhere else to that place, not just from that place to the freeway (which is only an interim destination). Thus, the introduction of an additional link to an existing network provides a capacitated vector of flows that includes the pair of places at the two ends of the link, but also a vector of connection opportunities. The addition of several new OD pairs has resulted from the addition of a single link.

Having introduced the concept of incremental cost, a definition of average incremental cost can be generated as follows :

(4. 2.8) $AIC_i = IC_i/Y_i$

The average incremental cost of introducing product i to the market provides an unambiguous measure of the average cost in the multi-product output context. This definition has a clearer interpretation when examining the technological properties of a \

Measures of cost complementarity take on importance in the economics of network operations, particularly hierarchical transportation systems. The lumpiness of network size increases from adding links, or lanes on a link, to a hierarchical network is a classic case of cost complementarity. Theoretically, cost complementarity is present between any two related products using a total firm output cost function that is twice differentiable if :

(4.2.9) $\partial^2 C/\partial Yi\partial Yj < 0$

or

(4.2.10) $\partial MCi/\partial Yj < 0$

or

$\partial MCj/\partial Yi < 0$

Ideally, the specific technical properties of the cost function specified should be able to provide for cost complementarity or its absence.

4.2.1.3 Multi-Product Ouput: Economies of Scope

Economies of scope is similar to a measure of average cost divided by marginal cost. The technical property of economies of scope can be expressed as follows in the multi-product output context:

(4. 2.11) $SCn(Y) = [C(Yn) + C(Ym\text{-}n) - C(Y)]/C(Y)$

The quantity C(Yn) + C(Ym-n) represents the total cost of producing both vectors of flows separately and C(Y) represents the cost of producing both vectors of flows simultaneously.

If SCn > 0 then there are economies of scope

If SCn < 0 then there are diseconomies of scope

If SCn = 0 then there are no economies of scope

Simple examples of the back-haul and introducing a link to an existing hierarchical network are instructive. For a large hierarchical network, serving the entire network from a single added point can be done for the cost of a single link (plus any costs for expanding the rest of the network if it is congested, or the congestion costs which result). A non-hierarchical, point-point system must add one link for each additional market. When considering the back-haul, since the transportation operator (the trucker or the passenger car driver) must return his vehicle to the origin point anyway, there is very little cost associated with operating bi-directional service (two-way links) in a market. However, if flows are peaked, for instance highways in rush hour, it may make sense to allocate the network asymmetrically over the course of the day, more lanes in the (inbound) peak direction during morning, more in the (outbound) peak direction in the afternoon.

In situation with no economies of scope :

(4. 2.12) $C(Y) = C(Ym\text{-}n) + C(Yn)$

which implies that the cost of producing both networks of flows separately is equivalent to producing them together.

4.2.1.4 Multi-Product Output: Economies of Scale

The technical property of economies of scale can be calculated in the multi-product output context. The technical property of economies of scale in the multi-product output case is:

(4. 2.13) $Sn = ICn / \Sigma_{(i \in N)}(Yi^{*}\partial c(Y)/\partial Yi)$

where: constant returns to scale for Sn = 1

increasing returns to scale for Sn > 1

decreasing returns to scale for Sn < 1

The technology associated with economies of scale is clearly different from that of economies of scope. With economies of scale, the cost of producing more transportation output within the same network is lower for larger levels of output. The economic interpretation of economies of scale is :

(4. 2.14) S = cost/(amount produced)*(marginal cost) = cost/revenue

We see from the above formula that in the case of constant returns to scale, cost is equal to revenue.

Clearly, the technological properties that are attributed to an industry are directly related to the assumptions concerning transportation product. When considering a series of services across a network, it is important to consider the different costs associated with offering different types of services over a single aggregate measure. The resulting technical properties depend heavily upon the output specification.

4.2.2 Model

We want to estimate a model predicting total expenditures as a function of price inputs (interest rates, wage rates, and material costs), outputs (miles traveled by passenger vehicle, single unit truck, and combination truck), and network variables (the length of the network, the average width of links). We also want to distinguish between long run and short run total expenditures. In the long run, everything varies. In the short run, capital costs are assumed fixed.

The hypothesis of the expenditure model is that total expenditures increase with outputs, with prices, and with the size of the network, so all signs should be positive. However, the amount of increase with output depends on the nature of the output.

Outputs: Three classes of output (Y) are defined: passenger cars (Ya), single unit trucks (Ys), and combination trucks (Yc). Because of their relative damage to the roadway, costs associated with passenger cars are expected to be less than those associated with single unit trucks, which is less still than those associated with combination trucks. However, this may not be the case if there are economies of scope associated with roadways. For instance, suppose a network is designed for peak rush hour flows, and that these flows are dominated by passenger cars. In the off-hours, capacity is underutilized. If it is during those hours that trucks use the roadway, then the government expenditure on transportation to serve those trucks may in fact be less than that for passenger vehicles. At a minimum, because these two effects (efficient capacity utilization vs. greater damage) are offsetting, the relative additional costs to serve trucks would not be as great as that indicated by an engineering analysis based solely on damage which does not consider scope economies.

Inputs: Several price measures are included in the model. The first, to measure the price of capital (Pk), including the entire built stock of the highway network, is measured by taking the interest rate, which reflects the cost of money. States with lower bond ratings or higher interest rates must pay more to borrow, and have a higher opportunity cost for fixed investment. Second, the price of labor (Pl) is measured by taking the average wage rate of state employees (normalized to the national average). Third, the principal materials used in constructing and maintaining roadways are for surfacing, we include the price of bituminous concrete to represent the price of materials (Pm).

Network: We have included two variables to describe the network to try to measure economies of density. The first is the length (Nl) in linear miles of roadway, the second is the width (Nw) the average number of lanes of interstate highways. When providing capacity, there is a trade-off between building more skinny facilities or fewer wider facilities. We hope to capture this trade-off by including both network variables.

The model is estimated two ways, first using ordinary least squares (OLS) and then using feasible generalized least squares (weighted least squares (WLS)). WLS, where the reciprocal of variance is used as a weight, corrects for the clear heteroskedasticity in the data, wherein the size of the residual is correlated with the size of the dependent variables. Two functional forms: a linear model and a Cobb-Douglas (using the log of both dependent and independent variables) model are estimated. The results are given below in section 4.2.5. Alternative model formulations are given in equations 4.2.16 - 4.2.22 , the variables are defined in the table below:

Long Run Total Expenditures

(4. 2.15) $LRTE = Ck + Cl + Cm = f(Ya, Ys, Yc, Pk, Pl, Pm, L, W) + e$

linear:

(4. 2.16) $LRTE = ß0 + ß1Ya + ß2Ys + ß3Yc + ß4Pk + ß5Pl + ß6Pm + ß7L + ß8W + e$

Cobb-Douglas:

(4. 2.17) $LRTE = ß0\, Ya^{ß1}\, Ys^{ß2}\, Yc^{ß3}\, Pk^{ß4}\, Pl^{ß5}\, Pm^{ß6}\, L^{ß7}\, W^{ß8} + e$

Short Run Total Expenditures

(4. 2.18) $SRTE = Cl + Cm = f(Ya, Ys, Yc, Pk, Pl, Pm, L, W) + e$

Linear:

(4. 2.19) $SRTE = ß0 + ß1Ya + ß2Ys + ß3Yc + ß4Pk + ß5Pl + ß6Pm + ß7L + ß8W + e$

Cobb-Douglas:

(4. 2.20) $SRTE = ß0\, Ya^{ß1}\, Ys^{ß2}\, Yc^{ß3}\, Pk^{ß4}\, Pl^{ß5}\, Pm^{ß6}\, L^{ß7}\, W^{ß8} + e$

Table 4. 2-1: Definitions of Variables in Cost Function Estimation

Variable	Definition
LRTE	Long Run Total Expenditure = Ck + Cl + Cm
SRTE	Short Run Total Expenditure = Cl + Cm
Ck	Expenditure -Capital ($ thousands) Ck= SC_{1988} * 1000 * I * Pk, where: SC_{1988} = 1988 Stock of Capital (millions), I = 1.20 = price inflator 1988 - 1993, Pk = Price of capital
Cl	Expenditure - Labor ($ thousands) = Administration + Law & Safety
Cm	Expenditure - Maintenance ($ thousands) = facilities + structures + traffic
Ya	Output - passenger car = vehicle miles traveled per year (millions)
Ys	Output - single unit truck = vehicle miles traveled per year (millions)
Yc	Output - combination truck = vehicle miles traveled per year (millions)
Pk	Price - capital = interest rate based on Moody's Bond Rating of state
Pl	Price - labor = average wage of state government employee ($) divided by
Pm	Price - materials = price index of materials = price of bituminous concrete ($/cu yd) divided by national average
Nl	Network Size - linear miles of roadway
Nw	Network Size - average width of roadway (lanes)
e	residual

4.2.3 Data Sources And Description

The data used in the model of highway infrastructure costs come from several sources. Total expenditures data are developed from two sets of information: data compiled by the Federal Highway Administration on maintenance, operating, and administrative costs (FHWA 1993); and capital stock data collected by Gillen et al (1994). The capital stock series was inflated from 1988 to 1993 levels (a 20% inflation was taken), and then was discounted to reflect an annualized cost. The annual cost was assumed to equal the total cost multiplied by the price of capital or interest rate - a state with a higher interest rate will has a higher opportunity cost for investing money in fixed assets. The annualized capital cost was added to annual expenditures on maintenance, operations, and administration to create an estimate of long run total expenditures (LRTE). The short run total expenditures (SRTE) assumes that the stock of capital is fixed in the short term (though it varies in the long term), and thus looks at the allocation of costs for maintenance and labor.

Table 4.2-2: Expenditures Data

	SC Stock Capital 1988 millions	Capital Expend. 1993 thousd	Cm Maint. Expend. 1993 thousd	Cl1 Admin. Expend. 1993 thousd	Cl2 Law Safe Expend. 1993 thousd	Interest 1993 thousd	Bond Retire. 1993 thousd
Average	10457.72	588205	137505	143064	138985	70994	89979

Note: (1988 and 1993) U.S. Dollars

Three independent variables of the model represent outputs from the transportation system, the 1993 vehicle miles traveled of cars (Ya), single unit trucks (Ys), and combination trucks (Yc), from the FHWA Highway Statistics Report (1993). The data has been analyzed by Hartgen and Spears (1994), who compared the economic performance of states. However their study suffered from a number of flaws, many of which are due to poor data. The principal problem is that the data is reported as linear miles of roadway, and no correction is made for the number of lanes per linear model. While the number of miles with less than or equal to 4 lanes and more than 4 lanes is reported, there is no indication of the number of miles of 2 lane, 3 lane, 4 lane etc. roads.

Table 4.2-3: Outputs Data

	Ya Auto VMT (millions)	Ys Single Truck VMT (Millions)	Yc Comb. Truck VMT (millions)	%URBAN	%FREEWAY
Average	32738	7352	4890	0.53	0.27

Several measures were used to obtain the price of inputs into transportation construction and maintenance costs. The price of labor (Pl) was measured from the average wage of state government employees (in dollars per year) for 1993 (BLS, 1995), normalized by dividing by the national average.

The price of capital (Pk), was defined as interest rate paid by that state for borrowed money. The table below shows typical interest rate yields for AAA rated stocks based on time until maturity, we couple this with Moody's ratings for each state and typical additions to interest rates paid for lower rated bonds (shown in Table 4.12) garnered from recent offerings.

Table 4. 2-4: Interest Rate Yields

Maturity	12/13/95	6/13/95
Two Year	3.92	4.29
Five Year	4.32	4.62
Seven Year	4.52	4.82
Ten Year	4.82	5.12
Fifteen Year	5.28	5.60
Twenty Year	5.50	5.80
Thirty Year	5.62	5.92

Source: Triple-A Rated, Tax-Exempt Insured Revenue Bonds.
Notes: This information provided by the Public Securities Association (PSA) and Bloomberg L.P. to be used solely as a bench- mark for particular categories of municipalbonds. The yields for maturities beyond ten years represent a callable bond. The yields are a composite of round lot ($250,000 or above)prices based on bonds which have coupons that reflect current market conditions.

Table 4.2-5: Assumed Interest Rates

Bond Rating	Interest Rate
AAA	4.75
AA1	4.95
AA	5.15
A1	5.35
A	5.55
BBA1	5.75
BBB	5.95

by Moody’s Bond Rating

The third main input is materials. The principal material used in highway construction is concrete for pavement. We computed indexes of construction materials prices by taking the price of an input (FHWA 1994b), and dividing by the national average of the price of that input. The indexes, reflecting relative prices, with a mean at 1, can then be added to create a composite index for construction materials. For instance, the price of bituminous concrete in a state, and divided by the national average of the unit price of bituminous concrete, provides an index representing the relative price of bituminous concrete. The materials for which data was available (bituminous concrete (price per ton), common excavation (price per cubic yard), reinforcing steel (price per pound), structural steel (price per pound), and structural concrete (price per cubic yard) were included in the database. Boske (1988) discusses the data and the use of indexes with this data, though only bituminous concrete was used in the final regressions.

Table 4. 2-6: Price Data

	Pl Gov Salary (1993)	Pk Bond Rating (1994)	Pm Bit. Concrete (1993)	Excav (1993)	Reinf. Steel (1993)	Struct Steel (1993)	Struct Concrete (1993)
Average	27168	AA	18.81	2.5	0.467	0.861	261.89

Source: FHWA 1994b, BLS 1995
Notes: Units: Bituminous Concrete $/ton, Excavation $/cu yd, Reinforcing Steel $/lb, Structural Steel $/lb, Structural Concrete $/ton, (1993) U.S. Dollars.

A number of variables, given in FHWA (1993) describe the network. Total linear miles (Nl) is a key variable used to enable us to distinguish between economies of scale and economies of density in the analysis. Also the width of interstate roadways (Nw) was computed using information on miles of interstate greater than four lanes and less than four lanes. While wider roads are more expensive to maintain than narrower ones, it may be more efficient to build fewer and wider roads than more and skinnier ones. Potentially there is some difference in the cost based on whether the road is urban or rural, so that data was included in the database.

Table 4.2-7: Network Size Data

	L - TotalMiles	L - %Freeway	L - %Urban	W - %UrbFwy > 4 lanes	W - %RurFwy > 4 lanes
Average	76563	0.017	0.24	0.39	0.07

While summaries of the data were given in the tables above, the data for each state are given in the appendix.

4.2.4 Results

Four models (linear and log-linear forms for long run and short run total expenditures) were estimated using ordinary least squares regression, and again with weighted least squares regression to correct for heteroskedasticity. The coefficients from the log-linear (Cobb-Douglas) weighted least squares are used for further analysis, the other regression results are given in the appendix for information purposes.

Table 4. 2-8: Correlations and Collinearity

Correlations:	Ya	Ys	Yc	Nl	Nw	Pk	Pl	Pm	POP90
Ya	1.0000	.8941**	.7547**	.6394**	.9398**	-.0665	.4596*	.0428	.9800**
Ys	.8941**	1.0000	.8019**	.7187**	.8980**	-.0619	.4143*	.1242	.9081**
Yc	.7547**	.8019**	1.0000	.7563**	.6188**	-.0921	.1811	.0138	.7715**
Nl	.6394**	.7187**	.7563**	1.0000	.5471**	-.0067	-.0446	-.0179	.6361**
Nw	.9398**	.8980**	.6188**	.5471**	1.0000	-.1056	.5459**	.1152	.9198**
Pk	-.0665	-.0619	-.0921	-.0067	-.1056	1.0000	-.1918	-.0130	-.0083
Pl	.4596*	.4143*	.1811	-.0446	.5459**	-.1918	1.0000	.0953	.5102**
Pm	.0428	.1242	.0138	-.0179	.1152	-.0130	.0953	1.0000	.0768
POP90	.9800**	.9081**	.7715**	.6361**	.9198**	-.0083	.5102**	.0768	1.0000

*Note: Number of cases: 411-tailed Signifigance: * - .01 ** - .001*

4.2.4.1 Long Run Total Expenditures, Log-Linear Model, OLS & WLS

Largely, the hypotheses were borne out, the signs were in the expected direction. For feasible generalized (weighted) least squares, the t-statistics cannot be directly interpreted to indicate statistical significance, though the t-statistics for the corresponding OLS regression were generally significant, and are shown in the last two columns for comparison purposes. Three variables are of concern: Nw, reflecting the width of the roadway, and Pm, the price of materials were not significant variables. More importantly, there is wide variance around the estimate of the coefficient for Yc, combination trucks. Other regressions, with different sets of independent variables have shown coefficients on Yc about 50% larger, indicating that the true value is probably higher and collinearity, which is obviously high in this data, may be causing problems about certainty of parameter estimates. To avoid collinearity problems, we dropped Nl and Nw from the final model.

This can be expressed as the equation below:

(4. 2.21) $$LRTE = 79221\, Pk^{1.83}\, Pl^{0.786}\, Pm^{0.00492}\, Ya^{0.439}\, Yc^{0.225}\, Ys^{0.179}$$

Table 4. 2-9: LRTE: WLS and OLS Model Statistics

Result	OLS Value	WLS Value
Multiple-R	.97074	.99799
R-Square	.94233	.99598
Adjusted-R-Square	.93216	.99527
Standard-Error	.22339	.99311
F	92.59963	1402.4
Signif F	.0000	.0000

Table 4. 2-10: OLS Analysis of Variance

	DF	Sum-of-Squares	Mean-Square
Regression	6	27.72708	4.62118
Residual	34	1.69677	.04990

Table 4. 2-11: LRTE: OLS Regression Results

Variable	B	SE-B	Beta	T	Sig-T
LNPk	1.992169	.521143	.161935	3.823	.0005
LNPl	.494536	.372093	.081089	1.329	.1927
LNPm	-.016939	.080218	-.008844	-.211	.8340
LNYa	.481381	.104233	.576816	4.618	.0001
LNYc	.155522	.086340	.190284	1.801	.0805
LNYs	.199068	.090394	.215236	2.202	.0345
(Constant)	11.738659	1.557675		7.536	.0000

Table 4. 2-12: LRTE: OLS Residuals Statistics

	Min	Max	Mean	Std-Dev	N
*PRED	12.1196	15.4688	13.6682	.8326	41
*RESID	-.3524	.3543	.0000	.2060	41
*ZPRED	-1.8600	2.1627	.0000	1.0000	41
*ZRESID	-1.5776	1.5860	.0000	.9220	41

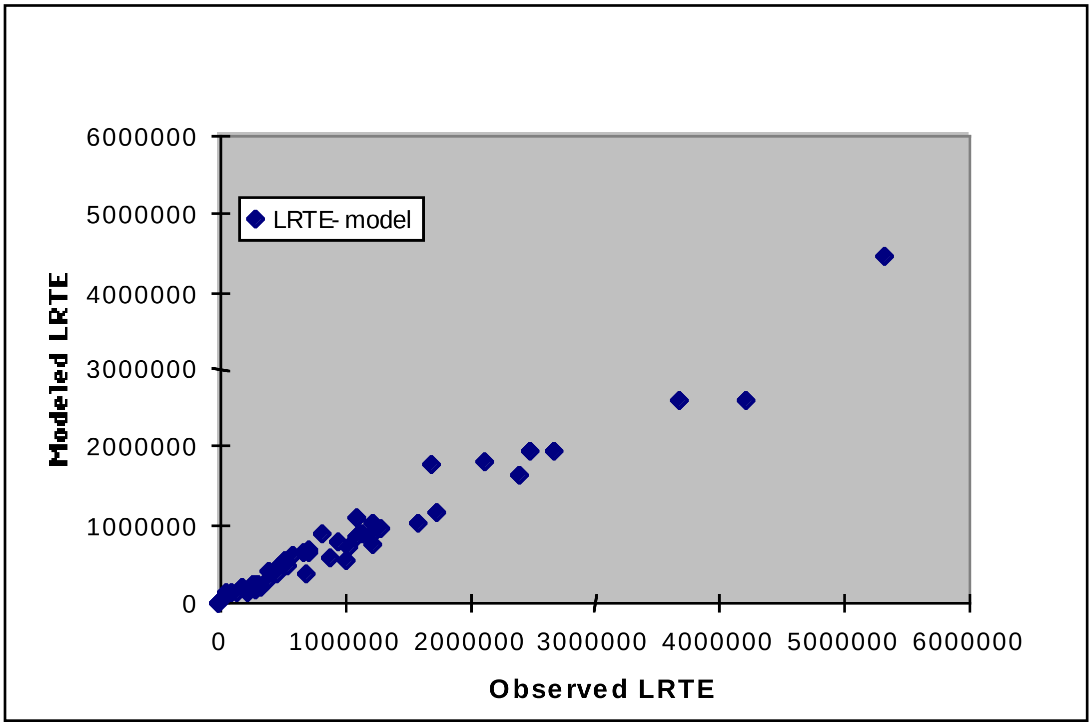
Table 4. 2-13: LRTE: WLS Analysis of Variance

	DF	Sum-of-Squares	Mean-Square
Regression	6	8299.15090	1383.19182
Residual	34	33.53323	.98627

Table 4. 2-14: LRTE: WLS Model Coefficients

Variable	B	SE-B	Beta	T	Sig-T
LNPk	1.831407	.162832	.126203	11.247	.0000
LNPl	.786103	.234942	.121752	3.346	.0020
LNPm	.004942	.022269	.002636	.222	.8257
LNYa	.439197	.044709	.551639	9.824	.0000
LNYc	.225037	.044866	.200160	5.016	.0000
LNYs	.179319	.036711	.170755	4.885	.0000
(Constant)	11.280739	.562629		20.050	.0000

Figure 4. 2-1: Long Run Total Expenditure: Model vs. Observed



4.2.4.2 Short Run Total Expenditures

The methodology used to estimate short run total expenditures involved estimating a capital expenditures model which could be subtracted from the long run total expenditures model. We also estimate a direct short run total expenditures model.

Table 4. 2-15: SRTE and Capital Expenditures: OLS Model Statistics

Result	Capital Expenditures	Variable Expenditures
Multiple-R	.96184	.94997
R-Square	.92513	.90245
Adjusted-R-Square	.91192	.88524
Standard-Error	.24371	.33522
F	70.02311	52.4263
Signif F	.0000	.0000

Table 4. 2-16: OLS Analysis of Variance: Capital

	DF	Sum-of-Squares	Mean-Square
Regression	6	24.95391	4.15898
Residual	34	2.01941	.05939

Table 4.24: OLS Regression Results: Capital Expenditures

Variable	B	SE-B	Beta	T	Sig-T
Constant	14.011152	1.699332		8.245	.0000
LNPk	2.650501	.568536	.225022	4.662	.0000
LNPl	.779421	.405931	.133481	1.920	.0633
LNPm	.006966	.087513	.003799	.080	.9370
LNYa	.346849	.113712	.434082	3.050	.0044
LNYc	.256666	.094192	.327990	2.725	.0101
LNYs	.168647	.098615	.190447	1.710	.0963

This can be expressed as the equation below:

(4. 2.22) $$CAPE = 1214690\, Pk^{2.65}\, Pl^{0.779}\, Pm^{0.00697}\, Ya^{0.346}\, Yc^{0.256}\, Ys^{0.169}$$

Table 4. 2-17: OLS Analysis of Variance: SRTE

	DF	Sum-of-Squares	Mean-Square
Regression	6	35.34735	5.89122
Residual	34	3.82075	.11238

Table 4. 2-18: OLS Regression Results: Short Run Total Expenditures

Variable	B	SE-B	Beta	T	Sig-T
Constant	5.111415	2.337439		2.187	.0357
LNPk	.587764	.782024	.041410	.752	.4575
LNPl	.097047	.558360	.013792	.174	.8630
LNPm	-.071497	.120375	-.032354	-.594	.5565
LNYa	.724319	.156411	.752249	4.631	.0001
LNYc	.007780	.129562	.008250	.060	.9525
LNYs	.221243	.135645	.207332	1.631	.1121

(4. 2.23) $SRTE = 165.67\, Pk^{0.587}\, Pl^{0.097}\, Pm^{-0.071}\, Ya^{0.724}\, Yc^{0.0077}\, Ys^{0221}$

4.2.4.3 Long Run Average and Marginal Costs

Recalling the long run total expenditure function and the marginal cost calculation we can compute long run marginal cost functions for the three classes of vehicles. These are solved for average values (the values for each state are given in the appendix.

(4. 2.24) $LRTE = 79221\, Pk^{1.83}\, Pl^{0.786}\, Pm^{0.00492}\, Ya^{0.439}\, Yc^{0.225}\, Ys^{0.179}$

(4. 2.25) $MCi = \partial C(Y)/\partial Yi = \partial LRTE(Y)/\partial Yi = MCi(Y)$

(4. 2.26) $LRMCa = 79221\, Pk^{1.83}\, Pl^{0.786}\, Pm^{0.00492}\, (0.439)Ya^{-0.561}\, Yc^{0.225}\, Ys^{0.179}$

(4. 2.27) $LRMCs = 79221\, Pk^{1.83}\, Pl^{0.786}\, Pm^{0.00492}\, Ya^{0.439}\, Yc^{0.225}\, (0.179)Ys^{0.821}$

(4. 2.28) $LRMCc = 79221\, Pk^{1.83}\, Pl^{0.786}\, Pm^{0.00492}\, Ya^{0.439}\, (0.225)\, Yc^{-0.775}\, Ys^{0.179}$

Applying the marginal cost equations to the national totals for Ya, Yc, Ys and national average prices, we get the long run marginal costs given in the table below.

Table 4. 2-19: Long Run Marginal Costs by Vehicle Class

	LRMC-Auto	LRMC-Sing	LRMC-Comb	LRMC-Truck
$/vkt	0.0188	0.0431	0.0514	0.04644
$/vmt	0.0314	0.0718	0.0858	0.0774

The average cost function is well defined for the single output but, under the definition of a vector of flows the measure of average costs becomes ambiguous:

(4. 2.29) $ACi = C(Y)/Y$

The average cost does not uniquely exist. Unless the outputs in the vector Y are assumed to be equivalent or systematically related, the above measure of average cost has no closed form. Some type of index must be used in place of the vector Y in the calculation of an "average" cost. In this way, the calculation of average cost requires a weighting of the outputs. The incremental cost of introducing the additional output (vector of flows) Yn is equal to :

(4. 2.30) $ICn = C(Y) - C(Ym\text{-}n)$

where:

$Y = \{Y1, ..., Ym\}$

$Yn = \{Y1, ..., Yn\}$

$Ym\text{-}n = \{Yn+1, ... , Ym\}$

To estimate the incremental cost, we can thus evaluate the long run total expenditure function at two values. For example, to estimate LRICa, the long run incremental cost per unit of automobile travel (1000 vehicle miles traveled), we can evaluate at the means for all values except Ya, which we evaluate at the mean (E(Ya)) and at 1.

(4. 2.31) $LRTE = 79221\, Pk^{1.83}\, Pl^{0.786}\, Pm^{0.00492}\, Ya^{0.439}\, Yc^{0.225}\, Ys^{0.179}$

(4. 2.32) $LRICa = (E(Ya)^{0.439} - 1^{0.439})\,(Za) / E(Ya) = \underline{\$0.029}$ /vmt ($0.017/vkt)

where:

(4. 2.33) $Za = 79221\, Pk^{1.83}\, Pl^{0.786}\, Pm^{0.00492}\, Yc^{0.225}\, Ys^{0.179}$ evaluated at the mean

$= 10049$

(4. 2.34) $LRICs = (E(Ys)^{0.179} - 1^{0.179})\,(Zs) / E(Ys) = \underline{\$0.1045}$ /vmt ($0.063/vkt)

where:

$$Zs = 79221\ Pk^{1.83}\ Pl^{0.786}\ Pm^{0.00492}\ Yc^{0.225}\ Ya^{0.439} \text{ evaluated at the mean}$$

$$= 195{,}949$$

(4. 2.35) $LRICc = (E(Yc)^{0.225} - 1^{0..225})\ (Zc) / E(Yc) = \underline{\$0.168}$ /vmt ($0.101/vkt)
where:

$$Zc = 79221\ Pk^{1.83}\ Pl^{0.786}\ Pm^{0.00492}\ Ys^{0.179}\ Ya^{0.439} \text{ evaluated at the mean}$$

$$= 142{,}605$$

In Table 4.28, we summarize the marginal and average incremental costs at the average values of inputs. The results are compared with similar computations by Ivaldi and McCullough (1995) using a different estimation procedure known as the Generalized McFadden and similar though not identical data set.

Table 4. 2-20: Long Run Marginal and Average Incremental Costs

Vehicle Type	MC $/VMT	MC$/VKT	AIC $/VMT	AIC $/VKT	MC Ivaldi-McCullough$/VMT	MC Ivaldi-McCullough$/VKT
Ya	0.0314	0.0188	0.029	0.017	0.010 (0.011 - 0.017)	0.006 (0.007 - 0.010)
Ys	0.0718	0.0431	0.1045	0.063	0.043 (0.007 - 0.097)	0.026 (0.004 - 0.058)
Yc	0.0858	0.0514	0.168	0.101	0.086 (0.08 - 0.26)	0.051 (0.048 - 0.156)

Note: Parenthesis refer to range of state level highway agency marginal costs (Ivaldi-McCullough 1995, p.43)

4.2.4.4 Short Run Average and Marginal Costs

Recalling the long run total expenditure function (eq 4.40) and the marginal cost calculation (eq 4.45), we can compute long run marginal cost functions for the three classes of vehicles. These are solved for average values in table 4.40 (the values for each state are given in appendix.

(4. 2.36) $$SRTE = 165.67\ Pk^{0.587}\ Pl^{0.097}\ Pm^{-0.071}\ Ya^{0.724}\ Yc^{0.0077}\ Ys^{0221}$$

(4. 2.37) $$MCi = \partial C(Y)/\partial Yi = \partial SRTE(Y)/\partial Yi = MCi(Y)$$

(4. 2.38) $$SRMCa = 165.67\ Pk^{0.587}\ Pl^{0.097}\ Pm^{-0.071}\ (0.724)Ya^{-0.276}\ Yc^{0.0077}\ Ys^{0221}$$

(4. 2.39) $$SRMCs = 165.67\ Pk^{0.587}\ Pl^{0.097}\ Pm^{-0.071}\ Ya^{0.724}\ Yc^{0.0077}\ (0.221)Ys^{-0.779}$$

(4. 2.40) $$SRMCc = 165.67\ Pk^{0.587}\ Pl^{0.097}\ Pm^{-0.071}\ Ya^{0.724}\ (0.0077)Yc^{-0.992}\ Ys^{0221}$$

Applying the marginal cost equations to the national totals for Ya, Yc, Ys and national average prices, we get the short run marginal costs given in table 4.29

Table 4.2-21 Short Run Marginal Costs by Vehicle Class

	SRMC-Auto	SRMC-Sing	SRMC-Comb
$/vkt	0.0055	0.0075	0.0003
$/vmt	0.0092	0.0125	0.00066

The average cost function is well defined for the single output but for multiple outputs does not uniquely exist. We use the incremental cost. To estimate the incremental cost, we can thus evaluate the short run total expenditure function at two values, for instance to estimate SRICa, the short run incremental cost per unit of automobile travel (1000 vehicle miles traveled), we can evaluate at the means for all values except Ya, which we evaluate at the mean (E(Ya)) and at 1

(4. 2.41) $SRTE = 165.67\, Pk^{0.587}\, Pl^{0.097}\, Pm^{-0.071}\, Ya^{0.724}\, Yc^{0.0077}\, Ys^{0221}$

(4. 2.42) $SRICa = (E(Ya)^{0.724} - 1^{0.724})\,(Za) / E(Ya) =$ $\underline{\$0.0125}$ /vmt ($0.0075 /vkt)
where:

$Za = 165.67\, Pk^{0.587}\, Pl^{0.097}\, Pm^{-0.071}\, Yc^{0.0077}\, Ys^{0221}$ evaluated

at the mean = 224.15

(4. 2.43) $SRICs = (E(Ys)^{0.221} - 1^{0.221})\,(Zs) / E(Ys) =$ $\underline{\$0.0477}$ /vmt ($0.0298 /vkt)
where:

$Zs = 165.67\, Pk^{0.587}\, Pl^{0.097}\, Pm^{-0.071}\, Ya^{0.724}\, Yc^{0.0077}$ evaluated

at the mean =58250

(4. 2.44) $LRICc = (E(Yc)^{0.0077} - 1^{0.0077})\,(Zc) / E(Yc) =$ $\underline{\$0.0054}$/vmt ($0.0032/vkt)
where:

$Zc = 165.67\, Pk^{0.587}\, Pl^{0.097}\, Pm^{-0.071}\, Ya^{0.724}\, Ys^{0221}$ evaluated

at the mean = 390,152

In the table below, we summarize the marginal and average incremental costs at the average values of inputs.

Table 4. 2-22: Short Run Marginal and Average Incremental Costs

	SRIC-Auto	SRIC-Sing	SRIC-Comb
$/vkt	0.00075	0.0298	0.0032
$/vmt	0.00125	0.0477	0.0054

4.2.5 Economies Of Scale, Scope, Density, And Network Utilization

4.2.5.1 Economies of Scale

The technical property of economies of scale can be calculated in the multi-product output context. The technical property of economies of scale in the multi-product output case is:

(4. 2.45) $Sn = ICn / \Sigma\ (i \in N)(Yi^* \partial c(Y)/\partial Yi)$

where we have:

returns to scale for Sn = 1

increasing returns to scale for Sn > 1

decreasing returns to scale for Sn < 1

The technology associated with economies of scale is clearly different from that of economies of scope. With economies of scale, the cost of producing more transportation output within the same network is lower for larger levels of output. The economic interpretation of economies of scale is :

(4. 2.46) S = cost/(amount produced)*(marginal cost) = cost/revenue

Table 4. 2-23: Long Run Economies of Scale

Vehicle Type	MC $/VKT	AIC $/VKT	S = AIC/MC	Economies of Scale
Ya	0.0188	0.017	0.92	Decreasing
Ys	0.0431	0.063	1.45	Increasing
Yc	0.0514	0.101	1.96	Increasing

Table 4.2-24: Short Run Economies of Scale

Vehicle Type	MC $/VKT	AIC $/VKT	S = AIC/MC	Economies of Scale
Ya	0.0055	0.00075	0.14	Decreasing
Ys	0.0075	0.0298	3.97	Increasing
Yc	0.0003	0.0032	10.67	Increasing

We find that there are economies of scale for trucks, and diseconomies of scale for passenger cars. This suggests complementarities in the provision of infrastructure, probably explained by the peaked nature of capacity requirements for cars as compared with trucks, which offsets the requirements for thicker pavement.

4.2.5.1 Economies of Density

Returns to density (RTD), following Caves, Christensen, and Tretheway (1984), is defined as the proportional increase in physical outputs made possible by a proportional increase in all inputs with the network (linear miles), output attributes, and input prices held constant:

(4. 2.47) $$RTD = \sum_i \left[\partial \ln C / \partial \ln Yi \right]^{-1}$$

Returns to density exist if unit costs fall as the highway network adds traffic to the road miles it already serves and the new traffic causes no change to output attributes. We expect to find this. This is in contrast to returns to scale (RTS), which is the proportional increase in outputs and linear miles of roadway served made possible by a proportional increase in all inputs and output attributes and input prices held constant. This is defined similarly as:

(4. 2.48) $$RTS = \left[\partial \ln C / \partial \ln P + \sum_i \partial \ln C / \partial \ln Yi \right]^{-1}$$

Because of multi-collinearity problems, linear miles and width had to be dropped as variables, and so we cannot distinguish economies of density from economies of scale.

4.2.5.2 Economies of Scope

Economies of scope describes whether it is cheaper to produce two products jointly or separately. In this case, is it cheaper to provide roads for the use of both cars and trucks, or provide separate facilities for each. While we expect there to be some economy of scope in having the different vehicle types sharing capacity, particularly since they have somewhat different peaking characteristics, there is a diseconomy that trucks do more damage to the roadbed, and thus require thicker pavements than would be needed for cars alone. However, the diseconomy is probably outweighed by sharing of capacity, particularly since roadways are highly indivisible, you can't build half a lane.

Baumol (1977a,b), Baumol, Bailey and Willig (1977), and Panzar and Willig (1977) have introduced the notion of "subadditive" cost function as a method of characterizing the structure of joint production of multiple outputs. A cost function is said to be subadditive at an output vector Y* if and only if it is cheaper to have a single firm (agency, facility) produce Y* than it is to split production among more than one firm (agency, facility) in any fashion. Subadditivity provides the basis to determine the least cost organization of the highway system.   While the subadditivity of a cost function per se is very difficult to test, its sufficiency conditions expressed in terms of various scale and scope economies are easier to test. Baumol (1977b) has shown that a cost function is strictly subadditive at output vector Y* if the ray average costs are strictly declining and (non-strict) transray convexity holds at the output vector. Ray average cost declines if the ray overall cost elasticity is less than one, meaning ray increasing returns to scale are greater than one.

Transray convexity concerns the properties of the cost function when the product mix changes. It implies inter-product complementarity. Baumol (1977a) has noted that transray convexity is related to economies of scope. Panzar and Willig (1978) have shown that cost complementarity between products i and j can be examined by evaluating the following second-order derivatives of each data point:

(4. 2.49) $\partial^2 C/\partial Yi\, \partial Yj$

Economies of scope is similar to a measure of average cost divided by marginal cost. The technical property of economies of scope can be expressed as follows in the multi-product output context:

(4. 2.50) $SCn(Y) = [C(Yn) + C(Ym\text{-}n) - C(Y)]/C(Y)$

The quantity $C(Yn) + C(Ym\text{-}n)$ represents the total cost of producing both vectors of flows separately and $C(Y)$ represents the cost of producing both vectors of flows simultaneously.

If SCn > 0 then there are economies of scope

If SCn < 0 then there are diseconomies of scope

If SCn = 0 then there are no economies of scope

(4. 2.51) $LRTE = 79221\, Pk^{1.83}\, Pl^{0.786}\, Pm^{0.00492}\, Ya^{0.439}\, Yc^{0.225}\, Ys^{0.179}$

(4. 2.52) LRTE(Y) @(Yc = 32738, Ya = 32738, Ys = 7352) = 964340

(4. 2.53) LRTE(Ya) @(Yc = 1, Ya = 32738, Ys = 7352) = 142605

(4. 2.54) LRTE(Yc) @(Ya = 1, Yc = 4890, Ys = 7352) = 10048

(4. 2.55) $SCn(Y) = [C(Yn) + C(Ym\text{-}n) - C(Y)]/C(Y)$

(4. 2.56) $SCn(Y) = [142605 + 10048 - 964340]/964340 = -0.84 < 0$ - diseconomy of scope

Testing for cost complementarities, we find them to be almost zero, so that increasing the amount produced of one class (auto) will not change the cost of the other (combination truck).

(4. 2.57) $\partial^2C/\partial Ya\partial Yc = 79221 Pk^{1.83}\, Pl^{0.786}\, Pm^{0.00492}\, (0.439)Ya^{-0.651}\, (0.225)Yc^{-0.775}\, Ys^{0.179}$
$= 0.000233$

4.2.6 Comparison

We can compare the econometric approach taken above with other studies. Miller and Moffet (1993) calculate total annual road capital and operating expenses attributable to cars as $85.7 billion per year, including $48 billion of pavement wear costs, $24.8 billion of other maintenance, and $12.6 billion of expansion and construction costs. They subtract road user fees from cars and light trucks of $21.5 billion, and estimate an annual capital and operating cost of $64 billion per year or $0.021 per pmt ($0.013/pkt). To estimate the full cost, not including user payments (which are simply transfers), application of their methodology produces an estimate of $0.028 per pmt ($0.017/pkt), which is about 50% higher than our estimate of $0.018/vmt ($0.011/vkt) average cost. Obviously the methodologies are dissimilar, which explains the difference in part. We take an econometric approach. They adopt a crude engineering approach, but extrapolate the results to the national system. Furthermore, they adopt FHWA (1982) cost estimates of pavement wear as a fixed $/ESAL-mile, with passenger cars responsible for 0.05 ESAL per mile. However the damage per mile is non-linear function of ESALs increasing with the third or fourth power (Small, Winston, Evans 1989). This suggests that the amount of pavement damage attributed to automobiles by the Miller and Moffet (1993) study is significantly overstated.

4.3. Engineering Allocation

There is an alternative approach to estimating the maintenance cost of highways. The alternative is to compare highway damage caused by cars to the damage caused by various classes of trucks. One such comparison shows that road surfaces suffer more at the wheels of a truck than a car. An allocation method based upon a comparison of vehicles types according to which type takes more “life” from a roadway, would distribute costs most equitably. It would hold those drivers who cause the most damage most accountable for the increased level of maintenance. When we determine the total cost of maintenance, then we can then allocate those costs based on the relative damage caused by the different classes of vehicles. In particular, two types of pavement distress: fatigue cracking and rutting or permanent deformation are analysed.

4.3.1 Methodology

In an FHWA Study (Hudson et al 1992), a tandem axle tractor trailer and a tridem axle trailer (combination trucks) were used in conjunction with a single unit truck to load actual pavements using three different loading configurations for each vehicle type. For the purposes of the engineering cost allocation, the tandem and tridem axle trailers are combined to a common tandem trailer with axle weights representative of the heavy loading configuration for the tandem trailer. The medium loading configuration is used for the single axle truck. For the representative passenger car, axle weights for a small four wheel drive vehicle are assumed. The table below illustrates the representative vehicles and their axle weights. All trucks are assumed to have dual tires on each side of tach axle, and passenger cars are assumed to have single tires on each side of each axle.

Table 4. 3-1: Representative Vehicles

Vehicle Type	Axle Configuration		Axle Mass	(kg)
	Front Rear	Front	Middle	Rear
Passenger Car	• •	400	-	1100
Single Unit Truck	• •	3600	-	8100
Combination Truck	• •• ••	3800	9800 each	9900 each

Terrell and Rimristong (1976) conducted a study which examines the response of asphalt concrete pavement for various truck axle and tire configurations. This study uses theoretical pavement structures, examining three different asphalt concrete surface thicknesses on a standard thickness of untreated base material. Four different tire widths and two different tire configurations (dual or single on each side on an axle) were also tested. They constructed a series of damage curves showing the number of load applications to failure for fatigue or rutting as a function of axle weight and the variables described previously. For our purposes, 15.24 cm (6 in.) of asphalt concrete, 25.4 cm (10 in) dual tires for both types of trucks and 20.3 cm dual tires for passenger cars were assumed (single tire results were not available. The figures below reproduce the results from the 1976 study for the assumed conditions, with extrapolation to lower axle weights assuming a linear relationship (on a semilog plot) between axle weight and application to failure.

Figure 4. 3-1: Fatigue Damage Curves

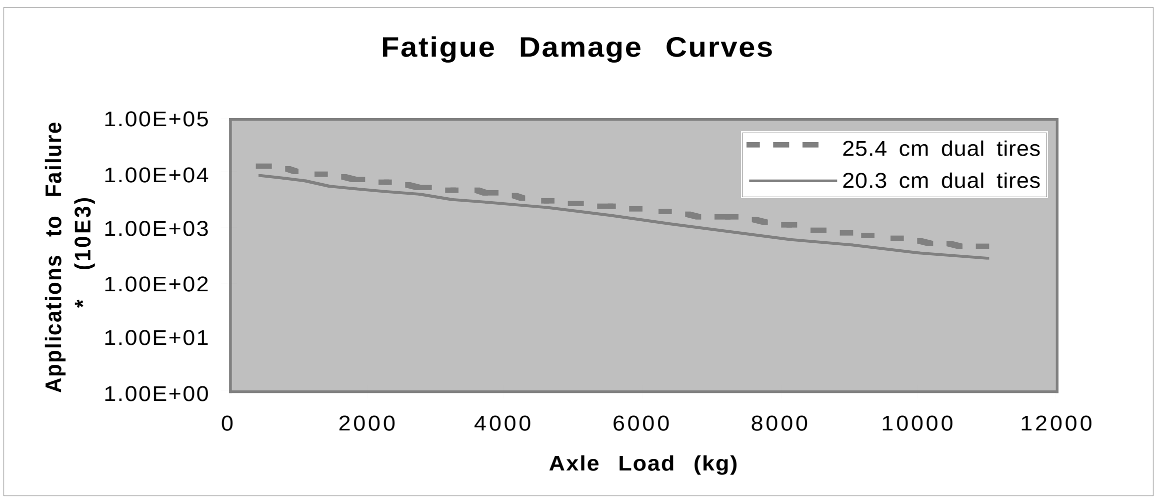
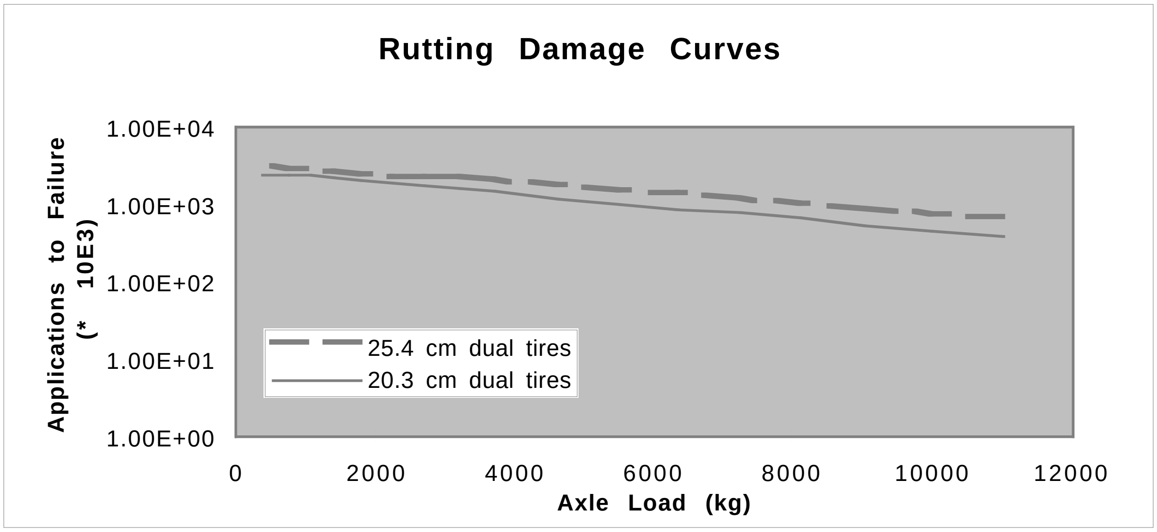


Figure 4. 3-2: Rutting Damage Curves



Using these damage curves and Miner's hypothesis of cumulative damage, the damage caused by a single pass of each vehicle type is determined. Miner's hypothesis states that the linear summation of cycle ratios must be less than or equal to one:

(4. 3.1) $\sum_i n_i/N_i \leq 1$

where:

n_i= number of applications of axle weight i

N_i = number of applications to failure of axle weight i

i = axle weight (kg) [for each axle load anticipated]

A single pass of each type of vehicle equals one for each axle of the representative vehicle. The number of applications to failure for each axle of the representative vehicle are determined using the damage curves in the figures above. The summation of cycle ratios for each representative vehicle gives a measure of the damage caused by a single pass of that vehicle.

4.3.2 Results

To determine the proportions of total cost to allocate to each vehicle class, the amount of damage caused by a single vehicle of each type is determined. Tables 4.34 and

4.35 show a measure of this damage, the linear summation of cycle ratios, for each vehicle type for both fatigue and rutting. The results verify the expectation that trucks cause considerably more damage to the pavement than passenger cars. Single unit truck cause approximately four times more damage than passenger cars if fatigue is the primary distress and twice as much damage if rutting is the primary distress. Combination trucks inflict more than 25 times the damage that passenger cars cause if fatigue is the primary distress and almost seven times more damage if rutting is the primary distress.

Table 4. 3-2: Relative Damage: Fatigue Damage Ratio

Vehicle Type	Front	Middle	Rear	Total
Passenger Car	0.00012	-	0.00014	0.00026
Single Unit Truck	0.00022	-	0.00091	0.0011
Combination Truck	0.00023	2(0.0015)	2(0.0016)	0.0066

Table 4. 3-3: Relative Damage: Rutting Damage Ratio

Vehicle Type	Front	Middle	Rear	Total
Passenger Car	0.00040	-	0.00045	0.00085
Single Unit Truck	0.00052	-	0.00097	0.0015
Combination Truck	0.00054	2(0.0012)	2(0.0012)	0.0055

Table 4. 3-4: Costs Relative to the Cost/VKT of Auto

Vehicle Type	LRMC	LRAIC	Fatigue	Rutting
Passenger Car	1	1	1	1
Single Unit Truck	2.292	3.705	4.23	1.76
Combination Truck	2.734	5.94	25.38	6.47

We can compare the marginal and average incremental cost estimated in section 4.2 with the relative fatigue and rutting damage caused by trucks. While the economic cost per vkt of a single unit truck is 2.29 times that of a car at the margin, and 3.7 times on average, it does 4.23 times as much damage due to fatigue and 1.76 times as much due to rutting. Similarly, fatigue damage associated with combination trucks is more than the additional marginal or average cost. This is to be expected because in addition to pavement wear costs, there are capacity costs associated with all vehicles, which are more equally distributed between vehicle types.

Factors other than traffic-induced loaring also affect the wear of pavement structures. Environmental conditions, including changes in temperature, freeze-thaw cycles, and moisture can cause thermal cracking of the pavement, uplift of the underlying base materials, and stripping of the asphalt from the aggregate causing a loss of strength of the surface layer. All of these factors contribute to the deterioration of an asphalt concrete pavement. Some estimates conclude that the ratio between damage caused by traffic-induced loading and damage caused by environmental factors may be 1:1 on highways with high volumes of trucks. On low volume roadways, environmental factors may account for 80% of the (slower) pavement deterioration. A method is needed to allocate environmentally induced damage costs between classes of users.

Furthermore, vehicle speed, representing the time while the pavement is loaded, also influences its lifespan. These conditions -- loading time and temperature -- also affect the damage curves for fatigue and rutting used in this analysis because the resistance of asphalt concrete to distress is sensitive to these conditions. The stiffness of asphalt concrete strongly depends on the time and temperature of loading. During the winter months, when the stiffness of the pavement is high, the number of applications to failure can be an order of magnitude higher than during the summer months (Terrel and Rimsritong 1976). For this reason, asphalt concrete pavements are usually studied over a wide temperature range representing an entire year of temperature fluctuations. With each change in temperature, a new stiffness is used to characterize the pavement. With this change in stiffness, a different damage curve is used to find the number of applications to failure for fatigue or rutting distress

4.4. Time And Social Costs

This section summarizes the external costs of travel for passenger car travel and the cost of time. Underlying each of these cost estimates are a number of critical assumptions which are discussed more fully in Chapter 3, which details the development of social cost estimates. They are briefly discussed below.

4.4.1 Congestion And Time

The average cost of time is measured by *Average time* in minutes per kilometer as given by equation (3.3.3m). It is composed of two parts: A fixed portion reflecting the uncongested time, which is a private cost, and a variable portionrepresenting congestion, and which is a function of volume. The travel time functions given in Chapter 3 can be monetized by multiplying the cost, which is given above in minutes per mile by a value of time. If we take a speed of 100, and a value of time of $10 per hour (again, a conservative number) a 677 km trip will take 6 hours and 45 minutes. This amounts to an average of <u>$0.10/pkt</u> ignoring congestion costs.

Congestion costs, assuming a modest average traffic level of 1500 vehicle per hour per lane, is $10/hour value of time and 1.5 persons per car result in an average cost <u>$0.005/pkt</u>.

4.4.2 Accidents

The accident cost is obtained by determining the value of life, property and injury per accident and multiplying by an equation representing accident rates. As discussed in Chapter 3, the value of life property and injury has been estimated at $120,000 for rural accidents, which are at higher speeds and thus more likely to be fatal or cause serious injury than urban accidents, which cost $70,000 on average

In Chapter 3 we compute the average annual total accident rate per hour at a level Qh = 6000 vph and a = 0.63 is 2.214. Dividing by 365 (days per year) , and then multiplying by 33% (the proportion of four and half hour peak period traffic in the peak hour), and dividing by the number of vehicles, we get the probability of an accident per hour per vehicle is 0.000000 34. Multiplying this by the cost of an accident, we get <u>$0.040/vkt</u> (0.27/pkt) for rural travel or <u>$0.023/vkt</u> (0.15/pkt) for urban travel. These results are similar to values estimated using average accident rates, which we estimated at

$0.028/vkt. Marginal accident costs, with the same assumptions, range from $0.026/vkt - $0.044/vkt. We use a composite urban and rural average cost of 0.20/pkt for our comparison tables.

The average amount paid per year in insurance for collision, property damage, and liability, given above in table 4.7 was $617 per year. This ranges between $0.025/pkt at 24,000 km/yr and $0.038/pkt at 16,000 km/year. Given that some fraction of insurance costs paid by users result in profit to the insurers, the cost estimates are very similar to the total costs of accidents, and confirms our decision to treat insurance as a transfer.

4.4.3 Noise

The complete integrated noise model for each of the modes is complex, requiring the combination of a number of equations. For analytical purposes, these were converted to simpler average cost models. Some of the variables can be re-incorporated into the model through the use of multiplicative adjustment factors for density (fD), House Value (fH), and the Cost per decibel deflator (fC). It should be noted that the average cost of noise depends not only on same direction flow (Qhi), but also on opposite directional flow (Qhj), complicating this problem. In Chapter 3, with typical values of Qh = 6000, we obtain a marginal cost of $0.009/vkt and an average cost of $0.006/vkt, or 0.0045/pkt, which we use for intermodal comparisons.

4.4.4 Air Pollution

Air pollution costs are estimated for both local effects, and global externalities, such as greenhouse gases. These costs are largely independent of the flow on the link, but rather depend on metropolitan or global levels of pollution. Because of the difficulty in estimating equations which differentiate the level of pollution based on background levels of pollution, and their determinants, and based on the analysis in Chapter 3 we have adopted simpler constant average and marginal costs for pollution.The Local Air Pollution Cost is $0.0043/pkt, while the Global Environmental Impact Cost is $0.0003/pkt

4.5. Composite Costs

Finally, we assemble the cost for all of the cost categories, after being careful not to double count, and produce our estimates in the table below. The total long run average cost is \$0.34/vkt traveled, including user fixed and variable costs, the cost of time to both the driver and passenger in traveling and in congestion, the cost of accidents, the cost of pollution and the cost of noise.

Table 4. 5-1: Average and Marginal Long and Short Run Costs

Cost Category	Short Run Marginal Cost	Short Run Average Cost	Long Run Marginal Cost	Long Run Average Cost
User Fixed + Var.	\$0.049	\$0.130	\$0.049	\$0.130
Infrastructure	\$0.0055	\$0.00075	\$0.018	\$0.0174
External: Congestion	\$0.033	\$0.068	\$0.033	\$0.0068
External: Accidents	\$0.035	\$0.031	\$0.035	\$0.031
External: Pollution	\$0.0046	\$0.0046	\$0.0046	\$0.0046
External: Noise	\$0.009	\$0.006	\$0.009	\$0.006
User: Time	\$0.50	\$0.50	\$0.15	\$0.15
Total	\$0.2861	\$0.3292	\$0.299	\$0.34

note: \$/vkt

For a 677 kilometer trip, such as between San Francisco and Los Angeles, an automobile trip generates on the order of \$32 worth of externalities, but 14% of that is congestion costs already borne by travelers and most of the rest is accident costs also primarily borne by users. Pollution and noise costs for the trip are estimated to be on the order of \$7.00, or for a trip which uses about 17 gallons (about 68 liters), an additional externality tax would be \$0.10/liter or \$0.42/gallon. This tax would reduce demand, and thus reduce the congestion tax rate needed to have efficient utilization of the road.

4.6. Appendices

4.6.1 Appendix 1, Summary of Data on Automobile Costs.

Much of the data erating costs came from the document :

United States Federal Highway Administration (1984). “Costs of Owning and Operating Automobiles and Vans,” Washington: U.S. Government Printing Office.

Unfortunately, the 1984 version was the last printing of that document. That document appeared quite sporadically when it was published, somewhat less than bi-annually. The most recent versions are 1979, 1982 and 1984. Hertz also published a new car operating costs pamphlet which has data up to 1987 only. It is no longer in publication.

The only remaining publisher of annual operating cost data is the American Automobile Association (AAA). Fortunately, their document “Your Driving Costs,” appears annually. Unfortunately, the UCB Transportation Library is missing some of the yearly publications of “Your Driving Costs” making a time series collection of all data in the pamphlet difficult.

The data available in the “Your Driving Costs” is for one small auto, one intermediate auto, one large auto, and a national average measure compiled by AAA. Light truck and utility vehicle data for two specific models appear in the 1993 version only.

The AAA “Your Driving Costs” data is compiled and managed by :

Runzheimer International

Runzheimer Park

Rochester, WI 53167

(414) 767-2200

The time series of the AAA “Your Driving Costs” appears in the American Automobile Manufacturers Association (AAMA) yearly publication “AAMA Motor Vehicle Facts and Figures ‘93” or whatever the year happens to be. These data are available only up to 1993 in the UCB Transportation Library. Unfortunately, the only data which are compiled are for the intermediate (Ford Taurus/Chevy Celebrity 6 cylinder or similar) autos are available from the AAMA data. The data available from AAA are a little more aggregate than that in the FHWA. For instance, depreciation is provided as a single number instead of by age and by use, separately. Gas and Oil costs are aggregated. Scheduled and unscheduled maintenance costs are aggregated. License, registration and taxes are aggregated. This is the best and most current continuous time series available on automotive operating costs.

4.6.2 Appendix 2: Data (Refers to section on Infrastructure Costs)

Table 4.A.1 Expenditures by State

State	SC Stock Capital 1988 millions	Capital Expend. 1993 thousd	Cm Maint. Expend. 1993 thousd	Cl1 Admin. Expend. 1993 thousd	Cl2 Law Safe Expend. 1993 thousd	Interest 1993 thousd	Bond Retire. 1993 thousd
Alabama	8905.74	470232	157868	72558	57359	11128	20436
Alaska	NA	242000	33400	30088	40116	13411	21623
Arizona	7955.02	480799	68839	70527	78446	154305	359239
Arkansas	4829.36	362332	93412	42524	45163	661	449
California	42835.42	2135323	342460	1046908	1182559	58263	35336
Colorado	6574.39	341276	125208	52531	96886	43258	63757
Connecticut	7236.71	588122	49314	75613	17130	168579	206380
Delaware	2112.78	205535	29119	50696	36496	46059	26331
Dist. of Col.	NA	108194	27954	19715	0	73135	46061
Florida	19987.9	1684969	197397	428351	271756	232516	153681
Georgia	12440.08	737696	163517	113627	127181	46645	300966
Hawaii	NA	303746	15081	38613	16365	18968	22637
Idaho	3010.18	124933	21457	43930	14397	341	545
Illinois	28835.59	1469756	256982	260011	126439	129070	115485
Indiana	10713.72	635631	189409	195916	41838	52231	12687
Iowa	10535.56	412640	58645	95273	66895	23439	53258
Kansas	7667.17	433598	89575	183109	275074	44942	142628
Kentucky	12137.85	NA	NA	88047	109820	103564	143452
Louisiana	13572.38	598835	71494	85661	116970	107470	107504
Maine	2547.35	138465	76578	17086	42300	12015	15933
Maryland	11768.02	471633	100747	108364	161614	81688	330508
Massachusetts	9194.59	NA	NA	214814	177051	174108	245634
Michigan	18795.61	561494	94263	205891	201637	35674	44873
Minnesota	13417.77	608127	97845	146484	180927	56605	127591
Mississippi	6702.66	433576	37830	33114	64869	31566	57622
Missouri	11494.67	500132	155672	177283	124228	11715	19421
Montana	4165.41	190349	18401	16843	19424	13958	1723
Nebraska	5423.15	272526	36708	43639	42934	15349	27120
Nevada	2782.09	NA	NA	23360	24049	12962	16786
New Hampshire	2401.79	171552	58160	96270	46005	21722	4533
New Jersey	15409	1041696	197709	381121	254093	238792	220850
New Mexico	4388.96	316817	52572	65312	26275	2532	2014
New York	37413.16	2205223	287345	616785	283252	586457	409463
North Carolina	10338.95	820790	384228	127094	203642	28870	17703
North Dakota	3129.3	123086	30041	20627	15228	6931	13499
Ohio	23735.85	822230	398983	335689	213155	51708	109564
Oklahoma	6698.98	333481	85064	191811	41384	56248	85638
Oregon	6837.71	317143	136717	64501	73433	14067	24162
Pennsylvania	24206.95	1285147	524044	152494	443935	190151	225189
Rhode Island	1980.89	221563	27882	9798	28023	14684	19770
South Carolina	4777.93	406976	127178	52696	86404	917	824
South Dakota	3227.74	189051	31853	21403	30636	843	1813
Tennessee	11110.42	569278	180047	84136	59239	6057	16894
Texas	36718.22	1978812	659794	473048	804375	351868	246617
Utah	4317.48	230994	57500	40831	33745	0	0
Vermont	1819.61	109862	9748	15067	21072	2015	5990
Virginia	14931.72	625766	429187	143235	168008	99058	190483
Washington	12142.25	676259	64302	239299	173064	72751	95899
West Virginia	7562.87	467439	145015	31528	38247	29209	41355
Wisconsin	10981.49	650001	73606	128447	261228	72021	135877
Wyoming	3571.6	158786	30126	24522	23896	187	1159
Total	533344.04	28233871	6600276	7296290	7088262	3620713	4588962
Average	10457.72	588205	137505	143064	138985	70994	89979

Notes: 1988 and 1993 U.S. Dollars

Table 4.A.2 Prices by State

State	Pl Gov Salary (1993)	Pk Bond Rating (1994)	Pm Bit. Concrete (1993)	Excav (1993)	Reinf. Steel (1993)	Struct Steel (1993)	Struct Concrete (1993)
Alabama	25028	AA	25.49	1.6	0.419	0.862	217.9
Alaska	37943	AA	31.89	1.89	0.464	1.161	855.03
Arizona	24995	X	22.42	5.21	0.354	1.62	206.73
Arkansas	22793	AA	26.28	1.31	0.544	0.674	259.97
California	33080	A1	28.79	3.15	0.414	1.07	256.86
Colorado	27380	X	28.35	2.48	0.362	0.79	201.17
Connecticut	35320	AA	32.4	5.33	0.631	0.887	336.99
Delaware	28593	AA1	26.85	3.4	0.632	0.632	261.13
Dist. of Col.	43855	X	54.49	10.13	0.488	0.898	616
Florida	27116	AA	19.02	2.51	0.377	0.66	320.1
Georgia	24431	AAA	30.47	2.14	0.399	0.868	308.24
Hawaii	30420	AA	65.14	18.58	0.585	0.585	616.43
Idaho	22276	X	21.82	2.79	0.482	0.714	242.58
Illinois	29712	A1	29.97	4.26	0.605	0.868	387.64
Indiana	25309	X	22.9	6.97	0.474	0.811	295.89
Iowa	24183	X	22.93	2.17	0.43	0.782	242.23
Kansas	22923	X	24.42	2.15	0.553	0.755	279.65
Kentucky	23908	AA	28.41	7.43	0.513	0.792	307.8
Louisiana	22383	BAA1	28.62	5.79	0.325	0.685	215.76
Maine	24466	AA	24.53	4.24	0.811	0.806	300.09
Maryland	32930	AAA	26.2	2.48	0.505	0.808	286.69
Massachusetts	31609	A1	28.96	3.17	0.719	0.683	93.8
Michigan	30074	A1	26.64	3.23	0.557	1.1	268.24
Minnesota	28052	AA1	19.28	1.58	0.447	0.825	150.76
Mississippi	20777	AA	29.17	1.65	0.334	0.74	211.04
Missouri	24807	AAA	23.54	2.57	0.606	0.771	317.83
Montana	23744	AA	23.74	3.21	0.513	0.655	238.51
Nebraska	23214	X	22.21	2.03	0.781	0.635	304.88
Nevada	30929	AA	20.67	3.33	0.478	0.994	236.94
New Hampshire	26304	AA	26.4	3.09	0.482	1.115	209.89
New Jersey	35532	AA1	27.28	7.11	0.75	1.175	320.62
New Mexico	25083	AA1	22.47	2.68	0.592	2.241	298.37
New York	33575	A	29.27	4.76	0.727	0.978	426.54
North Carolina	24581	AAA	25.82	1.92	0.448	0.826	250.09
North Dakota	21716	AA	53.34	1.02	0.581	2.157	328.51
Ohio	27157	AA	22.5	3.66	0.467	0.704	269.34
Oklahoma	23145	AA	27.52	2.16	0.467	1.126	213.21
Oregon	27778	AA	27.54	7.14	0.456	0.665	252.68
Pennsylvania	29870	A1	30.46	3.7	0.634	0.998	317.11
Rhode Island	31024	A1	31.17	3.35	0.483	0.885	247.97
South Carolina	24142	AAA	24.89	2.66	0.443	0.851	218.8
South Dakota	21562	X	12.8	1.22	0.47	0.47	204.59
Tennessee	24812	AAA	22.78	1.93	0.443	0.834	220.25
Texas	24957	AA	31.76	2.66	0.322	0.748	221.41
Utah	24221	AAA	24.44	2.63	0.466	1.481	208.36
Vermont	24989	AA	32.83	2.13	0.491	0.82	263.2
Virginia	29028	AAA	25.33	2.72	0.495	0.795	269.71
Washington	29721	AA	28.29	2.37	0.524	0.976	306.82
West Virginia	23614	A1	26.51	3.04	0.535	0.961	305.65
Wisconsin	27228	AA	2.08	1.65	0.44	1.083	171.78
Wyoming	23275	X	18.08	1.26	0.555	0.555	268
Average	27168	AA	18.81	2.5	0.467	0.861	261.89

Source: FHWA 1994b, BLS 1995.
Notes: Units: Bituminous Concrete $/ton, Excavation $/cu yd, Reinforcing Steel $/lb, Structural Steel $/lb, Structural Concrete $/ton; 1993 and 1994 U.S. dollars.

Table 4.A.3 Outputs by State

	Ya Auto VMT (millions)	Ys Single Truck VMT (Millions)	Yc Comb. Truck VMT (millions)	%URBAN	%FREEWAY
Alabama	29461	7137	9164	0.50	0.20
Alaska	2723	1057	61	0.48	0.29
Arizona	20435	10643	3969	0.61	0.27
Arkansas	14029	3205	5847	0.35	0.24
California	217495	32116	12936	0.80	0.42
Colorado	26874	1378	2556	0.59	0.32
Connecticut	21789	3242	1428	0.77	0.41
Delaware	5356	1060	475	0.61	0.15
Dist. of Col.	3459	93	11	1.00	0.24
Florida	96026	14095	9747	0.71	0.22
Georgia	50160	17596	10147	0.59	0.28
Hawaii	6841	1190	36	0.73	0.29
Idaho	5615	3384	1766	0.33	0.22
Illinois	64662	12465	10514	0.68	0.27
Indiana	36430	9442	11201	0.49	0.23
Iowa (*)	15135	3148	5643	0.36	0.21
Kansas	15885	5195	3084	0.47	0.24
Kentucky	23122	9347	5593	0.44	0.25
Louisiana	20440	8822	4593	0.50	0.25
Maine	7983	3041	1127	0.26	0.19
Maryland	27153	11948	2794	0.69	0.37
Massachusetts	39503	5604	2241	0.81	0.37
Michigan	61071	16142	7006	0.63	0.26
Minnesota (*)	32868	5185	3109	0.51	0.26
Mississippi	17133	4435	4671	0.33	0.17
Missouri	38590	7126	7538	0.53	0.31
Montana	4818	2518	1189	0.24	0.25
Nebraska	8402	3558	2661	0.39	0.19
Nevada (*)	54715	1488	1539	0.59	0.30
New Hampshire	7307	2388	372	0.37	0.25
New Jersey	43976	10350	5084	0.80	0.27
New Mexico	11899	2782	3771	0.37	0.26
New York	82651	18626	8604	0.72	0.31
North Carolina	49100	7227	11211	0.50	0.22
North Dakota	4060	1258	755	0.26	0.20
Ohio	71213	11767	12242	0.61	0.29
Oklahoma	23173	7653	4293	0.51	0.25
Oregon	16551	8164	3211	0.44	0.28
Pennsylvania	60862	14562	13775	0.58	0.23
Rhode Island	5982	1091	486	0.85	0.30
South Carolina	25581	3924	5544	0.40	0.26
South Dakota	5381	1191	646	0.21	0.22
Tennessee	33838	8757	7399	0.55	0.28
Texas	112296	32682	18350	0.65	0.32
Utah	11229	3429	1648	0.64	0.35
Vermont	4814	911	293	0.28	0.22
Virginia	46783	10532	6131	0.53	0.28
Washington	33719	12476	3191	0.66	0.32
West Virginia	11681	2223	2574	0.28	0.28
Wisconsin	36561	5637	5430	0.47	0.20
Wyoming	2786	1683	1748	0.26	0.32
Total	1669617	374971	249407		
Average	32738	7352	4890	0.53	0.27

note: (*) adjust sing truck & cars (move 10% cars --> sing)

Table: Network Size by State

State	L - TotalMiles	L - %Freeway	L - %Urban	W - %UrbFwy > 4 lanes	W - %RurFwy > 4 lanes
Alabama	92209	0.010	0.21	0.14	0.00
Alaska	13849	0.076	0.13	0.19	0.00
Arizona	55763	0.023	0.29	0.27	0.00
Arkansas	77192	0.008	0.10	0.34	0.01
California	169201	0.023	0.48	0.88	0.21
Colorado	78721	0.015	0.16	0.33	0.03
Connecticut	20357	0.027	0.57	0.69	0.22
Delaware	5544	0.009	0.34	0.73	NA
Dist. of Col.	1107	0.030	1.00	0.71	NA
Florida	112808	0.015	0.44	0.48	0.10
Georgia	110879	0.013	0.24	0.62	0.14
Hawaii	4106	0.024	0.44	0.86	NA
Idaho	58835	0.010	0.06	0.03	0.00
Illinois	136965	0.016	0.26	0.49	0.02
Indiana	92374	0.014	0.21	0.41	0.04
Iowa	112708	0.007	0.08	0.31	0.05
Kansas	133256	0.007	0.07	0.42	0.00
Kentucky	72632	0.012	0.14	0.38	0.05
Louisiana	59599	0.015	0.23	0.33	0.01
Maine	22510	0.017	0.11	0.02	0.04
Maryland	29313	0.024	0.47	0.73	0.54
Massachusetts	30563	0.025	0.64	0.80	0.36
Michigan	117659	0.012	0.24	0.60	0.12
Minnesota	129959	0.008	0.11	0.45	0.03
Mississippi	72834	0.010	0.11	0.00	0.00
Missouri	121787	0.012	0.13	0.57	0.01
Montana	69768	0.017	0.03	0.00	0.00
Nebraska	92702	0.005	0.05	0.25	0.00
Nevada	45778	0.013	0.10	0.31	0.00
New Hampshire	14938	0.018	0.19	0.27	0.12
New Jersey	35097	0.020	0.68	0.82	0.50
New Mexico	60812	0.016	0.10	0.29	0.01
New York	111882	0.021	0.35	0.55	0.07
North Carolina	96028	0.013	0.23	0.26	0.03
North Dakota	86727	0.007	0.02	0.08	0.00
Ohio	113823	0.017	0.28	0.29	0.02
Oklahoma	112467	0.009	0.11	0.34	0.00
Oregon	96036	0.008	0.10	0.40	0.04
Pennsylvania	117038	0.018	0.28	0.22	0.02
Rhode Island	6057	0.023	0.78	0.67	0.00
South Carolina	64158	0.014	0.16	0.36	0.02
South Dakota	83305	0.008	0.02	0.00	0.00
Tennessee	85037	0.014	0.19	0.44	0.03
Texas	294142	0.015	0.27	0.54	0.02
Utah	40508	0.023	0.15	0.66	0.02
Vermont	14166	0.024	0.09	0.00	0.00
Virginia	68429	0.019	0.23	0.43	0.15
Washington	79428	0.013	0.22	0.60	0.19
West Virginia	35045	0.016	0.09	0.10	0.05
Wisconsin	110978	0.007	0.14	0.39	0.10
Wyoming	37642	0.024	0.06	0.00	0.00
Total	3904721				
Average	76563	0.017	0.24	0.39	0.07

4.6.3 Appendix 3: Long Run Marginal Costs by State

Table: Long Run Marginal Costs by State

State	LRMC-Auto ($/mi)	LRMC-Comb	LRMC-Sing	LRMC-Truck
Alabama	0.0168	0.0356	0.0220	0.0280
Alaska	0.0235	0.0311	0.4288	0.0528
Arizona	0.0201	0.0198	0.0422	0.0259
Arkansas	0.0183	0.0409	0.0179	0.0260
California	0.0109	0.0379	0.0748	0.0485
Colorado	0.0108	0.1082	0.0464	0.0680
Connecticut	0.0157	0.0540	0.0976	0.0674
Delaware	0.0173	0.0449	0.0796	0.0556
Dist. of Col.	0.0101	0.1942	1.3389	0.3126
Florida	0.0109	0.0379	0.0436	0.0402
Georgia	0.0132	0.0193	0.0266	0.0219
Hawaii	0.0110	0.0326	0.8676	0.0568
Idaho	0.0253	0.0215	0.0328	0.0254
Illinois	0.0154	0.0410	0.0387	0.0400
Indiana	0.0172	0.0340	0.0228	0.0279
Iowa	0.0188	0.0463	0.0205	0.0297
Kansas	0.0176	0.0276	0.0370	0.0311
Kentucky	0.0181	0.0229	0.0305	0.0257
Louisiana	0.0228	0.0271	0.0414	0.0320
Maine	0.0195	0.0262	0.0563	0.0343
Maryland	0.0171	0.0199	0.0677	0.0290
Massachusetts	0.0135	0.0489	0.0972	0.0627
Michigan	0.0158	0.0307	0.0563	0.0385
Minnesota	0.0123	0.0400	0.0531	0.0449
Mississippi	0.0157	0.0311	0.0235	0.0272
Missouri	0.0119	0.0331	0.0249	0.0289
Montana	0.0244	0.0240	0.0404	0.0292
Nebraska	0.0227	0.0275	0.0292	0.0282
Nevada	0.0072	0.1349	0.1037	0.1190
New Hampshire	0.0168	0.0264	0.1347	0.0410
New Jersey	0.0161	0.0351	0.0568	0.0422
New Mexico	0.0180	0.0394	0.0231	0.0300
New York	0.0167	0.0380	0.0655	0.0467
North Carolina	0.0112	0.0389	0.0199	0.0273
North Dakota	0.0199	0.0328	0.0435	0.0369
Ohio	0.0129	0.0399	0.0305	0.0351
Oklahoma	0.0160	0.0249	0.0353	0.0286
Oregon	0.0215	0.0224	0.0453	0.0289
Pennsylvania	0.0174	0.0373	0.0314	0.0344
Rhode Island	0.0202	0.0569	0.1016	0.0707
South Carolina	0.0122	0.0407	0.0229	0.0303
South Dakota	0.0167	0.0386	0.0566	0.0449
Tennessee	0.0134	0.0266	0.0250	0.0259
Texas	0.0126	0.0223	0.0315	0.0256
Utah	0.0151	0.0254	0.0420	0.0308
Vermont	0.0158	0.0427	0.1056	0.0581
Virginia	0.0128	0.0291	0.0397	0.0330
Washington	0.0168	0.0232	0.0722	0.0332
West Virginia	0.0177	0.0478	0.0328	0.0397
Wisconsin	0.0136	0.0451	0.0373	0.0413
Wyoming	0.0331	0.0281	0.0215	0.0247
Average of States	0.0165	0.0403	0.0968	0.0444

CHAPTER FIVE: AIR TRAVEL COSTS

The full cost (FC) of an intercity air trip will be composed of the airport costs including construction (ICC) and operation and maintenance of terminals and airside facilities (IOC), plus the cost of providing services by the air carrier (CC) plus the costs of providing air traffic control (ATC) and air navigation costs (ANS) by the FAA plus the social costs of air pollution (SPC), noise (SNC), congestion (SCC), accidents (SAC), and user time costs (UTC). This is represented below as:

$$FC = \alpha_1(ICC + IOC) + \alpha_2(ATC + ANS) + \alpha_3(CC) +$$
$$\alpha_4(SPC) + \alpha_5(SNC) + \alpha_6(SCC) + \alpha_7(SAC) + \alpha_8(UTC)$$

In this full cost measure the infrastructure costs, ATC and ANS costs, and carrier costs, commercial passengers are responsible for only a portion of the costs of providing the service. For example, airport infrastructure is used by cargo, General Aviation and military users and the costs attributable to these users should not necessarily be allocated to commercial passengers. In the full cost equation we have indicated the costs need to be weighted or apportioned among users. These weights are represented by the a_i's and the weights are not necessarily constant across cost components. From this stylized general relationship we provide measures of the short and long run average and marginal costs of intercity passengers trips by air.

5.1. Airway Infrastructure & Operating Costs

The FAA provides several user groups with essentially four services. these include air route traffic control centers, terminal radar control areas, air traffic control towers and flight service stations. In a study undertaken for the FAA (see Golaszewski (1987) and US Government 1987 and 1992) the unit costs of FAA services were estimated and an allocation among user groups was undertaken. The study differed from all previous approaches to cost measurement and allocation in that cross-sectional statistical cost functions were used to estimate the cost of providing specific services to specific classes of people by facility type. The major weakness of the study was the inability to include measures of capital costs, however, given the age of the airway system capital it is not clear that our estimates will be significantly biased. The reasoning is that with ‘vintage’ capital, the capital-labor ratio will be lower than with newer capital. Thus, what we miss in capital cost will show up in operating costs. Ideally, however, we would like to have an economic measure of annual capital costs included in the cost function.

Golaszewski (1987) provides a detailed description of the construction of the cost estimates for ATC services for four types of services/facilities; air route traffic control centers (ARTCC), terminal radar control areas (TRACON), air traffic control towers (ATCT) and flight service centers (FSS). These services are provided to different user groups or beneficiaries and these groups have further sub-categories based on differing criteria. These are illustrated in Table 5.1 with assigned cost allocations for two years (FAA, 1992).

Table 5.1: Allocation of Costs by Detailed User group

User Group	1985 Share	1991 Share	1991 Cost ($ M)
Air Carrier	60%	62%	$5,021
Domestic	42%	41%	$3,300
International	2%	2%	$189
Freight	2%	2%	$171
Commuter	14%	17%	$1,361
General Aviation	27%	26%	$2,143
Air Taxi	3%	3%	$216
Piston	13%	12%	$1,009
Turbine	10%	10%	$817
Rotorcraft	1%	1%	$101
Public Sector	13%	12%	$973
Civil Aviation	1%	1%	$47
Military	11%	10%	$871
Public Interest	1%	1%	$55

Source: US Government FAA Report 1992

Our interest is primarily in the domestic air carrier user group. This, of course, means that we need to determine what proportion of the costs are ‘attributable’ to this group. The detailed cost allocation, by detailed user group is contained in Table 5.2.[iii] These cost categories formed the basis of the ATC cost functions. However, ATC equipment and maintenance costs, R&D Expenditures and general overhead were not included in the variable cost estimates and allocated across users on a Ramsey pricing basis.[iii] As Golaszewski (1987) reports the major cost categories included were site labor costs, site maintenance costs and site communications costs. He also reports that the reason no capital costs were included was that the FAA expenses the capital cost in the year of purchase.

The marginal cost estimates are developed from calibrating several linear cost functions for each of the four categories identified above. The empirical results are not reproduced here only the tables which identify the marginal and unit cost measures. It is these measures which are aggregated in the full cost measure. The estimates are based on a series of calibrated linear cost functions which are estimated as statistical multiple-output cost functions. There are several weaknesses in these estimates including the failure to include input costs, a size measure to control for heteroskedasticity[iv] or a measure of traffic density.

Table 5.2: Cost Allocation by Detailed User Group and Expense Category

Category	Total	AC Dom	AC Int'l	AC Frt	AC Comm	Air taxi
Direct Cost-Public Interest	24.7	0.0	0.0	0.0	0.0	0.0
Navaid Maintenance	388.3	138.1	7.0	10.0	50.0	13.5
Safety Regulation	126.8	44.3	7.2	3.2	29.3	8.0
ARTCC	566.1	229.3	12.5	15.6	45.4	14.0
Towers	113.0	8.0	0.6	0.9	10.1	9.4
TRACONS	525.7	201.6	8.8	15.6	104.9	10.4
FSS	239.5	10.5	0.5	0.8	14.2	14.7
Total Operations	1984.1	632.1	31.5	46.1	254.0	70.0
Facilities & Equip	1358.0	671.4	34.3	47.9	215.4	27.6
R&D	265.0	158.0	7.9	11.4	56.1	2.4
AIP Grants	924.7	477.5	35.5	0.7	92.5	5.2
Total Dir Costs	4531.9	1939.0	109.2	106.1	617.8	105.2
Indirect Costs	703.7	237.0	12.0	16.8	95.2	26.5
Total Costs	5235.6	2176.0	121.2	122.8	713.0	131.7

Category	GA Pist	GA-Turb	Rotor	Civ-gov	Mil	Pub-int
Direct Cost-Pub Int	0.0	0.0	0.0	0.0	0.0	19.1
Navaid maint	42.7	41.7	6.3	2.9	76.1	0.0
Safety Regulation	16.1	13.9	2.1	1.0	6.6	0.0
ARTCC	35.1	86.9	0.0	3.1	123.8	0.0
Towers	42.5	14.2	8.4	2.4	16.6	0.0
TRACONS	79.4	12.8	7.2	2.1	83.1	0.0
FSS	137.6	20.4	10.5	3.1	27.3	0.0
Total Operations	353.5	189.8	34.5	14.6	339.1	19.1
Facilities & Equip	67.8	117.3	8.1	6.0	162.2	0.0
R&D	7.9	8.6	0.9	0.5	11.3	0.0
AIP Grants	164.0	129.1	6.8	4.0	9.5	0.0
Total Dir Costs	593.1	444.9	50.3	25.1	522.0	19.0
Indirect Costs	89.8	75.2	13.5	5.7	125.8	6.1
Total Costs	682.9	520.1	63.8	30.7	647.8	25.2

Source: US Government FAA Report 1986; note: (1985 $M)

Tables 5.3, 5.4 and 5.5 report the cost calculations estimated by Golaszewski (1987. Where necessary we have adjusted the dollar magnitudes to 1994 $'s and these are clearly indicated in the table. In Table 5.3 marginal, joint and total costs are provided for four user groups. Only the values for 'air carrier' will enter our calculations. The 'marginal cost' calculation would be used in the calculation of short run marginal costs while the total variable costs would be used in the unit cost calculation.

Table 5.3: ATC: Marginal and Joint Costs by Facility and User Group

Facility Type	Air Carrier ($1994 M)	Commuter	General Aviation	Military
ARTCC Marginal Costs	$297.64	$38.1	$119.4	$103.8
ARTCC Joint Costs	$57.30	$7.3	$19.4	$20.0
ARTCC Total Variable Costs	$354.94	$45.4	$139.0	$123.8
FSS Marginal Costs	$13.64	$12.0	$167.6	$22.9
FSS Joint Costs	$2.62	$2.3	$18.6	$4.3
FSS Total Variable Costs	$16.25	$14.2	$186.2	$27.3
TRACON Marginal Costs	$206.32	$69.6	$87.5	$55.1
TRACON Joint Costs	$104.952	$35.4	$24.3	$28.0
TRACON Total Variable Costs	$311.280	$105.0	$111.8	$83.1
ACTCC Marginal Costs	$2.89	$2.3	$33.7	$3.7
ACTC Joint Costs	$10.05	$7.8	$43.0	$12.8
ACTC Total Variable Costs	$12.95	$10.1	$76.7	$16.6
Marginal Cost Proportion	74.9%	69.8%	79.5%	74.0%

Source: Golaszewski (1987); note: (1985 $M) (except air carriers, 1994 $M)

Table 5.4: Development of ATC System Costs

Cost Category	Air Carrier ($1994 M)	Commuter	General Aviation	Military
Site Marginal Costs	$377.9	$122.0	$408.2	$185.5
Site Joint Costs	$127.0	$52.8	$105.5	$65.1
ATC equipment maintenance	$155.0	$50.0	$107.1	$76.1
not allocated to Sites				
Facilities & Equipment	$753.6	$215.3	$226.8	$150.8
Research & Development	$177.3	$56.1	$20.3	$11.8
General Overhead	$239.0	$82.0	$185.2	$121.3
Estimated ATC System Costs	$1,829.8	$578.2	$1,053.1	$610.1
Marginal Costs % of Total Costs	20.7%	21.1%	38.8%	30.4%
Total Cost Factor	4.83	4.74	2.58	3.29

Source: Golaszewski (1987); note: (1985 $M) (except air carriers, 1994 $M)

In the calculations of the long run costs we use the values contained in Table 5.5. These values have been increased to ensure all costs are covered and are equivalent to an assumption of constant long run average and marginal costs

Table 5.5: Approximate Unit Total Costs of ATC Services

Facility Type	Output Type	Air Carrier ($1994 M)	Commuter	General Aviation	Military
ARTCC	IFR Departure	$185.33	$132.06	$65.17	$140.15
	Over	$92.67	$66.02	$32.59	$70.08
TRACON	Operation, Second	$85.15	$60.67	$8.88	$42.11
	& Over				
ACTC	Operation	$52.63	$8.82	$3.72	$14.64
FSS	Pilot brief	$45.63	$32.52	$17.70	$22.57
	IFR Flight Plan	$45.63	$32.52	$17.70	$22.57
	VFR Flight Plan	$91.00	$64.84	$35.29	$45.00
	Air Contact	$25.74	$18.34	$9.98	$12.73

Source: Golaszewski (1987); note: (1985 $M) (except air carriers, 1994 $M)

5.2. Airport Infrastructure & Operating Costs

The costs of using the airport resources can be divided into terminal costs and airside costs. The reason for dividing the two is that terminals are used by passengers and the costs are wholly attributable to commercial air services while the airside resources are a function of aircraft movements. Aircraft movements include scheduled commercial, commuter, general aviation, and military. Furthermore, the majority of aircraft also carry freight (cargo and mail) in their belly. We, therefore, have joint product and some portion of airside costs may be attributable to non-passenger outputs. As in the case of airway cost calculations we cannot allocate all of the airside costs to scheduled commercial [passenger] air services. In order to determine the appropriate allocation we estimate economic cost functions in which the airside costs are regressed on each type of movement. The second distinction we make, as elsewhere, is short versus long run costs. In the former we treat existing infrastructure as non-congested and provide an estimate of servicing an additional passenger or additional movement. In the long run estimates we include a measure of the capital costs and thus the marginal and average cost figures are those associated with expansion of the airside (or terminal) system when additions to capacity must take place.

5.2.1 Terminal Costs

Our estimates of terminal costs were developed from data from twenty two large airports with each airport having data for a five year period. The total number of observations was, therefore, 110. We also had the added benefit of using a panel which reduces the problems associated with either exclusive time series or cross-sectional data.

Tables 5.6 and 5.7 present the final estimates. Alternative functional forms as well as the inclusion of dummy variables for some airports were included in the estimations but were insignificant in the final outcome. The simple arithmetic relationship had the best statistical fit. In table 5.6 the constant term is significant, indicating the presence of fixed costs and the parameter estimates on the linear and second order term are both statistically significant at the 5 percent level. The results indicate that short run marginal costs are rising at a relatively constant rate; the second order coefficient is non-significant. The marginal cost per passenger is $1.62 while the average cost per passenger would be (924358/#passengers) + $1.62. Since marginal is less than average cost it implies there are some cost economies with increasing passengers. Interestingly, the calculated average variable cost per passenger was $4.25.

Table 5.6: Terminal Short Run Cost Relationship

Dependent variable:	Terminal O&M Costs
Mean of dependent variable	.133472E+07
Adjusted R-squared	.934831
F-statistic (zero slopes)	173.137
Log of likelihood function	-376.417

Variable	Estimated Coefficient	Standard Error	t-statistic
C	924358.	294210.	3.14183
PAX	1.63558	.532615	3.07085
PAXSQ	.365951E-06	.131151E-06	1.79029

The long run cost relationship is illustrated in Table 5.7 in which total costs, capital plus operating costs, were regressed on values for passengers.[v] Again the model which had the best statistical fit was the simple linear model. In our estimates neither the second order term nor the constant term were statistically significant. At the sample mean the long run marginal cost per passenger is equal to the long run average cost per passenger. The estimates of the long run cost are $5.72 per passenger. Simple averages taken from the sample, total costs divided by the number of passengers was $7.45 per passenger.

We also undertook a simple examination of the composite airport costs, airside plus terminal. The simple averages were; $5.99 AVC per passenger and $201.99 per movement. These are numbers which are used frequently when illustrating differences between air and other modal costs. However, these numbers are biased in that they reflect composite outputs and have not taken into consideration full cost responsibility across outputs for terminals and airside facilities.

How do these numbers compare with previous estimates? There are relatively few investigations against which to compare our work. In 1979, Morrison, reported estimates which he had developed during his thesis work.[vi] The values he calculated were for airside facilities only. He estimated the [short run] marginal cost of an air carrier operation was $12.34 when this is expressed in 1994 dollars, the figure is $25.34. This figure would be compared against our cost per movement which we develop below. The only other study we have found was undertaken by the Royal Commission on National Passenger Transportation in Canada in the period 1990-1993. In their report, *Directions*, they used an engineering approach to develop a measure of $14.00 CAN per passenger for terminal services. This figure in 1994 US $'s is $10.24. This would be comparable to our measure of $5.72 per passenger.

Table 5. 7: Terminal Long Run Cost Relationship

Dependent variable:	TOTCST
Mean of dependent variable	.7452284E+07
Adjusted R-squared	.820163
F-statistic (zero slopes)	55.7271
Log of likelihood function	-366.985

Variable	Estimated Coefficient	Standard Error	t-statistic
C	118849.	201747.	.589101
PAX	5.72460	.365227	4.72199
PAXSQ	-.139461E-06	.899338E-07	-1.55071

5.2.2 Airside Costs

We undertook a similar analysis for estimates of airside costs. In this case we wanted to be able to both establish a measure of the appropriate short and long run costs but also an allocation of costs across the different user groups. The estimates were developed from our sample of 22 airports. As before we estimated parameters on the basis of a ‘variable’ cost model in which capital [capacity] is considered a quasi-fixed factor of production and the adjustments to output are made using the variable factors, hence variable costs. In a subsequent model we used measures of total cost, capital plus operating, and estimated the long run cost relationships.

Table 5.8 reports our estimates for the short run model. Total operating and maintenance costs was regressed on numbers of movements for scheduled air carrier, commuter and general aviation (Total IFR & VFR) as well as airport specific dummy variables. We also investigated second order terms but they were not statistically significant. The simple linear model seemed to perform as good or better than any other. The short run marginal cost of a scheduled air carrier movement is $81.87, for a commuter carrier it is $17.87 and for general aviation it is $12.57. Using the data from the US airports the measured simple average variable cost is $43.66 per movement; not distinguishing between general aviation, commuter and air carriers. Figures from Morrison’s study (1979) is $12.34 (in 1975 dollars), when this is expressed in 1994 dollars, the figure is $25.34..

Table 5.9 reports the long run cost measures. The estimates used the sum of capital and operating costs and undertook a similar costing exercise as we did with the short run cost estimates. The long run marginal and average (since the constant term is not significant) cost air carriers is $117.11, for commuters is $22.43 and for general aviation $17.08. For the latter two user groups there is a relatively small increase in the marginal cost from the short run estimates. It is also evident from the estimates that, like Morrison, we find evidence of constant returns to scale. This means that size does not confer an advantage nor disadvantage on the costs of airside facilities. However, this is not true in the case of terminals where we find some evidence of falling costs with capacity utilization. Interestingly, when one calculates the simple average total cost we obtain a figure of $93.84.

Table 5.8: Estimates of Short Run Airside Costs

Dependent variable:	OMCOSTS
R-squared	.884481
Adjusted R-squared	.855601
F-statistic (zero slopes)	30.6263
Log of likelihood function	-297.413

Variable	Estimated Coefficient	Standard Error	t-statistic
C	-297116.	288657.	-1.02
SCHED	81.87	19.8017	4.13
COMMUT	17.57	4.22907	4.16
TOTGA	12.49	5.09142	2.45

Table 5.9: Estimates of Long Run Airside Costs

Dependent variable:	TOTCSTS
R-squared	.873691
Adjusted R-squared	.842114
F-statistic (zero slopes)	27.6684
Log of likelihood function	-311.927

Variable	Estimated Coefficient	Standard Error	t-statistic
C	-271559.	576163.	-.471
SCHED	117.1058	39.5245	2.963
COMMUT	22.43706	8.44128	2.658
TOTGA	17.0825	10.1625	1.681

5.3. Carrier Costs

There are two approaches we might take in constructing our carrier cost function. One is to estimate an econometric cost function in which outputs, input prices and levels of technology are contained in the cost function derived from some underlying production function and the optimizing behavior of firms (see Gillen, D, T. Oum and M. Tretheway, 1985 for an example). This aggregate approach is useful for understanding the characteristics of the underlying production structure, input substitution, scale and scope economies and cost efficiency. These measures are important in long term decision-making regarding mergers, network structure and size and input substitution. However, it is too aggregate for our purposes. We take the system as given and wish to understand what the cost would be to add another passenger (or flight) to the segment in an existing network. These measures can be directly related to pricing decisions. We proceed to estimate a statistical cost function in which we distinguish the additional costs of carrying another passenger when flight capacity must and need not be expanded.

In the carrier cost model the basic unit of the cost analysis is the flight segment. In describing the carrier's cost we distinguish costs which vary by segment and those which vary by route. In many cases the source of the difference in costs will be in the airline system or station (airport costs). For example, if carrier J were to extend its operation from point B to point C, in an AB market, the additional costs would be increased by the flight operating costs and some passenger costs but since it was already using the airport at B, the cost of adding operations from this station may be relatively small.

The cost analysis has two objectives in this research. First, it provides information about marginal cost per passenger which influences price (passenger fare = cost plus markup). Second, it provides total cost of flight segment which is used to compute profit for specific carrier-segment combination.

5.3.1 Measurement of Fareclass

Since costs are different between fareclasses, it is necessary to estimate the cost of each fareclass by carrier and by flight segment. However, in the long run carriers allocate total usable space in a plane between fareclasses (First, Business and Economy seats) in such a way to equalize the marginal revenues per square foot for all fare categories. Therefore, given knowledge of the physical space required to put a seat of each class and the optimal load factors for each fare class, it is possible to convert passengers of all classes into a scaler (standard class equivalent) for costing purpose. For example, for a carrier-segment combination (henceforth referred to simply as 'segment') the passenger volume can be scalarized as:

(5. 3.1) $$Y = a_1 Y + a_2 Y_2 + a_3 Y_3$$

where Y is the total passenger volume (standard class equivalent), Y_i is number of *ith* fareclass passengers, and a_i is the conversion factor for *ith* fareclass to the standard fare class equivalent. The sizes of a_1 and a_2 can be determined by the procedure explained in Oum, Gillen and Noble (1985).[vii] The unit cost of Y_1 is a_1 times the unit cost of Y. In the remainder of this note we represent the multiple fareclasses as a single class of service.

In order to compute a carrier's total cost on a segment, say S, it is necessary to identify the total traffic volume using that segment by aggregating all O-D traffic traveling via segment S as follows:

(5. 3.2) $$Y^S = \sum_{OD} \sum_{r \in S} q_r^{OD}$$

where Y^S is the total traffic volume on segment S, and q_r^{OD} is the O-D demand volume choosing route r and is computed from the demand model.

5.3.2 Measurement of Segment Cost

The segment cost has two components: the costs which vary with passengers and flights, and those which remain unchanged. The latter consists of some portion of airport costs and the indirect costs of the carrier to be allocated to the segment. Therefore, the segment cost (C) can be written as:

(5. 3.3) $$C = A_s + C^s(Y, F)$$

where:

A_s = segment cost which does not vary with passenger volume (Y) or flight frequency (F),

$C^s(Y, F)$ = segment cost which varies with Y and F.

Two simply alternative specifications for the segment cost function are represented in equations 5.3.4 and 5.3.5.

(5. 3.4) $$C(\bullet) = A_s + b_1 Y + b_2 F + b_3 Y F$$

(5. 3.5) $$C(\bullet) = a\ Y^{b1}\ F^{b2}$$

The <u>total variable cost</u> of segment S, $c^s(Y, F)$, consists of two components: the costs related to operating aircraft, and the costs associated with passenger handling at the airports and a portion of indirect and administration costs related to number of passengers and flight frequency.[viii]

The cost associated with operating aircraft on a segment (henceforth referred to as flying operations cost (FOC) . FOC can be measured by adding the cost per block hour multiplied by the number of block hours required for the flight segment:

(5. 3.6) $FOC_s = B_s \bullet H_s \bullet f(Y_s)$

where:

B_s is cost per block hour for the aircraft used,

H_s are the block hours required for segment S, and

$f(Y_s)$ is flight frequency which depends on number of passengers on segment, Y_s .

The indirect and administration costs related to a particular segment can be computed via the following procedure.

Collect data for total indirect cost (IC) for a set of U.S. airlines from Form 41 data and transform it in the following way:

IC = total operating expenses

= flying operations costs + maintenance costs+ depreciation and amortization

Regress IC on the following variables:

(5. 3.7)
$$IC = I(Y, RPK, F, S, W, D) = a + c_1 Y + c_2 RPK + c_3 F + c_4 S + c_5 W + c_{13} YF + c_{15} YW + c_{45} (S . W) + \sum c_{fi} D_i$$

where:

Y is firm's total number of passenger enplanements,

RPK is total revenue-passenger-kilometers (or RPM),

F is the total number of revenue flight departures performed,

S is the number of route segments served,

W is input price index, and

D are firm dummy variables.

Evaluate the following expression in order to calculate incremental indirect cost of adding a route segment s:

$$\Delta IC = I(Y + \Delta Y, RPK + \Delta RPK, F + \Delta F, S+1, W, D)$$

(5. 3.8) I (Y, RPK, F, S, W, D)

The segment total cost function in (5.3) can now be obtained by adding equations (5.3.6) and (5.3.8).

(5. 3.9) $C(Y_s, f_s) = FOC_s + \Delta IC = [1 + \{(L / L_B) - 1\}] B_B H_s f(Y_s) + \Delta IC$

Using information from the FORM 41 data for a set of eight major US carriers we estimated short and long run cost functions. The short run cost takes the existing capital stock of a carrier as given and estimate the marginal cost of adding a passenger, evaluated on the average. This is akin to the variable cost function estimates obtained in Gillen, Oum and Tretheway, 1992). The long run cost function estimation treated the capital costs as fully variable and the marginal cost estimates include variation in flight capital.

Table 5.3.1 reports the block-hour costs for each type of aircraft which would be most likely used on domestic [California] routes. To this figure we need to add an amount which reflects the opportunity cost of the flight capital. The difference between these two figures is the difference between short and long run costs. In the table we have selected four representative aircraft. In the calculations we use an assumed load factor of 68% (Aviation Daily, 1995) and use in the calculations the values for the B737-300 series aircraft since this is the most popular on shorter haul domestic routes in California.

Table 5.10 Dollars per Block Hour (1995)

	B737-300	B737-400	B737-500	MD-80
Crew Cost	456	554	267	506
Fuel & oil	425	428	403	484
Rentals	423	585	319	310
Insurance	11	19	12	11
Taxes	17	20	23	22
Total Flying Operations	1332	1608	1024	1333
Airframe Maintenance	157	126	114	136
Engine Maintenance	116	54	60	74
Maintenance Burden	153	135	162	119
Total Maintenance	426	315	336	329
Depreciation	92	84	118	130
Other	22	10	34	34
Total Block Hour Cost	1872	2018	1512	1826
Avg Seats per Flight	131	144	112	139
Avg Stage Length	572	662	565	775
Op Cst per ASM (¢)	4.11	3.98	3.9	3.64
Price of Aircraft ($ M)	27.9	31.6	26.8	27.5

Source: Aviation Daily (1995), Aircraft prices from Air Finance Journal (June 1994).

Table 5.11: Cost of Aircraft Capital

	B737-300	B737-400	B737-500	MD-80
Price of Aircraft ($ M)	27.9	31.6	26.8	27.5
Annual Opportunity Cost of Capital at 7.5 percent	$2,092,500.00	$2,370,000.00	$2,010,000.00	$2,062,500.00
Total Block Hours	3759.5	3759.5	3759.5	3759.5
Opportunity Cost per Block Hour	$ 556.59	$ 630.40	$ 534.65	$ 548.61
Cost per Seat mile ($'s)	$ 0.008	$ 0.009	$ 0.008	$ 0.008

The short run average and marginal cost is equal to the block hour cost x average load factor x (stage length/velocity). The long run average and marginal cost would include the short run values plus the cost of aircraft capital.

5.4. Social Costs

There are four types of externalities which must be included in the full cost measure of air transportation. These include noise, congestion delay, accident costs and air pollution externalities. these measures have been calculated in chapter 3 and are reproduced here for completeness.

5.4.1 Noise Costs

The valuation of the noise externality is based on a survey of international results, described in Chapter 3, which gives us a value of $0.0043/pkt.

5.4.2 Congestion Delay Costs

For airport delay the average delay equation is simply the average cost in units of minutes, as a function of operations and capacity (annual service volume), as discussed in Chapter 3:

$$ACat = 0.19 + 2.33 (Q_a/Q_{ao})^6$$

where:

Q_a is the actual volume and

Q_{ao} is the annual service volume or airside capacity of the airport.

Annual Service Volume (ASV) is calculated from an FAA model that takes into consideration the airport's aircraft mix index, runway layout, percentage of time runways are used in a specific operating condition (e.g., northeast parallels in IFR weather), hourly runway capacity under that condition, and historic monthly traffic records.

A question naturally arises as to the validity of a capacity model that has some airports regularly operating at levels substantially above their theoretical limit (La Guardia and Chicago O'hare, for example). Rather than try to defend the accuracy of the modeled capacities, we think that the resulting ASVs can be used to index airports by taking into account their differing physical, climatelogical, and operating conditions.

The total cost is simply the average cost per unit multiplied by the number of units.

$$\text{Total delay Cost} = \text{Average delay Cost} * Q_a = 0.19\ Qa + 2.33\ (Qa/Qao)^7$$

The marginal is thus:

Marginal Social Cost= $\partial TCa/\partial Qa = 0.19 + 16.31\ (Q_a/Q_{ao})^6$

To operationalize this measure we used information from the series of airports which were included in the estimation of the airport costs. Each airport has annual service volume [ASV] figure and we used the average ASV across this panel. The average delay per flight is approximately 6.5 minutes. The total delay costs would then be calculated as 6.5 x number of passengers x value of time. With a $10/hr value of time this figure is $1.08.

5.4.3 Accident Costs

The air mode has been and continues to be the safest of the existing modes of transportation for intercity travel. The accident costs are therefore relatively small in comparison to other modes. If, for large airlines we have 0.0008 fatal accidents per million aircraft miles, an average number of passengers per flight of 100, an average of 13 deaths per fatal crash, and a value of life of $2.4 million, the cost for accidents on large aircraft can be calculated as $0.00025/PMT or ($0.00042/ PKT) . Taking more conservative values of life and including non-life costs (injury and medical, accident cleanup, etc.), and assuming a higher number of fatalities could quadruple the estimate to $0.001/PMT ($0.0017/ PKT) were PMT is passenger miles traveled and PKT is passenger kilometers traveled of travel.

5.4.4 Pollution Costs

The cost of air pollution caused by air travel (basically the health damages from particulates, sulfur oxides, hydrocarbons, carbon monoxide, and nitrogen oxides, plus the greenhouse damages due to carbon) is $0.00087/pkt, as developed in Chaper 3.

5.5. Composite Costs

The total cost of air travel can now be summarized and summed by including all of values calculated above. Table 5.12 provides the full range of cost estimates, their units of measurement and any distinctions between short and long run values as well as differences in marginal and average values. In most cases there is little difference between marginal and average but there are differences in the short and long run. Once a stage length and aircraft are selected the values in this table can be used to obtain the full costs of air travel. Table 5.13 summarizes this by passenger kilameter of travel.

Table 5.12: Full Costs of Intercity Air Travel

		Short Run		Long Run	
	Units	Marginal Cost	Average Cost	Marginal Cost	Average Cost
Airways System					
ARTCC	IFR Departure	$185.33	$185.33	$185.33	$185.33
TRACON	per Operation	$85.15	$85.15	$85.15	$85.15
ACTC	per Operation	$52.63	$52.63	$52.63	$52.63
FSS	IFR Flight Plan	$45.63	$45.63	$45.63	$45.63
	per Air Contact	$25.74	$25.74	$25.74	$25.74
Airport Infrastructure					
Terminal Costs	per pax	$1.62	$1.62	$5.72	$5.72
Airside Costs	per movement	$81.87	$81.87	$117.11	$117.11
Carrier Costs					
Block Hour Costs	block-hour	$1,872.00	$1,872.00	$1,872.00	$1,872.00
Seats (assume 131)	per seat	$14.29	$14.29	$14.29	$14.29
Op Cost per ASK	per ASK	$ 0.03	$ 0.03	$ 0.03	$ 0.03
Load Factor (assumed 68%)	per RPK	$0.04	$0.04	$0.04	$0.04
Indirect Costs	per RPK	$ 0.06	$ 0.06	$ 0.06	$ 0.06
Capital Costs	per ASK	$ -	$ -	$0.01	$0.01
Social Costs					
Noise	per pax-km	$0.0043	$0.0043	$0.0043	$0.0043
Congestion	per pax	$1.083	$1.083	$1.083	$1.083
Accidents	per pax-km	$ 0.00042	$ 0.00042	$ 0.00042	$ 0.00042
Pollution	per pax-km	$ 0.00087	$ 0.00087	$ 0.00087	$ 0.00087
User Time Costs ($10/hr)	per kilometer	$ 0.0114	$ 0.0114	$ 0.0114	$ 0.0114
	(at 877 KPH)				

Table 5.13: Long Run Average Cost of Air in California Corridor

Cost Category	Average Cost
Infrastructure: Airways (ARTCC)	$0.0034
Infrastructure: Airways (TRACON)	$0.0015
Infrastructure: Airways (ACTC)	$0.0009
Infrastructure: Airways (FSS)	$0.0008
Infrastructure: Airport Terminal	$0.0094
Infrastructure: Airport Airside	$0.0022
Carrier: Capital Cost (Planes)	$0.0606
Carrier: Operating Cost (airline operations)	$0.0340
External: Accidents	$0.0004
External: Congestion	$0.0017
External: Noise	$0.0043
External: Pollution	$0.0009
User: Time	$0.0114
Total Cost by Air	$0.1315

note: $/pkt

Table 5.13 gives summary results of the full cost of air travel per passenger kilometer for the California corridor. These costs, $79 for the trip from San Francisco to Los Angeles, are in line with fares in the corridor, currently $59, (and since the cost estimates include social costs and user time costs, they are expected to be higher than the fares, which only reflect cost to carriers, including the fleet and air system charges), and are less than high speed rail and highway travel, as expected.

[i]

[ii] Operating Site costs include labor, maintenance and leased communication cost at ARTCC, FSS, Towers and TRACON's. Facilities and Equipment costs include capital expenditures to replace or improve airport and airway facilities and equipment. R&D include expenditures made by FAA on R&D programs to build and maintain a 'safe efficient airport and airway system'. Airport Grants include development grants made to sponsors of primary, commercial services, reliever and GA airports. Navaid Maintenance and Regulatory costs are those incurred by the FAA in providing and maintaining navigational equipment NOT located at operating sites and of regulating airmen, aircraft operations and manufacturing and airports. Overhead costs included those for headquarters, regional administration and procurement.

[iii] The Ramsey method uses the inverse of the elasticity of demand for facility use to allocated overheads to obtain economically efficient prices.

[iv] The use of weighted least squares would be appropriate in the estimations but it is not clear from the discussion whether anything beyond OLS was employed.

[v] We were not able to distinguish between domestic and international passengers. One would expect that airports with greater proportions of international passengers would have higher costs.

[vi] See S. Morrison (1979), Optimal Pricing and Investment Policies for Airport Landing Areas (unpublished Ph.D. dissertation, department of Economics, University of California, Berkeley)

[1] See T. Oum, D. Gillen and D. Noble, "Demands for Fareclasses and Pricing in Airline Markets" Logistics and Transportation Review, Vol. 23, (1986)

[2]. The aircraft cost can be measured by adding the cost per block hour multiplied by the number of block hours required for the flight segment and a portion of the indirect airline costs which are attributable flight frequency (more on this later). Note that the block-hour costs need to be adjusted upward by the amount of interest cost on the capital tied up in aircraft. It appears that the cost per block hour available in Form 41 data includes only the aircraft rentals paid for leased aircraft, and does not appear to include the interest cost on the owned aircraft.

CHAPTER SIX: HIGH SPEED RAIL

6.1. Infrastructure Costs

The 677 km Los Angeles-San Francisco high speed line would link Union Station in downtown Los Angeles to a new Transbay Terminal in downtown San Francisco. While the exact alignment for the route is under study, one alignment, shown in Figure 6.1, was selected for analysis. This route runs through Palmdale, the Tehachapi mountains, the Central Valley, serving Bakersfield and Fresno, the Pacheco Pass and the Santa Clara Valley, serving San Jose and the San Francisco Peninsula.

The cost of building the new infrastructure has been estimated to $9.6 billion as shown in Table 6.1 using methodology outlined in Leavitt et al (1992a). Briefly, the methodology estimates for each segment the detailed cost of earthworks, structures, buildings, rail, power and signals, and right-of-way. While the cost per kilometer through the Central Valley is less that $6 million, construction costs through the urban segments and mountain passes are significantly higher, averaging $19 to $30 million per km (Leavitt et al., 1994). The average cost for the Los Angeles-San Francisco new high speed line is $14 million per km. Assuming an opportunity cost of capital of 7.5%, the annual capital cost of the alignment is $719.8 million (or just over $1 million per km).

Table 6. 1: Los Angeles-San Francisco High Speed Line Infrastructure Cost

SEGMENT	Distance (km)	Cost (US $)	Cost per km (US $)	Travel Time (min)	Travel Speed (kph)
Los Angeles Basin	38.8	$ 742,000,000	$19,100,000	17.2	135
Techachapi Mnt. via Palmdale	136.2	$2,760,000,000	$20,260,000	27.6	296
Central Valley	324.7	$2,010,000,000	$ 6,190,000	61.5	317
Pacheco Pass-Gilroy	53.8	$1,590,000,000	$29,550,000	10.3	313
Gilroy-San Jose	45.9	$ 531,000,000	$11,570,000	18.0	153
San Jose-San Francisco	77.6	$1,964,000,000	$25,310,000	38.5	121
Total	677.0	$9,597,000,000	$14,180,000	173.1	234

Source : Leavitt et al (IURD #612) 1994, Table 3.1.3 p.74 (Central Valley Route Alternative)

Note: Central Valley includes cost for 41-km Fresno Loop.

To compare the California numbers with high speed lines built or to be built in France, Table 6.2 shows the average infrastructure cost per mile for the South-East, Atlantic, Mediterranean and East TGVs. The infrastructure costs on a per mile basis for the South-East TGV and the Atlantic TGV are comparable to, though lower than, the estimated per mile cost of the high speed line in California's Central Valley. Construction costs for the Mediterranean TGV and the East TGV are closer to the average cost per mile of the Los Angeles-San Francisco line including the urban segments and mountain passes. Aside from the general differences in land and construction costs, there has been inflation over time between the dates when the French and California systems are constructed. Like California, the higher cost of the Mediterranean TGV and East TGV is due to their more urbanized or mountainous areas.

Table 6. 2: French TGV Infrastructure Costs

ROUTE	Distance (km)	Cost (US $)	Cost Per km (US $)
South-East	1004	$ 2,058,000,000	$2,049,000
Atlantic	726	$1,724,000,000	$2,375,000
Mediterranean	800	$4,047,000,000	$ 5,058,000
East	1080	$4,371,000,000	$4,047,000
Total	3610	$12,200,000,000	$3,380,000

Source : SNCF, Note: in Millions of 1994 US Dollars

The average infrastructure cost per passenger is simply the annual capital cost divided by the number of passengers, and thus declines with increases in passengers. Estimates of the number of passengers vary, being determined simultaneously with the service level provided, as well as the fares. The method for forecasting which provides the results reported here is based on growing existing air and highway ridership to the year 2010, and then apportioning the demand to the new mode of high speed rail based on a logit mode choice model.

Table 6. 3: Annual 2010 HSR Ridership, Distance, and Fares

Market Segment	Ridership	Distance (km)	Passenger-km	Fares ($ U.S.)
Northern California - Southern California	7,648,000	677	5,177,696,000	$56
Fresno - Northern California	326,000	291	94,866,000	30
Fresno - Southern California	635,000	386	245,110,000	30
Bakersfield - Northern California	121,000	462	55,902,000	40
Bakersfield - Southern California	371,000	215	79,765,000	25
Total	10,555,000		5,653,339,000	

Source: Leavitt et all 1993 (IURD #609) Tables 2.2, 4.1

Note: One-way fares, distances, trips per year

The key variables are travel time, service frequency, and fares to be competitive with air travel, as shown in Table 6.3, results in forecasts ranging to 5.6 billion passenger - kilometers for the mainline (Leavitt et al 1993). Dividing the total infrastructure cost estimate of $719.8 million per year by the estimate of 5.6 billion passenger - kilometers per year, gives an estimate of the capital cost of infrastructure of $0.129/pkt.

6.2. Carrier Costs

Our model for estimating carrier costs is divided into two components. The first is the operating cost, and second is carrier capital cost. Due to the absence of data on high speed rail operating costs in the United States, carrier operating and vehicle costs from the French TGV were used as a baseline. The number of operating units (trains) required depends on the amount and pattern of demand. A train use simulation model, SIMEX, developed for the French Railway, and a model which allocates demand temporally across the day and week (MATISSE), were extended and applied to the California corridor.

6.2.1 Simulating The Number Of Operating Units

In order to estimate the total operating cost of the Los Angeles-San Francisco high-speed rail system, the number of train-kilometers and trainset-kilometers as well as the number of train-hours and trainset-hours must be calculated. *A priori*, those quantities cannot be expressed by a simple algebraic function of the level of travel demand since they depend upon numerous factors such as the fluctuations of the demand within the day and the week for every origin-destination (OD) considered in the studied network as well as the schedules, the capacity of the trainsets and the stopping pattern (the sequence of stations served by a same train) of the different services. SIMEX, designed by the French Railroad, is a simulation program which translates from the level of travel demand to the number of train(set) -kilometers and train(set) -hours. SIMEX enables one to measure and optimize operating cost for a given set of OD markets, providing a very detailed estimate of the operating cost and the number of trainsets required to supply services. It also provides the optimal train schedules and the expected mean load factor and revenue for each train.

In the SIMEX simulation program, the travel demand by time of day is previously estimated. The model requires estimates of passengers' time targets within the day as well as the variation of the total demand within the week. SIMEX considers four time target distributions depending on the travel time of the OD market being, based on the actual fluctuations of the demand observed for four French domestic OD markets: Paris-Le Mans (50 minutes), Paris-Lyon (2 hours), Paris-Bordeaux (3 hours) and Paris-Marseilles (4 hours and 40 minutes). Those distributions vary whether the program is run for a random weekday or a weekly peak day (such as Friday evening or Sunday evening). The time target distributions are expressed in terms of hourly percentage of the daily demand. Every OD market is characterized by a travel time and the corresponding time target distribution.

Obviously, supply characteristics affect the travel demand. Thus, the optimal supply proposed by SIMEX must be consistent with the volume of travel demand on which the simulation is based. An algorithm, in which the model for temporal allocation of demand (a variation of the French MATISSE model) and the SIMEX simulation program are sequentially used, is run until the optimal supply proposed by SIMEX corresponds to the level of demand during that time of day predicted by MATISSE. The simulation program developed for the Californian corridor is based on a similar approach, using Calspeed travel demand estimates, summarized in Table 6.3.

For the model we have defined two classes of train service: non-stop and local. Non-stop service connects the primary market Los Angeles and San Francisco, while local service connects those cities along with the secondary market of trips from and to Bakersfield, Fresno and San Jose. The travel time between Los Angeles and San Francisco is 2 hours and 53 minutes according to Table 6.1. Every station is characterized by a 10 minute stopping time, which exceeds the actual time the train stops at the station in order to take into account the delay due to deceleration and re-acceleration. Assuming three stops, the Los Angeles-San Francisco local train travel time is 3 hours and 23 minutes.

We assume the trainsets used for the Los Angeles-San Francisco high speed line to have 350 seats. However, the design for the system on average assumes some slack to allow for peaking, for instance seasonal variation in demand, and also must accommodate the day to day random variance. Therefore the design factor load on a segment must be less than 90% of maximum capacity so that the number of available seats will be high enough to take into account the normal daily fluctuations of demand. Finally, the mean daily factor load for both local and non-stop services must be greater than 65% of maximum capacity.

The modeling process consists of several components. The first is the estimation of service attractiveness, then non-stop and local services are scheduled respectively.

6.2.1.1 Service Attractiveness

The measure of service attractiveness compares local and non-stop trains for individuals with a choice between the two. For instance, an individual with a desired departure time between a local and a non-stop train will compare the schedule delay against the longer travel time of a local train.

A passenger traveling between Los Angeles and San Francisco will choose the local if it provides the lowest total travel time, taking into account the frequency delay. Therefore, a passenger whose time target is S will choose the local train if :

(6. 2.1) $$TT_{ns} + \delta(A/2 + x(S)) \geq TT_{loc} + \delta(A/2 - x(S))$$

where :

TT_{loc} = local service travel time

TT_{ns} = non-stop service travel time

d = frequency delay weighting coefficient.

S = time target

A = average time between two services (It is assumed that A is greater than $\Delta TT / \delta$)

x(S) = time between clock time of previous train + A/2, and desired clock time target (S).

Thus for every moment on the clock which an individual might have as his time target, that individual will have to choose the previous or next train. If the trains are both non-stop or both local, the choice is simply the train nearest the time target (assuming indifference to arriving early or late), however if one is non-stop and one is local, the choice becomes more complicated.

Given a choice between two local trains (1 and 2), a passenger will choose local 1 rather than local 2 if his time target is closer to the time of departure of local 1. The average period of time during which local 1 is expected to attract passengers can be localed as :

(6. 2.2) $$\Pi = A - \Delta TT / 2\delta.$$

In the case where the choice is between a non-stop and a local train, the period of time which the local train dominates is given by:

(6. 2.3) $$\Pi = A - \Delta TT / \delta.$$

The next step is to estimate the probability that a train is non-stop or local. A local train can be scheduled between two other local services (with a probability P^0), between a non-stop train and a local service (with a probability P^1) and between two non-stop services with a probability P^2). Let N be the total number of train trips from Los Angeles to San Francisco, and N_{loc} and N_{ns} the number of local and non-stop trips from Los Angeles to San Francisco, respectively. We have:

(6. 2.4) $$P^0 = \frac{(N_{loc} - 1)(N_{loc} - 2)}{(N - 1)(N - 2)}$$

(6. 2.5) $$P^1 = 2\frac{(N_{loc}-1)N_{ns}}{(N-1)(N-2)}$$

(6. 2.6) $$P^2 = \frac{N_{ns}(N_{ns}-1)}{(N-1)(N-2)}.$$

The average period of time during which a local service is expected to attract passengers who have a choice can be expressed as follows :

(6. 2.7) $$E[\Pi_{loc}] = P^0\ A + P^1(A - \frac{\Delta TT}{2\delta}) + P^2(A - \frac{\Delta TT}{\delta})$$

Because in the peak period trains may come at a frequency much shorter than the difference in travel times, a similar exercise can be undertaken which looks not only at adjacent trains being local or non-stop, but also two trains away.

The total number of train departures from Los Angeles to San Francisco retained for the simulation is 54. Confining demand to be between 5 a.m. and 12 midnight, it turns out that the average period of time between two trains is A = 21 minutes. We further assume that the schedule delay is less valued by passengers as on-board travel time, and assume that d = 0.75. Since non-stop services are 30 minutes faster than local services, n is equal to 1.

Table 6.4 indicates the average period of time during which a local service is expected to attract passengers for a given level of frequency of local services. The proportion of Los Angeles-San Francisco passengers expected to travel by local trains depends upon this period of time. As stated before, just over 24 train departures are already required to carry the travel demand on secondary markets. Additional local services must be provided in order to carry the Los Angeles-San Francisco passengers expected to choose local trains.

Table 6.4: Number of Local Services Required for a Total Number of 54 Los Angeles-San Francisco Train Departures

N_{loc}	N_{ns}	P^0	P^1	P^2	E[P]	LA-SFO Demand	Total Travel Demand	Number of Local Services Required
24	30	0.03	0.09	0.06	2	304	6671	25.42
25	29	0.04	0.10	0.06	2	359	6726	25.62
26	28	0.04	0.11	0.06	2	420	6787	25.86
27	27	0.05	0.12	0.06	3	489	6856	26.12
28	26	0.06	0.13	0.06	3	566	6933	26.41
29	25	0.07	0.14	0.06	3	651	7018	26.74
30	24	0.08	0.15	0.06	4	746	7113	27.10

The minimum required number of local service must be such that the total local service travel demand is less than the capacity. The minimum required number of local services to be provided to meet the travel demand for both secondary markets and the Los Angeles-San Francisco markets is shown in Table 6.4, avoiding capacity constraints requires that the number of local services must be greater than 26.

Since non-stop trains provide faster services for passengers traveling between Los Angeles and San Francisco, one would tend to maximize the number of non-stop services. Thus, the number of services suggested by the model is:

- 26 local services calling at Bakersfield, Fresno and San Jose, and
- 28 non-stop services.

The expected length of the period of time during which each local service is expected to attract passengers traveling from Los Angeles to San Francisco, $E[\Pi_{loc}]$, when 26 local services are provided is only 2 minutes, as indicated in Table 6.6. The period of time during which a non-stop service is expected to attract passenger traveling between Los Angeles and San Francisco, noted $E[\Pi_{ns}]$ is such that :

(6. 2.8) $$N_{loc}E[\Pi_{loc}] + N_{ns}E[\Pi_{ns}] = H$$

where :

N_{loc} = number of local services

N_{ns} = number of non-stop services

H = total period during the day in which there is a transport demand

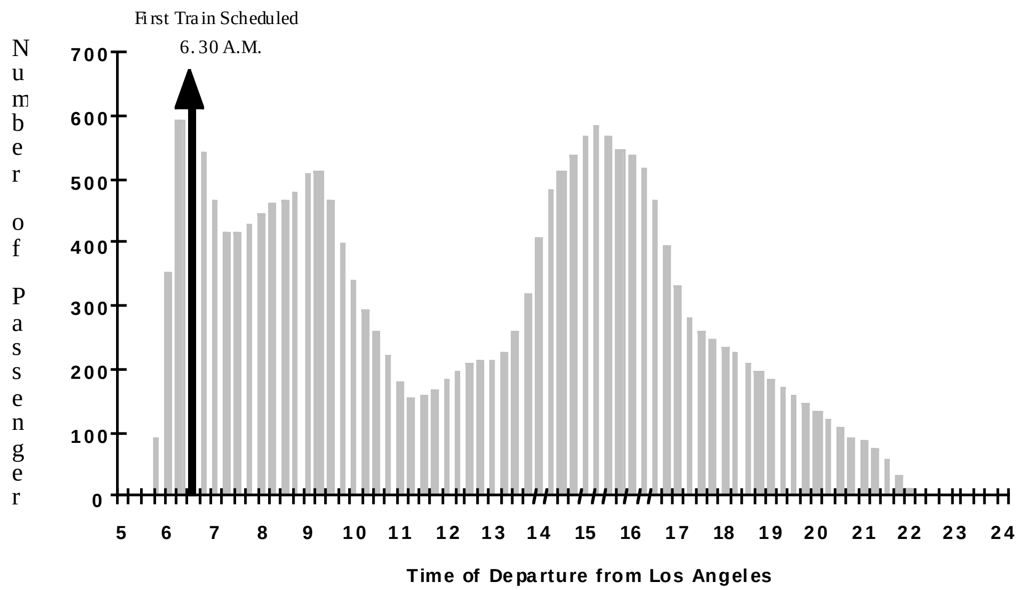
According to equation (6.2.8) and assuming that there is a transport demand between 5 a.m. and 12 a.m., the period of time during which a particular non-stop train is expected to attract passenger is 39 minutes. Secondary OD markets are served by 28 trains. Thus, the period of time during which an individual local train is expected to attract secondary market passengers is 44 minutes.

For most trips, users traveling between the cities of Los Angeles and San Francisco will choose non-stops, while all those traveling in the secondary markets will use local trains. This indicates that, while there are some economies on the use of track, there is little in the way of economies of density (serving multiple markets) on the trains themselves, particularly during the peak, when choices are available.

6.2.1.2 Non-Stop Service Scheduling Process

During off peak hours, the total demand for a local train, serving all the secondary OD markets as well as the Los Angeles-San Francisco market, may be high enough to provide a viable service, whereas the travel demand for a non-stop service only serving a single OD market may be too low. During peak periods, though, the disparity of the demand among the different segments of the new line, as shown in Figure 6.2, is likely to yield empty seats on the less heavily trafficked segments. To illustrate, suppose that the Los Angeles-Bakersfield travel demand for a train leaving at 6 a.m. is so high that many passengers willing to travel beyond Bakersfield cannot get a seat. The factor load is likely to be low on the Bakersfield-Fresno segment if the number of passengers expected to get on the train in Bakersfield is negligible compared to the number of those who get off at this station.

Figure 6.1: Expected Travel Demand for Non-Stop Services depending on the time of departure of the trains



Therefore, non-stop services should first be scheduled during peak hours so that the Los Angeles-San Francisco travel demand will be high enough to viably provide such a service. In addition, this is expected to smooth the demand allocated to local services and, thus, alleviate the problem of the disparity of the traffic volume expected on the different segments of the new line.

The non-stop service scheduling methodology used in the simulation program is pictured in Figure 6.1. The first non-stop service is scheduled at the time when the travel demand between Los Angeles and San Francisco is the highest. As shown in Figure 6.1, a train leaving Los Angeles at 6.30 a.m. would be expected to attract the greatest number of passengers. Since the maximum load factor is 90%, only 315 passengers are allocated to this train. Scheduling the 6.30 a.m. train affects the potential demand for non-stop services leaving Los Angeles between 6 a.m. and 7 a.m.. The new demand profile leads us to schedule the next train at 3.15 p.m.. The remaining demand after scheduling the 6.30 a.m. and the 3.15 p.m. trains leads us to schedule the next trains at 4 p.m., 2.30 p.m. and 9.15 a.m.. The same methodology is used to schedule the remaining Los Angeles-San Francisco non-stop services. If the factor load of a non-stop service is less than 20%, the program stops the non-stop scheduling process. Since the travel demand is assumed to be symmetric, the non-stop service scheduling process from San Francisco to Los Angeles leads to similar schedules and revenues. The model calculates total revenue for non-stop services to be $392,000 per day and per direction and an average factor load for non-stop services of 71%.

6.2.1.3 Local Service Scheduling Process

The local service scheduling process is somewhat more complex since it must be directly based on the maximization of revenue rather than maximizing the number of passengers attracted by a given service. While non-stop service revenue is proportional to the number of passengers carried, the travel demand potentially attracted by a given local service corresponds to different OD markets and, thus, different fares. Moreover, the disparity of the demand in the different segments of the new line is likely to yield empty seats on the less heavily trafficked segments as stated before. Thus, the local service which leads to the highest revenue does not necessarily correspond to the one which attracts the greatest number of passengers.

Every fifteen minutes, from 5 a.m. to 12 a.m., the potential demand for a local service is calculated. If the potential demand for a given local service on the most heavily trafficked segment exceeds 90% of the capacity, the demand on this segment is truncated and reallocated so the composition of the travel demand according to the different OD markets remains the same.

The Los Angeles-San Francisco travel demand is allocated to the different local services assuming that the average period of time during which a local train is expected to attract Los Angeles-San Francisco passengers is 2 minutes as discussed earlier. Thus, the conditional probability that a local train attracts Los Angeles-San Francisco passengers knowing the non-stop schedules is not taken into account at this stage of the simulation.

Then, knowing the composition of the demand according to the different OD markets, it is possible to calculate the expected revenue for the studied service. Although the travel demand is assumed to be symmetric, the local service scheduling process is likely to yield different schedules and revenues. To illustrate a train leaving Los Angeles at 8.30 a.m. will attract passengers from Los Angeles to San Jose and San Francisco whose time target is close to 8.30 a.m. while an 8.30 a.m. local service from San Francisco to Los Angeles will potentially attract San Francisco-Los Angeles passengers whose time target is close to 8.30 a.m. as well as San Jose-Los Angeles passengers whose time target is close to 8.57 a.m. (an 8.30 a.m. San Francisco-Los Angeles local service would leave San Jose at 8.57 a.m.). The final computations result in total revenue for local services for both directions is US $584,136. The remaining, unallocated demand, about 9% of Los Angeles to San Francisco demand is then allocated to local trains where there remains excess capacity.

6.2.2 Carrier Operating And Vehicle Cost Estimates

This section reports estimates of carrier operating costs as well as the costs per vehicle. A study conducted by INRETS and INTRAPLAN (1994) provided estimates of the average high speed rail operating cost for Europe. In this study, operating costs were divided into the categories of sales and administration, shunting, train operations, maintenance of way and equipment, and energy.

Sales and administration costs include labor costs for ticket sales and for providing information at the railroad stations. They also include costs for automated ticketing machine and travel agency commissions. In the INRETS/INTRAPLAN study, sales and administration costs have not been estimated on the basis of the required number of staff and automated ticketing machine for a given level of expected traffic volume but have been assumed to represent 10% of the passenger revenue.

Shunting, or track-switching, costs depend on the distance between the depot and the station as well as the average period of time trainsets stay at the depot. Nonetheless, to simplify, shunting costs could be approximated on a per train basis. The study conducted by INRETS/INTRAPLAN has shown that the cost of labor represents 80% of the total shunting cost.

Train operation can be divided into four activities: train servicing, driving, operations and safety on high speed lines, and operations and safety on conventional lines. Train operation costs consist exclusively of labor costs. Train servicing and driving for the South-East TGV and the Atlantic TGV requires two train companions per trainset and one driver per train (which may include one or two trainsets). Operations and safety on either high speed or conventional lines can be estimated on a per train basis.

Table 6.5: Energy Consumption of the South-East and the Atlantic TGV

Unit	South-East upgraded line	South-East new line	Atlantic upgraded line	Atlantic new line
Kwh/km per trainset	10.5	16.5	12	20
Kwh/pax/100 km	4.4	6.9	3.8	6.3
GOE/PK	10.3	16.2	8.95	14.9
GOE/RPK (ortho)	13.9	19.4	12.1	17.9

Source : Pavaux - ITA (1991), Leavitt et al. (1992)

Note: the capacities of the trainsets used for these calculations are the following : 368 seats for the South-East TGV and 485 for the Atlantic TGV. Again the load factor is 65%.; GOE = Grams of Oil Equivalent. Conversion coefficient : 1 Kwh = 235 GOE. This is the coefficient used by SNCF which takes into account electrical losses between the power generating station and the substations.; (ortho) indicates calculated for orthodromic distances, assuming that the average ratio between the actual distances on new lines and the orthodromic distance to be 1.2 on new lines and 1.35 on upgraded lines.

The cost of the maintenance of electric traction installations and catenary depends on the number of trains running on the infrastructure whereas the cost of maintaining the tracks depends on the number of trainsets. Theoretically, the cost of maintenance of equipment is dependent upon the distance run by every trainset as well as the duration of use. In the INRETS / INTRAPLAN study, the impact of the duration of use has been ignored so that maintenance of equipment cost can be estimated on a trainset per kilometer basis. According to the INRETS / INTRAPLAN study, the proportions of the cost of labor in the maintenance costs are 55% for maintenance of electric traction installations, 45% for maintenance of tracks and 50% for maintenance of equipment.

Costs can be estimated from the average consumption of energy required per kilometer which characterized the trainsets. The cost of energy is assumed to take into account the cost of transport and the electrical losses between the power generating station and the substations. Operating costs related to energy do not include any labor cost. Table 5 gives the average energy consumption for the South-East TGV and the Atlantic TGV running the new infrastructure and upgraded lines, respectively, at a load factor of 65%. Energy consumption per passenger varies with the speed and increases rapidly when the speed is over 300 kph (Pavaux, 1991).

Table 6.6 presents the average costs used in this study. These were adopted from estimates for high speed rail in Europe developed by INRETS/ INTRAPLAN (1994), which have been used by the French Railroad to estimate operating costs for future planned TGV lines. Average operating costs are expected to differ between California and Europe, especially when labor cost represents a significant percentage of the total average cost. Nonetheless, since there is no currently operating high speed rail system in California or elsewhere in the United States, it is difficult to estimate specific average costs for

California. Thus, INRETS / INTRAPLAN estimates are used to forecast the operating cost of high speed rail in California except for energy and sales and administration costs.

Sales and administration costs are dependent on the required number of staff and automated ticketing machine for a given level of expected traffic volume. Assuming that they represent 10% of the passenger revenue in California would imply that the revenue per passenger would be comparable to those observed in Europe. Thus, it may be more accurate to estimate sales and administration costs on a per passenger basis rather than revenue. As a first approximation, sales and administration costs in California will be assumed to be $5 per passenger.

Table 6.6: Carrier Operating and Capital Costs for Los Angeles-San Francisco Network.

Operating Cost Component	Units	Average Cost	Quantity	Cost
1. Sales and Administration	passengers	$5.00	10,555,000	$52,775,000
2. Shunting	train	$87.80	39,055	$3,429,029
3. Train Operations				
Train Servicing	trainset-hour	$92.20	120,523	$11,112,221
Driving	train-hour	$81.80	119,312	$9,759,756
Operations/Safety on Lines	train-km	$0.05	27,398,020	$1,315,105
4. Energy				
Energy on Lines	trainset-km	$2.50	27,654,076	$69,135,190
5. Maintenance of Way				
Electric Traction	train-km	$0.19	27,398,020	$5,205,624
Others MOW Costs	trainset-km	$1.78	27,654,076	$49,224,255
6. Maintenance of Equipment	trainset-km	$2.83	27,654,076	$78,261,035
Total Operating Cost (1->6)				$280,217,215
Total Passenger Revenue				$499,087,130
GROSS OPERATING SURPLUS				$218,869,915
Capital Cost of Rolling Stock				
Sales Tax	trainset	$89,246	42	$3,748,332
Interest and Depreciation of Rolling Stock	trainset	$1,189,952	42	$49,977,984
GROSS MARGIN				$165,143,599
Infrastructure Costs	fixed	$9,597 Million	7.5%	$719.8 Million
NET CONTRIBUTION (SUBSIDY)				$554.6 Million

Note: Average costs in 1994 US $ as Estimated in the INRETS / INTRAPLAN (1994) Study, except energy and sales and administration, as noted in text.

The unit cost rate for electrical power pricing in this analysis will be assumed to be $0.10 per kilowatt-hour, implicitly assuming full cost pricing within the electrical generation sector. According to Table 6.5, the energy consumption of an Atlantic TGV trainset cruising at 300 kilometers per hour on the new high speed line is 20 kilowatt-hours per kilometer. The maximum speed on the California high speed line has been assumed to be 320 kph, as shown in Table 6.1. Moreover, the average number of train stops on the new line is expected to be higher. Thus, the energy consumption on the new line for California will be assumed to be 25 kilowatt-hours per kilometer and per trainset.

The simulation estimates the expected number of passengers carried per train as well as the number of train or trainset-kilometers and train or trainset-hours. It turns out that 108 train-set departures per day are required for the Los Angeles-San Francisco corridor (54 in each direction). Assuming that a train must stay at least one hour at the destination station before being available to head out once again for a new service, the required number of trainsets is 40. This minimum number is usually increased by 5% in order to take into account the proportion of the total fleet unusable due to defect or maintenance. Thus the total number of trainsets in the fleet would be 42.

In the INRETS / INTRAPLAN study, a 350 seat capacity high speed trainset has been estimated to cost $17,849,000 (12 million ECU in 1991). Trainsets are supposed to be depreciated in fifteen year. The general sales tax on trainsets is assumed to be 5%, because the tax is applied to all sales transactions, and leaves the transportation sector, it is not considered a transfer here. The capital cost for the rolling stock is then to be $1,279,200 per trainset and per year, including interest and depreciation of rolling stock as well as sales tax, calculated at a 7.5% discount rate. Multiplying 42 trainsets by $1,279,200, and dividing by 5.6 billion passenger kilometers, gives a capital cost of rolling stock of <u>$0.00959</u> per passenger kilometer.

The total operating cost for the Los Angeles-San Francisco high speed rail system is $280 million for 10,555,000 passengers, 5.6 billion passenger-kilometers and 9.7 billion seat-kilometers. Table 6.6 shows the different components of the operating cost as well as the rolling stock and infrastructure capital cost. Dividing the operating cost of $280 million by 5.6 billion passenger-kilometers gives an average carrier operating cost of <u>$0.050/pkt.</u>

6.2.3 User Costs

Our general model of full costs includes several categories of user costs, including user capital costs, user operating costs, user time costs, and user congestion costs, as well as user transfers. Because we are dealing with a rail system, users are assumed to have no net additional capital costs, unlike a highway system. In our modeling analysis, we have excluded access costs to the high speed rail stations, just as in the analyses of competing air and highway modes, we exclude access costs to airports and the intercity highway system, which are comparable. User operating costs are thus the fares users pay to the rail carrier, which can be considered entirely a transfer, and are thus not included in the final calculation of costs. The fares we have assumed are given in Table 6.3 earlier in the paper.

Table 6.7: User Time Costs

Segment :	Distance (km)	Avg. Running Speed (kph)	Running Time (min)	Travel Time (min)	User Time Cost	User Cost ($/pkt)
San Jose-San Francisco	77	121	38	38	$6.33	$0.08
Bakersfield-Fresno	171	317	32	32	$5.33	$0.03
Fresno-San Jose	213	255	50	50	$8.33	$0.04
Los Angeles-Bakersfield	215	246	52	52	$8.66	$0.04
Fresno - San Francisco	291	198	88	98	$16.33	$0.06
Bakersfield - San Jose	384	280	82	92	$15.33	$0.04
Los Angeles - Fresno	386	276	84	94	$15.67	$0.04
Bakersfield - San Francisco	462	231	120	140	$23.33	$0.05
Los Angeles - San Jose	600	266	135	155	$25.83	$0.04
Los Angeles -San Francisco (non-stop)	677	234	173	173	$29.89	$0.04

Note: Travel Time = Running Time + 10 minutes per stop, Cost = $0.167/min * Travel Time

User time and congestion is worth some discussion. The non-stop travel times between points are given in Table 6.7, and need to be coupled with a 10 minute stop at each station for local trains. User cost of time depends on the speed of service, the expected speed of service for the various markets analyzed is given in Table 6.7. We also need to assume a value of time, for exposition we take the conservative value of $10/hour, recognizing that the value of time varies widely across individuals depending on numerous factors, and that through the literature a large range is found, a summary of values of time is given in chapter 3. The resulting costs per passenger kilometer traveled are given in Table 6.7. The user time cost in $/pkt ranges from $0.03 - $0.08, with the highest time cost on the trips with the slowest trains. The value of $0.04/pkt, found on the non-stop market from Los Angeles to San Francisco is the one most users will experience. We are assuming that there are no congestion costs on the rail system, that trains do not delay each other.

6.3. Social Costs

6.3.1 Air Pollution

Since high speed rail systems are electrically powered, we assume that there are no air pollution externalities caused by the rail system, and that the cost of pollution is internalized in the electric generation sector of the economy, which results in higher energy prices than would otherwise be found. While we do not consider pollution costs, we recognize this is an issue which is under debate. Some have argued that the incremental pollution due to the increase in power requirements from the public utility which supplies power to the HSR should be included as part of the social costs of HSR, because it represents an avoidable cost. With electrically powered trainsets, the pollution from power generation is moved backwards in the supply relationship. We argue that this pollution is properly associated with the electric power generation sector, in which additional pollution costs are, or should be, internalized.

For informational purposes, Table 6.5 provides energy usage by the French TGV system. As a point of comparison, Hirota and Nehashi (1995) report the Shinkansen as producing 2.30 tons of CO per billion passenger kilometers, 0.18 tons of SOx and 0.31 tons of NO, generated by burning 136 kcal of energy per passenger kilometer. The economic damages caused by that energy generation depend very much on where the power plants are located. With deregulated energy markets being implemented in California and elsewhere, it will be very difficult to assess those economic damages, since it will be unclear who is the marginal producer or user, the energy used for the high speed rail could be generated at any plant in the Western United States, from hydro-electric, nuclear, or coal, all with very different environmental consequences, and all subject to intense regulation.

6.3.2 Accidents And Safety

Because of the safety rates of the existing high speed rail systems, we will assume no risk of accident. This does not mean there is no safety cost, rather that it is incorporated in higher capital costs to design the system to be safer. These extra capital costs include the elimination of at-grade crossings with streets and highways, separation of freight and passenger traffic, and better controls.

6.3.3 Noise

For our analysis, the social costs of HSR are restricted to noise. Modeling the economic damage of noise pollution requires several elements. First is an estimate of noise production, second is the damage caused by noise in terms of reduced property values. Following the analysis shown in Chapter 3, we get the following estimates: At 200 kph, our best estimate of the expected cost of noise is $0.0025/pkt; at 320 kph it is $0.0043/pkt, assuming 5 trains per hour, though clearly these costs depend on local conditions as described above.

6.4. Composite Costs

The following table gives summary results of the full cost of high speed rail per passenger kilometer for the California Corridor. These costs are similar overall to the costs of highway travel, and much higher than for air travel. Given all of the uncertainty inherent in the data and the analysis, we estimate the full cost of the trip on the corridor between Los Angeles and San Francisco to be about $159 per trip.

Table 6.8: Long Run Average Cost of High Speed Rail

Cost Category	Average Cost
Infrastructure: Construction and Maintenance	0.129
Carrier: Capital Cost (Trains)	0.010
Carrier: Operating Cost (Railroad operations)	0.050
External: Accidents	0.000
External: Congestion	0.000
External: Noise	0.002
External: Pollution	0.000
User: Time	0.044
Total Cost by HSR	0.235

6.5. End Notes

1. Since the San Jose-San Francisco segment is a short, urban speed restricted segment, high speed rail may not be the best adapted service to serve this OD market. Therefore, the San Jose-San Francisco travel demand will not be taken into account when optimizing the schedules. Nonetheless, available capacity provided by local services from Los Angeles to San Francisco and vice-versa may be allocated to the San Jose-San Francisco OD market.

2. These HSR forecast used in this study are based on the assumptions that stations will be built in Palo Alto, Gilroy, Burbank, Santa Clarita and Palmdale. In our example the travel demand to and from these stations will not be taken into account.

CHAPTER SEVEN:

SUMMARY AND FULL COST COMPARISONS

We now apply the cost models developed in chapters three to six to estimate the full costs of the three modes as they arise in California. The corridor for which these estimates are computed represents one of the alignments of a proposed high speed rail system between Los Angeles and San Francisco. The estimates are made by applying the cost functions and unit cost estimates developed in the previous chapters to levels of demand as estimated by Leavitt et. al. (1994) for the year 2015. The models are applied to individual links, each of which represents a major city-pair market in the corridor. Long run average costs are also summarized for the corridor as a whole and used to make intermodal comparison of the full cost per passenger-kilometer and its elements.

7.1. Intermodal Comparison of Average Costs

The long run average costs per passenger-km are shown in Table 7.1.We find that for the California Corridor in terms of full costs, air transportation, at $0.1315 per passenger-km. is significantly less costly than the other two modes. High speed rail and highway transportation appear close in their average full cost, with rail costing $0.2350 and highway costing $0.2302 per passenger kilometer. If we look at the break-down of the full cost into its elements, then we find that rail, while always more costly than air, is less costly than highway in terms of social costs but more costly in terms of internal costs, primarily due to its high capital costs. We can see this comparison in Figure 7.1 where full costs are broken down into three categories: internal, travel time, and external.

Table 7.1: Intermodal Comparison of Long Run Average Costs

Cost Category	Air System	High Speed Rail	Highways
Infrastructure: Construction and Maintenance	$0.0182	$0.1290	$0.0120
Carrier: Capital Cost	$0.0606	$0.0100	$0.0000
Carrier: Operating Cost	$0.0340	$0.0500	$0.0000
External: Accidents	$0.0004	$0.0000	$0.0200
External: Congestion	$0.0017	$0.0000	$0.0046
External: Noise	$0.0043	$0.0020	$0.0045
External: Pollution	$0.0009	$0.0000	$0.0031
User: Fixed + Variable	$0.0000	$0.0000	$0.0860
User: Time	$0.0114	$0.0440	$0.1000
TOTAL	$0.1315	$0.2350	$0.2302

note: $/pkt, highways assume 1.5 passengers per car; all transfers are subtracted out

The internal, or private, monetary costs comprising infrastructure, carrier, and vehicle operating costs are clearly highest for rail ($0.19/pkt), followed by air ($0.11/pkt) and then highway ($0.10/pkt). It is important to recognize the high fixed costs inherent in these transportation systems, especially rail. In particular, the cost of infrastructure depends very much on how many passengers that cost is distributed over. While the highway and air system can spread their infrastructure costs over many transportation markets (many origin-destination pairs serving both passenger and freight), the high speed rail system is highly constrained, serving mostly passenger trips between the relatively few points along the line. If the demand for high speed rail were higher than what is assumed here, the average infrastructure cost per passenger would be lower.

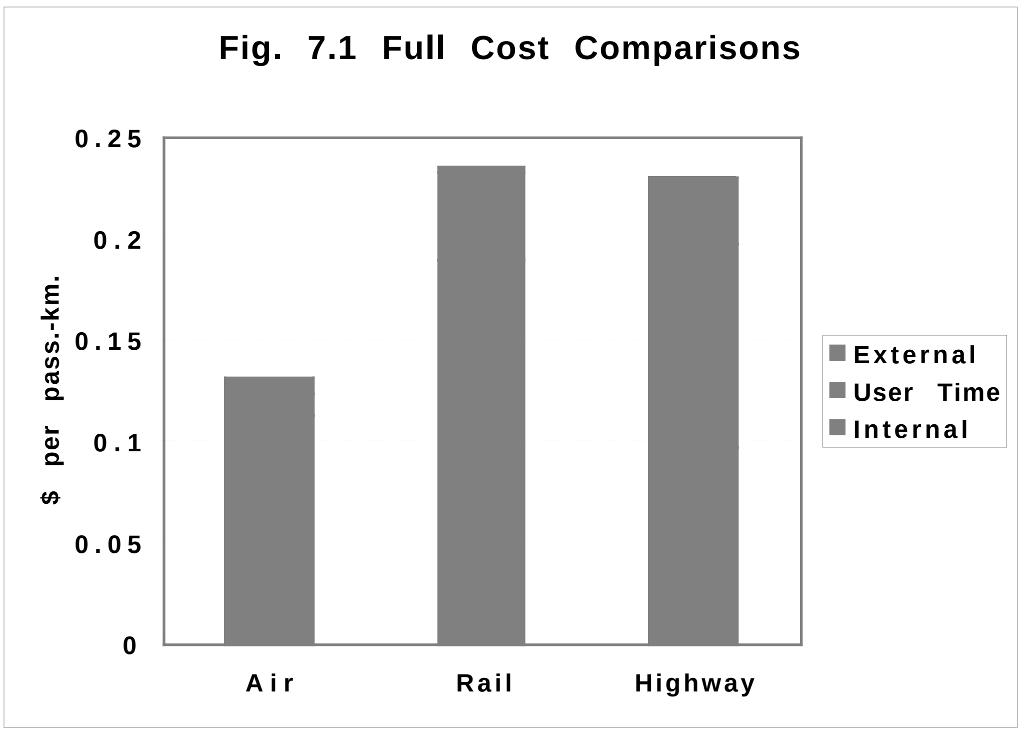
As is to be expected, user time costs are highest for the slowest mode, the highway system, followed by rail and then air. The analysis undertaken here attempts to be comparable between modes by using the same value of time for each ($10/hour). However, there is already self-selection by value of time in the decision of which mode to take. For this reason, the actual value of time of those using the fastest mode (air) is probably the highest. Those individuals will pay a higher money premium to save time, so there would not be a savings for moving them to a slower mode, their value of time remains unchanged, the average value of time of those using the mode would be increased. A second factor to consider when judging the importance of time costs is the way access costs are treated here. In this study, we assumed the cost of access from home or work to the various intercity travel departure point (airport, train station, inter-city freeway system) was approximately equal. However a distinction should be made between private and public transportation systems. The automobile/highway system allows point to point travel without any schedule delay, while air and train travelers can only depart on specific schedules. This schedule delay increases access costs, and may or may not be significant, depending on the frequency of service between the major markets. In the California corridor, between San Francisco and Los Angeles there are frequent departures currently by airplane, and high speed train service is also anticipated to have departures more than once an hour. Similarly, there is a money cost to get from home or work to the point of departure. Whether travel is by taxi, shuttle, passenger car, or mass transit, some outlay is required to get to the train station or airport. These access costs collectively favor automobile transportation over the other modes.

Combining private money and time costs we arrive at the internal system costs, which adds up to per passenger-km. costs of $0.124 for air; $0.233 for rail; and $0.198 for highway. In other words, if we disregard external costs then we find that high speed rail is nearly twice as costly as air and that the highway is not far behind.

However, when we include social costs, comprising congestion, air pollution, noise, and accidents, then the picture changes. For external, or social, costs we find that high speed rail is clearly less costly than the other modes. As was shown in Table 7.1 the only measurable social cost of high speed rail is that of noise, which at $0.002 per passenger-km. is significantly lower than that of air at $0.0043 and highway at $0.0045. We should note that these noise cost estimates, are quite tentative and even though they are based on fairly accurate measures of noise generation, depend on many assumptions regarding the type and distribution of land uses in the vicinity of the transportation systems. The noise costs of rail are based on current high speed rail technology, similar to the type that would likely be implemented in California. In the case of air on the other hand, we have not taken into consideration the upcoming switch to stage III aircraft which is mandated as of the year 2000. With the advent of stage III aircraft one can expect at least a halving of the cost of airport noise. The aircraft noise cost estimates are further based on a broad cross-section of estimates from other countries. The location of major airports in California are in areas of somewhat lower density than internationally, and more importantly, have approach and departure flight paths which can often be located over water, which further reduces the noise externality.

Given their small magnitude, it should be noted that social costs play a relatively minor role in the comparison of total costs across modes. The relatively high social cost of highway transportation is primarily due to the cost of accidents, an externality which is nearly absent in the other two modes. The accident and congestion externalities are already internalized to travelers making decisions, as the accident externality generates higher insurance costs while congestion increases travel time. The most relevant externalities are therefore pollution and noise, which have approximately equal costs in the case of highway transportation, whereas for the other two modes, noise appears to be the major source of social costs.

Figure 7.1:   Full Cost Comparisons



From Table 7.1 it can be seen that these externalities represent 1% of the full cost of high speed rail, 6% of the full cost of air, and a relatively large 14% of the full cost of highway transportation. Therefore, when comparing highway and high speed rail, careful judgment of the valuation of social costs is necessary to make a final comparison, for the differences in total costs shown here are not significant given the accuracy of data and the levels of modeling used to estimate the numbers. Increased sensitivity to social costs would favor investing in high speed rail as opposed to highways. In the case of comparison between rail and air the issue is not that clear cut. For one thing, the full cost of air is nearly half of that of rail, which means that any diversion of traffic from air to rail will result in significant increases in the cost of transportation. For another, the main source of difference in social costs is the cost of noise, which was discussed earlier. Here our estimates are quite conservative and tend to favor high speed rail transportation. Consequently, the difference in full cost between rail and air is far more significant and unlikely to change in favor of high speed rail on the basis of adjustments to data or to model parameters. One can confidently conclude that air transportation is a less expensive means of providing intercity transportation in the context of the California corridor, even when taking social costs into consideration.

While the numbers reflecting the per passenger-kilometer costs are estimates, they do compare reasonably with estimates of full costs contained in the Royal Commission on National Passenger Transportation Report (1993) completed for Canada, and reported in Chapter 2. They are also comparable to yield figures for US air carriers calculated from Morrison and Winston (1995).

7.2. Comparisons of Total Cost

Using the models from the previous chapters, we compare the full cost of the three modes in terms of the total cost of a trip in each of the major markets. These results are shown in Tables 7.2-7.4 for the air, highway, and rail modes respectively. The comparisons provide a quick assessment of the total full cost of a trip within the corridor by each of the modes. For example, for a trip between San Francisco and Los Angeles the total full cost would be $155.85 by highway, $82.02 by air, and $159.10 by high speed rail. The social costs imposed by a trip in each of these modes would be $21.08 by highway; $4.58 by air; and $1.35 by high speed rail. It is interesting to note that the recovery of these social costs might imply the addition of fare premiums in the air and rail systems equal to these amounts. But for highway transportation they would imply a premium of $1.50 per gallon of gasoline!

Figure 7.2: Air System Long Run Full Costs

		San Francisco	Fresno	Fresno	Bakersfield	Bakersfield	
		Los Angeles	San Francisco	Los Angeles	San Francisco	Los Angeles	TOTAL
HSR pkt/year ('000)		5,177,696	94,866	245,110	55,902	79765	5,653,339
percent diverted from Air		0.50	0.14	0.28	0.28	0.14	0.48
Air Diverted pkt/year ('000)		2,588,848	13,281	68,631	15,653	11,167	2,697,580
Air Distance (km)		626	251	418	420	200	
Cost Category	**Average Cost**						
Infrastructure: Airways (ARTCC)	$0.0034	$8,543	$110	$343	$78	$93	$9168
Infrastructure: Airways (TRACON)	$0.0015	$3,883	$50	$158	$36	$42	$4170
Infrastructure: Airways (ACTC)	$0.0009	$2,330	$32	$96	$22	$27	$2507
Infrastructure: Airways (FSS)	$0.0008	$2,071	$27	$82	$19	$22	$2221
Infrastructure: Airport Terminal	$0.0094	$23,559	$303	$940	$214	$255	$25271
Infrastructure: Airport Airside	$0.0022	$5,437	$69	$213	$49	$58	$5825
Carrier: Capital Cost (Planes)	$0.0606	$156,884	$805	$4,159	$949	$677	$163473
Carrier: Operating Cost	$0.0340	$88,021	$452	$2,333	$532	$380	$91718
External: Accidents	$0.0004	$1,087	$6	$29	$7	$5	$1133
External: Congestion	$0.0017	$4,401	$23	$117	$27	$19	$4586
External: Noise	$0.0043	$11,132	$57	$295	$67	$48	$11600
External: Pollution	$0.0009	$2,330	$12	$62	$14	$10	$2428
User: Time	$0.0114	$29,513	$151	$782	$178	$127	$30752
Total Cost by Air	$0.1315	$339191	$2096	$9610	$2192	$1762	$354851
Cost per passenger kilometer traveled		$0.13	$0.16	$0.14	$0.14	$0.16	$0.13
External Cost per Air Trip		$4.58	$1.84	$3.06	$3.07	$1.46	$4.19
Internal Cost per Air Trip		$68.42	$28.69	$46.40	$46.62	$22.86	$63.67
Full Cost per Air Trip		$82.02	$39.61	$58.53	$58.81	$31.56	$80.87

note: see chapter 5 for details; full costs in thousands; pkt assumes % diverted from HSR - estimated by authors

Table 7.2: Highway System Long Run Full Costs

		San Francisco Los Angeles	Fresno San Francisco	Fresno Los Angeles	Bakersfield San Francisco	Bakersfield Los Angeles	TOTAL
HSR pkt/year ('000)		5,177,696	94,866	245,110	55,902	79765	5,653,339
percent diverted from Highway		0.50	0.86	0.72	0.72	0.86	0.52
Highway Diverted pkt/year ('000)		2,588,848	81,585	176,479	40,249	68,598	2,955,759
Distance (km)		677	291	386	462	215	
Cost Category	**Average Cost**						
Infrastructure: Construction and Maintenance	0.0120	$31,066	$979	$2,118	$483	$823	$35,469
External: Accidents	0.0200	$51,777	$1,632	$3,530	$805	$1,372	$59,115
External: Congestion	0.0046	$11,909	$375	$812	$185	$316	$13,596
External: Noise	0.0045	$11,650	$367	$794	$181	$309	$13,301
External: Pollution	0.0031	$8,025	$253	$547	$125	$213	$9,163
User: Fixed + Variable (Cars)	0.0860	$222,641	$7,016	$15,177	$3,461	$5,899	$254,195
User: Time	0.1000	$258,885	$8,158	$17,648	$4,025	$6,860	$295,576
Total Cost by Highway	0.2302	$595953	$18781	$40626	$9265	$15791	$680416
Cost per passenger kilometer traveled		$0.23	$0.23	$0.23	$0.23	$0.23	$0.23
External Cost per Highway Trip		$21.80	$9.37	$12.43	$14.88	$6.92	$20.46
Internal Cost per Highway Trip		$134.05	$57.62	$76.43	$91.48	$42.57	$125.79
Full Cost per Highway Trip		$155.85	$66.99	$88.86	$106.35	$49.49	$146.25

note: see chapter 4 for details; full costs in thousands; pkt assumes % diverted from HSR estimated by authors

Table 7.3: High Speed Rail System Long Run Full Costs

		San Francisco	Fresno	Fresno	Bakersfield	Bakersfield	
		Los Angeles	**San Francisco**	**Los Angeles**	**San Francisco**	**Los Angeles**	**TOTAL**
pkt/year ('000)		5,177,696	94,866	245,110	55,902	79765	5,653,339
Distance (km)		677	291	386	462	215	
Cost Category	**Average Cost**						
Infrastructure: Construction and Maintenance	0.1290	$667,923	$12,238	$31,619	$7,211	$10,290	$729,281
Carrier: Capital Cost (Trains)	0.0100	$51,777	$949	$2,451	$559	$798	$56,533
Carrier: Operating Cost (Railroad operations)	0.0500	$258,885	$4,743	$12,256	$2,795	$3,988	$282,667
External: Accidents	0.0000	$0	$0	$0	$0	$0	$0
External: Congestion	0.0000	$0	$0	$0	$0	$0	$0
External: Noise	0.0020	$10,355	$190	$490	$112	$160	$11,307
External: Pollution	0.0000	$0	$0	$0	$0	$0	$0
User: Time	0.0440	$207,108	$5,692	$9,804	$2,795	$3,191	$248,747
Total Cost by HSR	0.2350	$1,216,759	$22,294	$57,601	$13,137	$18,745	$1,328,535
Cost per passenger kilometer traveled		$0.2350	$0.2350	$0.2350	$0.2350	$0.2350	$0.2350
External Cost per HSR Trip		$1.35	$0.58	$0.77	$0.92	$0.43	$1.30
Internal Cost per HSR Trip		$155.03	$72.46	$88.39	$110.42	$49.24	$152.02
Full Cost per HSR Trip		$159.10	$68.39	$90.71	$108.57	$50.53	$152.58

note: see chapter 6 for details; full costs in thousands; demand estimates from Leavitt et al. 1993 (IURD #609)

Table 7.4: Comparison of Total Annual Costs Between Modes

Mode	San Francisco Los Angeles	Fresno San Francisco	Fresno Los Angeles	Bakersfield San Francisco	Bakersfield Los Angeles	TOTAL
High Speed Rail	1216759	22294	57601	13137	18745	1328535
Highway	595953	18781	40626	9265	15791	680416
Air	339191	2096	9610	2192	1762	354851
Highway + Air	935144	20877	50235	11457	17554	1035266
HSR deficit:						
Highway + Air - High Speed Rail	-281615	-1417	-7366	-1680	-1191	-293268

note: comparison of total annual cost of diverted trips, see text for discussion

7.3. Summary and Implications

High speed rail appears to be the costliest of the three modes for the corridor analyzed. But it is close to highway transportation in terms of full costs, and definitely advantageous to it in terms of social costs. But the greater external costs generated by highway travel are compensated by lower infrastructure costs per user than high speed rail. It should also be noted that many of highway's costs are already borne by users: accidents, and congestion, while external to the driver, are internal to the highway transportation system.

It is crucial to understand the linkages between demand, supply, and cost. If the cost function is dominated by large fixed costs, as is the case with high speed rail, which must be provided independent of the number of riders, then providing more riders will lower the cost to the average user. Our cost estimates were made based on demand forecasts by Leavitt et al. (1994), and though the precise numbers may change with changes in forecasts, the general result will remain. It should be noted that the high speed rail forecast was based on subsidized fares. It is likely that if market fares (to recover the infrastructure and carrier costs) were in place without subsidy, that the system would be unsustainable.

In this regard, an important implication of the cost comparisons is the effect of diversion from the air mode to high speed rail. If, as is commonly predicted in demand studies, high speed rail is designed to divert traffic from air, then there will be an increase in the total cost of transportation. And as mentioned earlier, such an increase can be scarcely justified on the basis of the cost of noise. If on the other hand the high speed rail system is configured to divert traffic from highway transportation, then the switch is approximately a break-even proposition overall, with gains due to reduced social costs and higher speeds, but losses in private monetary costs such as infrastructure, operation, and maintenance of the respective systems. Table 7.5 shows such an analysis of this proposition.

The table shows the increases in the total cost of transportation that would result from the re-allocation of corridor demands among high speed rail, air, and highway transportation, assuming the rail alignment in the whole corridor, and the diversion of traffic predicted by the current models of mode choice. The implication is that the most cost effective high speed rail configuration in California would be as an alternative to highway, rather than to air transportation. It should be designed to complement rather than compete with air transportation. This means design alternatives should be sought that favor shorter distance markets (such as Los Angeles-San Diego or San Francisco-Sacramento), and that act as regional access connections to airports and tie in with local mass transit systems.

7.4. Further Research

A considerable amount of modeling and data estimation went into the development of costs used in this study. All these models can stand refinements, better data bases, and more sensitivity analyses. It would be useful to continue this type of research providing better estimates of the full cost of intercity transportation in order to inform decision making regarding investments in these systems. There are also important related topics the extend beyond the estimation of full costs. Two are mentioned below.

7.4.1 Full Cost Equilibrium

It is a fundamental premise of microeconomics that price influences the demand and that the demand consumed influences price. The price which determines a quantity that gives back the same price is considered an equilibrium point. In transportation the principle that price influences demand manifests itself by the greater number of shorter trips than longer trips, where travel time and cost form a generalized price. Similarly, quantity influences price, in the case of highway travel, price (in terms of travel time) rises as roads become congested, while in the case of public transit systems, total travel time between points may drop when increased demand increases service frequency, thus reducing schedule delay . If social costs are to be included in the price borne by individual travelers, it can be expected that their demand for travel would be reduced. An objective this research should be to develop a model which finds that “supply-demand” equilibrium point for various infrastructure scenarios.

The proposed approach would attempt to capture the interaction between demand and efficient pricing. The full costs study’s comprehensive review of capital, operating, and social costs and estimation of cost functions for air, rail, and highway transportation would be used as a base. Second, cost allocation methods would be reviewed, including average cost and marginal cost approaches. An approach which results in efficient pricing while recovering long term fixed (infrastructure) costs would be selected or developed. Third, equilibration methods in economics and transportation will be investigated. Issues relating to equilibration, such as whether the system has a single equilibrium point or multiple equilibria, and the rate of convergence to equilibrium will be considered. A model to solve the full cost equilibrium problem would be developed, integrating estimation of demand and estimation of costs and appropriate prices.

Several key output parameters from the system could be compared across scenarios and cases. First is the total demand for each mode in terms passengers on various segments. Second is the equilibrium “price” of each mode for various capital, operating, and social costs. Third is a net benefit measure such as change in consumer surplus between the “no build” and each case and scenario. This would enable an optimal mix of modes to be selected under different circumstances.

7.4.2 Direct and Indirect Subsidies to Intercity Transportation Systems

The successful deployment of high speed rail systems in France, Germany, and Japan has been an encouraging sign regarding the feasibility of such systems. However, given the regional patterns of development in California, and the economics of alternative modes of transportation such as highway and air systems, it is not clear that these successes can be translated from one environment to another. In particular, there are strong indications that a high speed rail system in California will require substantial public subsidies. Such subsidies might be justifiable on the grounds of public policy concerns with environmental impacts and with regional economic and social development. In order to inform the debate on the desirability of high speed rail technology in California the question arises as to what the direct and indirect subsidies currently given to other transportation modes are, and how they are justified. A comparative analysis, e.g. between California and France, where a successful TGV system is in operation would shed important light on the question of public subsidy to transportation systems, particularly in the early stages of their developments.

Currently, taxpayers knowingly support the transportation system through direct subsidies and unknowingly through hidden subsidies. Hidden subsidies are often manifested in uncharged social costs. They tend to hamper the development of a rational transportation policy as they can mislead governments trying to make decisions based on economic efficiency and competition. Hidden and direct subsidies, can arise in a number of ways. A complete accounting of the costs and revenues of transportation systems can allow an assessment of the magnitude of these subsidies. They could arise from less than full cost recovery of the infrastructure costs, the environmental costs of noise and air pollution, and the costs of accidents. They also arise from special financial assistance given by governments in the form of tax reduction or guarantees of loans at below market rates.

We expect that a comparison of subsidies to the various modes of intercity transportation will help to clarify the picture in terms of public investment prerogatives. In the case of California, such a clarification will be very valuable in informing decision making regarding the deployment of high speed rail systems.