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Transportation Elasticities

How Prices and Other Factors Affect Travel Behavior

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Abstract
This report investigates the influence that prices and service quality have on travel behavior. It summarizes research on various types of transportation elasticities and describes how to use this information to predict the travel impacts of specific price reforms and management strategies.

Contents

Introduction

Life is full of trade-offs. People must constantly choose how to spend their limited time and money. The decisions they make reflects their knowledge, preferences and values. This report describes methods for quantifying such trade-offs involving transportation decisions, such as how changes in fuel prices and parking fees affect automobile travel, and how changes in transit fares and service quality affect transit travel.

Prices are the direct, perceived costs to users for consuming a good. The term is sometimes limited to monetary costs, but it can include non-monetary costs such as time, discomfort and risk. For example, the price of an airplane trip includes the financial cost of the ticket, expenses for getting to the airport, plus the time and risk of travel. Factors such as discomfort and risk can be considered to affect travel time costs: a minute spent by travelers in comfort and safe conditions imposes less cost to consumers than the same minute spent in uncomfortable or unsafe conditions ("Travel Time Costs," Litman, 2005).

Price changes affect consumption decisions. For example, you may consider a particular product too expensive at its regular price but buy it when discounted. Similarly, a price increase may motivate you to shift brands or consume less. Such decisions are said to be *marginal*, that is, the decision is at the margin between different alternatives, and may therefore be affected by small price changes. Although individually these decisions may be quite variable (you might succumb to a sale today, but forego the same offer tomorrow), in aggregate they tend to follow a predictable pattern: when the price of a good declines its consumption tends to increase, and when a good's price increases its consumption tends to decline. This is called the "law of demand."

Transportation activities tend to follow this pattern. When the travel monetary, time, discomfort or risk costs decline, the amount of mobility (measured in trips, person-miles or ton-miles) tends to increase. Similarly, when travel costs increase, mobility declines. Price changes can have a variety of impacts on travel, affecting the number of trips people take, their destination, route, mode, travel time, type of vehicle (including size, fuel efficiency and fuel type), parking location and duration, and which type of transport services they choose (Institute for Transport Studies, 2004).

Even a small price difference can have a large effect on travel decisions, particularly if consumers have many competitive options. For example, in an area with many destination and travel options, a modest parking fee or road toll can significantly affect where and how people travel. Transportation prices can also affect how businesses organize manufacturing and distribution activities, and even product design. For example, declining shipping costs have greatly increased international trade, resulting in more centralized production of many goods, and allowing more prepackaging.

Economists measure price sensitivity using *elasticities*, defined as the percentage change in consumption of a good caused by a one-percent change in its price or other characteristics (such as traffic speed or road capacity). For example, an elasticity of -0.5 for vehicle use with respect to vehicle operating expenses means that each 1% increase in these expenses results in a 0.5% reduction in vehicle mileage or trips. Similarly, a transit service elasticity is defined as the percentage change in transit ridership resulting from each 1% change in transit service, such as bus-miles or frequency. A negative sign indicates that the effect operates in the opposite direction from the cause (an increase in price causes a reduction in travel). Elasticities can be calculated based on ratios, rather than absolute price values, such as the ratio between transit fares and automobile operating costs, or vehicle costs as a percentage of average income or wages.

Economists use several terms to classify the relative magnitude of elasticity values. *Unit elasticity* refers to an elasticity with an absolute value of 1.0, meaning that price changes cause proportional consumption change. Elasticity values less than 1.0 in absolute value are called *inelastic*, meaning that prices cause less than proportional changes in consumption. Elasticity values greater than 1.0 in absolute value are called *elastic*, meaning that prices cause more than proportional changes in consumption. For example, both a 0.5 and –0.5 values are considered *inelastic*, because their absolute values are less than 1.0, while both 1.5 and –1.5 values are considered *elastic*, because their absolute values are greater than 1.0.

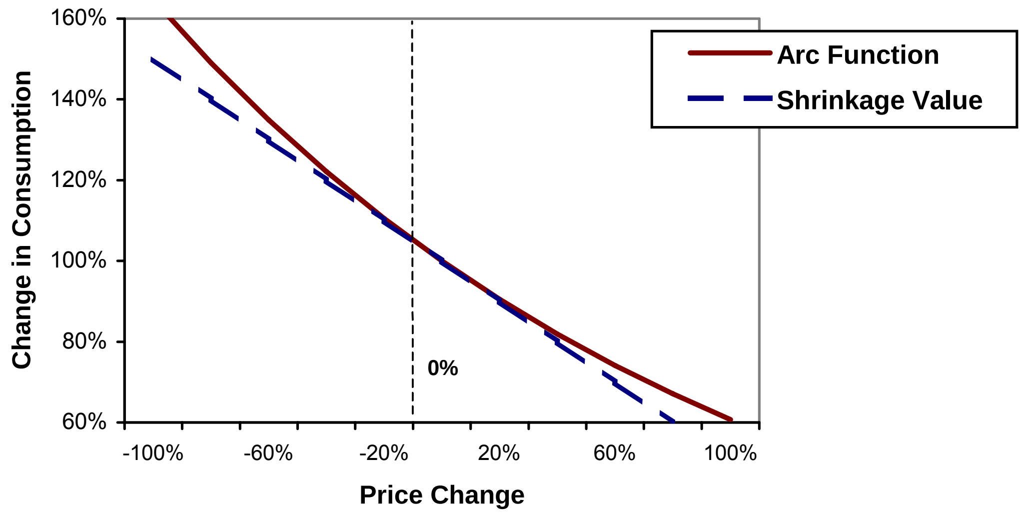
Several methods are used to compute elasticities, some more accurate than others. These methods and their application are described in detail, along with examples, in Pratt (2003), Appendix A, "Elasticity Discussion and Formulae" and in TRL, 2004.

The most frequently used form of elasticity (symbolized η) in transportation analyses is the *arc elasticity*, or its variation, the *mid-point* (or *linear*) *arc elasticity*. An *arc* elasticity reflects the change in consumption resulting from each 1% change in price, calculated in infinitesimally small increments. Measured in this way, a large price change consists of numerous incremental changes. For example, a –0.5 price elasticity applied to a 10% price increase is calculated as ten 0.5% reductions in consumption (e.g., trips taken, miles driven, fuel consumed, etc.). The first reduces current consumption by 0.5% to 99.5%, the second reduces this by another 0.5%, which is reduced by another 0.5% in the third step, a total of ten times. Note that each step affects an incrementally smaller base, resulting in an exponential function. Reasonably accurate arc elasticities can be calculated using a calculator or spreadsheet by raising the price change factor (ratio of new to old price, such as 1.5 for a 50% increase) to the elasticity exponent. For example, a 50% price increase in a commodity with an *own price elasticity* of -0.4 should result in new demand being 1.5^(-0.4) times as much as old demand, in this case, 0.85 times as much.. The results are an approximation, but accurate enough for most applications. For example, in the calculation described above, ten 1% increments gives a 4.889% reduction, while the log arc elasticity application formula in Pratt, 1999, Appendix A, page 19, gives a slightly smaller 4.654% reduction.

Arc elasticity is based on both the original and final values of demand and price or service, while elasticities involving a free fare (price equals zero before or after the change) must be calculated using the mid-point formulation. Arc elasticity is defined by a logarithmic formulation and, except for very large changes in price or service (P), and quantity demanded (Q), is closely approximated by a mid-point formulation based on the average value of each independent variable (Pratt, 1999).

A more simplistic form, known as a *shrinkage ratio* or *shrinkage factor*, uses a linear function to calculate how price changes affect consumption. A *shrinkage ratio* is defined as the change in demand relative to original demand divided by the change in price relative to the original price. Shrinkage ratios have historically been used as a means of reporting response to transit fare changes, primarily fare increases, but this method is not very accurate, particularly for large price changes. Figure 1 illustrates the difference between arc elasticities and shrinkage values. The differences are insignificant for small price changes, but become important when larger price changes are evaluated (greater than 50%).

Figure 1 **Arc and Linear Elasticities** (Litman 2009)



This figure compares arc elasticities and shrinkage values. Arc elasticities are based on an exponential function that is more accurate for evaluating larger price changes.

The *Elasticity Spreadsheet* (www.vtpi.org/elasticity.xls) shows both exponential and linear functions for calculating the changes in consumption for price changes using various elasticity values.

Definitions

Arc Elasticity

$$(\eta) = (\Delta \log Q)/(\Delta \log P)$$

or

$$(\eta) = (\log Q_2 - \log Q_1) / (\log P_2 - \log P_1)$$

Mid-Point (or Linear) Arc Elasticity

$$(\eta) = [(\Delta Q)/(Q_1 + Q_2)/2] \div [(\Delta P)/(P_1 + P_2)/2]$$

or

$$(\eta) = [\Delta Q(P_1 + P_2)] \div [\Delta P(Q_1 + Q_2)]$$

or

$$(\eta) = [(Q_2 - Q_1)(P_1 + P_2)] \div [(P_2 - P_1)(Q_1 + Q_2)]$$

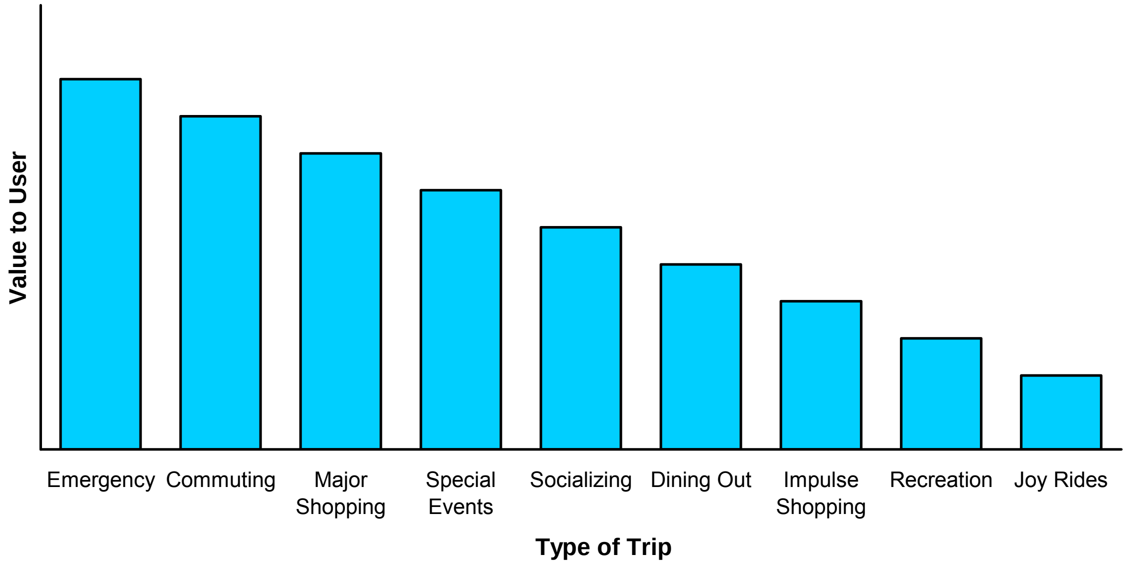
where η is the elasticity value, Q_1 and Q_2 are the demand before and after, and P_1 and P_2 are the price or service before and after.

Cross-elasticities refer to the percentage change in the consumption of a good resulting from a price change in another, related good. For example, automobile travel is complementary to vehicle parking, and a substitute for transit travel. As a result, an increase in the price of driving tends to reduce demand for parking and increase demand for transit travel. To help analyze cross-elasticities it is useful to estimate *mode substitution* factors, such as the change in automobile trips resulting from a change in transit trips. These factors vary depending on circumstances.

For example, when bus ridership increases due to reduced fares, typically 10-50% of the added trips will substitute for an automobile trip, that is, one automobile trip is reduced for each two to ten additional transit trips. Other trips will shift from nonmotorized modes, ridesharing (which consists of vehicle trips that will be made anyway), or be induced travel (including chauffeured automobile travel, in which a driver makes a special trip to carry a passenger). Conversely, when a disincentive such as parking fees or road tolls causes automobile trips to decline, generally 20-60% shift to transit, depending on conditions. Pratt (1999) provides information on the mode shifts that result from various incentives, such as transit service improvements and parking pricing.

To understand how prices affect travel decisions, think of all of the trips you might make during a certain time period, as illustrated in Figure 2. Such a ranking for an entire community includes millions of potential trips. This is a travel demand curve (a graph of the relationship between prices and consumption). If prices decline, travel usually increases as lower-value trips become more affordable, and if prices increase, travel usually declines, as consumers choose to forego some lower-value trips, or shift to a cheaper mode or destination.

Figure 2 **Travel Ranked by User Value**



Trips range in value. High value trips will occur even if user costs are high. Some trips have relatively low value and will only occur if prices are low.

The steepness of this curve indicates how sensitive (or "elastic") a particular good is with respect to price. A high elasticity (i.e., a gradual curve) indicates that a relatively small change in price will cause a relatively large change in consumption. A low price elasticity (i.e., a steep curve) indicates that price changes have relatively little impact on consumption.

Elasticity analysis is normally based on *real* (inflation adjusted) prices, as opposed to *nominal* or *current* prices (unadjusted for inflation). For example, if during a time period there is 10% inflation and nominal prices do not change, real prices will have declined by 10%. If during that time period prices increase by 10%, real prices will have stayed constant. If nominal prices increase 20% during that period, real prices will have increased by approximately 10%.

Although elasticities are often reported as single, point estimates, there are actually many factors that can affect the price sensitivity of a particular good. In other words, elasticities are actually functions with several possible variables, including the type of market, type of consumer and time period. For example, although the elasticity of vehicle travel with respect to fuel price may be defined as –0.3 (a single value), the actual value will vary between –0.1 and –0.8 depending on the type of trip (commercial, commute, recreational, etc.), the type of motorist (rich, poor, young, old, etc.), travel conditions (rural, urban, peak, off-peak), and the time period being considered (short-, medium- or long-run). Some of these variables are discussed in more detail in the next section.

Is Driving Insensitive to Price?

Economists have plenty of solid research showing that prices affect travel behavior, but non-economists often cite anecdotal evidence that travel is insensitive to price, and so argue that price reforms are an ineffective way to affect travel behavior. For example, they will point to a news article showing that a recent jump in fuel prices had little effect on automobile use, or data showing that people who live in countries with high fuel taxes continue to drive automobiles. "Motorists love their cars too much, they won't give them up, " the claim.

Such claims are partly true and largely false.

As it is usually measured, automobile travel is *inelastic*, meaning that a percentage price change causes a proportionally smaller change in vehicle mileage. For example, a 10% fuel price increase only reduces automobile use by about 1% in the short run and 3% over the medium run. Even a 50% fuel price increase, which seems huge to consumers, will generally only reduce vehicle mileage by about 5% in the short run, a change too small for most people to notice, although this will increase over time as consumers take the higher price into account in longer-term decisions, such as where to live or work.

But fuel prices are a poor indicator of the elasticity of driving, because over the long term consumers will purchase more fuel-efficient vehicles. Over the last few decades the real (inflation adjusted) price of vehicle fuel has declined significantly, and vehicle-operating efficiency has increased. Real fuel costs are now a third lower, and an average car is nearly twice as efficient. For example, the $0.35 paid for a gallon of gasoline in 1955 dollars is worth $2.35 in current dollars, and an average car of that time could only drive 12 miles on a gallon. Not surprisingly, consumers have responded to these trends by purchasing larger and more power vehicles, and driving more miles per year. Had fuel prices increased with inflation, fewer SUVs would be sold and motorists would drive fewer annual miles.

Residents of countries with high fuel taxes tend to purchase more fuel-efficient vehicles and drive fewer annual miles per capita. For example, fuel taxes are about 8 times higher in the U.K. than in the U.S., resulting in fuel prices that are about three times higher. U.K. vehicles are about twice as fuel efficient, on average, so per-mile fuel costs are only about 1.5 times higher, and automobiles are driven about 20% less per year, so annual fuel costs are only 1.25 higher than in the U.S. Since per capita vehicle ownership is lower, average per capita fuel expenditures are similar in both countries. Similar patterns can be found when comparing other countries with different fuel prices. This indicates that automobile use is sensitive to price.

The relatively low elasticity of driving with respect to fuel prices hides a much higher overall elasticity of driving. Fuel is only about a quarter of the total cost of driving (Litman, 2005). An elasticity of –0.3 for vehicle travel with respect to fuel price indicates that the overall price elasticity of driving is about –1.2, making driving an elastic good with respect to total vehicle costs. Various types of pricing reforms result in motorists paying more directly the costs of roads, parking (VTPI, 2005).

The price sensitivity of driving is more evident when measured with respect to parking fees and tolls. A modest parking or road fee can significantly influence travel demand. This partly reflects destination and route changes, but also includes changes in mode and travel distance (Pratt 1999). Increases in per-mile or per-trip costs cause motorists to drive less and rely more on other modes.

Factors Affecting Price Sensitivity

Various factors described below can affect how much a change in prices impacts travel activity.

Type of Price Change

Different types of charges can have different impacts on travel behavior. Fixed vehicle purchase and registration fees can affect the number and type of vehicles purchased. Fuel prices and emission fees affect the type of vehicle used. A road toll may shift some trips to other routes and destinations, while congestion pricing (a time-variable fee, higher during congested periods) may shift travel times, as well as changing mode and the total number of trips that occur. These impacts depend on the specific type of pricing – for example, an increase in residential parking fees is most likely to affect vehicle ownership, and a time-variable parking fee can affect when trips occur.

Table 1 **Impacts of Different Types of Pricing**

Type of Impacts	Vehicle Fees	Fuel Price	Fixed Toll	Congestion Pricing	Parking Fee	Transit Fares
Vehicle ownership. Consumers change the number of vehicles they own.	✓				✓	✓
Vehicle type. Motorist chooses different vehicle (more fuel efficient, alternative fuel, etc.)	✓	✓				
Route Change. Traveler shifts travel route.			✓	✓	✓	
Time Change. Motorist shifts trip to off-peak periods.				✓	✓	
Mode Shift. Traveler shifts to another mode.		✓	✓	✓	✓	✓
Destination Change. Motorist shifts trip to alternative destination.		✓	✓	✓	✓	✓
Trip Generation. People take fewer total trips (including consolidating trips).		✓	✓	✓	✓	
Land use changes. Changes in location decisions, such as where to live and work.			✓		✓	✓

Different price changes have different impacts on travel behavior.

Research on *mental accounting* (how consumers perceive expenditures) indicates that price impacts are affected by factors such as how prices compare with what is considered *normal* and *good value*, whether a financial incentive is presented as a discount or a surcharge, and the frequency of fee collection. Consumers tend to measure prices with respect to what they perceive as their *endowment* (what they consider is theirs), and place a greater value on losses than on gains. Some studies indicate that losses from an original endowment are valued at 2.25 times gains (Thaler 1999). For example, a typical motorist could be expected to respond 2.25 times as much to a new parking fee (they pay more if they use a parking space) than a parking cash out incentive (they receive a rebate for reducing their use of parking spaces) of the same amount (Shoup 1997).

Price Structure Complexity

In general, consumers tend to prefer simple price structures that minimize the "cognitive effort" of such decisions (that is, the need to make complex decisions). In a detailed study of how price structures affect consumer response to road pricing, Bonsall, et al. (2006) found the following:

- The method and timing of payments influences purchasing behaviour.
- The distribution on preferences for different payment methods is neither simply related to a desire for best value for money nor a simple reflection of disposable income.
- A significant proportion of consumers 'disengage' if they perceive cost structures to be too complex; this disengagement sometimes leads them to avoid exposure to that cost but sometimes leads them simply to pay-up regardless.
- Attitudes to motoring costs appear to differ from those to other expenses and that drivers rarely consider the costs of individual journeys - motoring expenses are widely perceived as unavoidable periodic events.
- The apparent belief that an increase in usage-based charges, whether increased fuel costs or distance charges, would engender more consideration of driving behaviour and of alternative modes.
- The emergence of a preference for any road user charges to be collected via a surcharge on fuel tax rather than through a separate distance charge - apparently due to the greater expected complexity of the latter system and a disinclination to have to pay another bill.
- Most people have very limited spatial knowledge or ability to estimate distances.
- The frequency with which people allude to the question of fairness when discussing complex pricing structures and the most appropriate basis for charging for consumption of services.
- In the context of purchasing goods and services, there exist a number of 'behavioural
- types' with distinct attitudes, preferences and behaviours, and that these 'types' reflect age and gender more than income.

Type of Trip and Traveler

Commute trips tend to be less elastic than shopping or recreational trips. Weekday trips may have very different elasticities than weekend trips. Urban peak-period trips tend to be price inelastic because congestion discourages lower-value trips, leaving only higher-value automobile trips. Travelers with higher incomes tend to be less price sensitive than lower-income travelers. Travelers on business tend to be less price sensitive than people traveling for personal activities.

Quality And Price Of Alternative Routes, Modes And Destinations.
Price sensitivity tends to increase with the quality and affordability of alternative routes, modes and destinations. For example, highway tolls tend to be more price sensitive if there are parallel untolled roadways. Driving is less price sensitive in automobile-dependent areas where the quality of alternatives is poor. Transportation elasticities can often be measured as ratios, such as:

- The elasticity of automobile mode split with respect to the ratio of automobile and transit travel time for a particular type of trip.
- The elasticity of automobile mode split with respect to the ratio of automobile operating costs and transit fares.
- The elasticity of household vehicle ownership and per capita vehicle ownership with respect to the quality of transit service in a community.

This information can be used to help identify problems and solutions. For example, increased automobile mode split can often be explained by factors such as the increased ratio of automobile travel speeds relative to the speed of alternative modes, and efforts to shift travel to other modes can be evaluated by setting targets for improving their relative quality and affordability.

Scale and Scope of Pricing
In general, narrowly defined transport is more elastic than broadly defined transport, because consumers have more alternatives. For example, demand for *peak-period automobile travel on a certain road* is usually more elastic than for *total personal travel along a corridor*, since a higher price for driving at a particular time at a particular road may shift travel to alternative routes, destinations, modes and travel times.

Most price components of driving (fuel, parking, tolls) are considered inelastic because they each represent a small portion of total user costs. Driving is actually quite elastic with respect to total costs. For example, since fuel is only about 15% of total vehicle costs, a -0.2 elasticity of driving with respect to fuel price represents an elasticity of -1.3 with respect to total financial cost. This implies that if all user costs were converted into variable charges, each 1% increase in this charge would reduce driving by -1.3%.

Time Period
Transportation elasticities tend to increase over time as consumers have more opportunities to take prices into effect when making long-term decisions. For example, if consumers anticipate low automobile use prices they are more likely to choose an automobile dependent suburban home, but if they anticipate significant increases in driving costs they might place a greater premium on having alternatives, such as access to transit and shops within convenient walking distance. These long-term decisions affect the options that are available. For example, if consumers are in the habit of shopping in their neighborhood, local stores will be successful. But if they always shop at large supermarkets, the quantity and quality of local stores will decline.

For this reason, the full effect of a price change often take many years (Button, 1993; Dargay and Gately, 1997). Short-term elasticities (usually defined as less than two years) are typically one-third of long-term elasticities (more than 10 years). Large price changes tend to be less elastic than small price changes, since consumers make the easiest accommodations first. Dargay and Goodwin (1995) argue that the common practice of using static rather than dynamic elasticity values overestimate welfare losses from increased user prices and congestion, because it ignores society's ability to respond to changes over time. Static elasticities skew investments toward increasing highway capacity, and undervalues transit, TDM, and "No Build" options.

Comparing Distant Places and Times

When properly measured, prices often turn out to have similar impacts in distant places and times. It is often best to evaluate price changes relative to wages or incomes than absolute values, particularly when comparing different times or countries. For example, when evaluating the impacts of parking fee changes on travel demand it may be better to measure the fee as a percentage of local hourly wages, so the results can be compared between different countries and time periods.

Large and Cumulative Price Changes

Extra care should be used when calculating the impacts of large price changes, or when summing the effects of multiple changes, because each subsequent change impacts a different base, as explained earlier in the discussion of *arc elasticities*. As a result, travel reductions are multiplicative, not additive. For example, if prices increase 10% on a good with a –0.5 elasticity, the first one-percent of price change reduces consumption by 0.5%, to 99.5% of its original amount. The second one-percent of price change reduces this 99.5% by another 99.5%, to 99.0%. The third one-percent of price change reduces this 99.0% by another 99.5% to 98.5%, and so on for each one-percent change. Thus, the reduction in consumption of a 10% price increase is calculated as $(1-0.005)^{10}$ (one minus 0.005, or 0.995, to the tenth power), which is 4.9%, not a full 5% that would be calculated by simply multiplying –0.5 x 10. Similarly, if three strategies are proposed for implementation, which individually provide a 5%, 6% and 7% reduction in vehicle travel, the total predicted reduction is 17%, calculated as (1-0.05) x (1-0.06) x (1-0.07) = 17.0, not 18% (5 + 6 + 7 = 18).

Transportation Elasticity Estimates

This section summarizes the results of many transportation elasticity studies.

Summaries

The tables below summarize some transport elasticity studies. The elasticities of various types of price changes are described in individual sections in this report.

Table 2 **Estimated Long Run Transport Elasticities** (Johansson & Schipper, 1997, p. 209)

Estimated Component	Fuel Price	Income	Taxation (Other than Fuel)	Population Density
Car Stock (vehicle ownership)	-0.20 to 0.0 (-0.1)	0.75 to 1.25 (1.0)	-0.08 to -0.04 (-0.06)	-0.7 to -0.2 (-0.4)
Mean Fuel Intensity (fuel efficiency)	-0.45 to -0.35 (-0.4)	-0.6 to 0.0 (0.0)	-0.12 to -0.10 (-0.11)	-0.3 to -0.1 (-0.2)
Mean Driving Distance (per car per year)	-0.35 to -0.05 (-0.2)	-0.1 to 0.35 (0.2)	0.04 to 0.12 (0.06)	-0.75 to 0.0 (-0.4)
Car Fuel Demand	-1.0 to -0.40 (-0.7)	0.05 to 1.6 (1.2)	-0.16 to -0.02 (-0.11)	-1.75 to -0.3 (-1.0)
Car Travel Demand	-0.55 to -0.05 (-0.3)	0.65 to 1.25 (1.2)	-0.04 to 0.08 (0.0)	-1.45 to -0.2 (-0.8)

Summarizes various studies. Numbers in parenthesis indicate original authors' "best guess" values.

After a detailed review of international studies, Goodwin (1992) produced the average elasticity values summarized in Table 3. He noted that price impacts tend to increase over time as consumers have more options (related to increases in real incomes, automobile ownership, and now telecommunications that can substitute for physical travel).

Table 3 **Transportation Elasticities** (Goodwin, 1992)

	Short-Run	Long-Run	Not Defined
Petrol consumption WRT petrol price	-0.27	-0.71	-0.53
Traffic levels WRT petrol price	-0.16	-0.33	
Bus demand WRT fare cost	*-0.28*	*-0.55*	
Railway demand WRT fare cost	*-0.65*	*-1.08*	
Public transit WRT petrol price			*0.34*
Car ownership WRT general public transport costs			*0.1 to 0.3*

Summarizes various studies of long-run price effects. ("WRT" = With Respect To).

Table 4 **Consumer Demand Elasticities, European Data** (Mayeres, 2000)

	Price, Peak	Price, Off-Peak	Income
Mileage "Committed" (essential trips)	-0.16	-0.43	0.70
Mileage "Supplementary" (optional trips)	-0.43	-0.36	1.53
Bus, Tram, Metro passenger-kms	-0.19	-0.29	0.59
Rail passenger-kms	-0.37	-0.43	0.84

Table 5 **Australian Travel Demand Elasticities** (Luk & Hepburn, 1993)

Elasticity Type	Short-Run	Long-Run
Petrol consumption and petrol price	-0.12	-0.58
Travel level and petrol price	-0.10	
Bus demand and fare	-0.29	
Rail demand and fare	-0.35	
Mode shift to transit and petrol price	+0.07	
Mode shift to car and rail fare increase	+0.09	
Road freight demand and road/rail cost ratio	-0.39	-0.80

This table shows elasticity values adopted by the Australian Road Research Board for planning and modeling.

Table 6a **Passenger Transport Elasticities** (Small & Winston, 1999, Table 2-2)

	Auto	Bus	Rail	Air
Urban Passenger, Price	-0.47	-0.58	-0.86	
Urban Passenger, In-Vehicle Time	-0.22	-0.60	-0.60	
Intercity Passenger, Price	-0.45	-0.69	-1.20	-0.38
Intercity Passenger, Travel Time	-0.39	-2.11	-1.58	-0.43

Table 6b **Automobile Utilization Elasticities** (Small & Winston, 1999, Table 2-2)

	One-Vehicle Household	Two-Vehicle Household
Short-run Operating Costs	-0.228	-0.059
Long-run Operating Costs	-0.279	-0.099

Table 7 **European Travel Elasticities** (de Jong and Gunn, 2001)

Term/ Purpose	Car-Trips WRT Fuel Price	Car-Kms. WRT Fuel Price	Car-Trips WRT Travel Time	Car-Kms. WRT Travel Time
Short Term				
Commuting	-0.20	-0.12	-0.62	
HB business	-0.06	-0.02		
NHB business	-0.06	-0.02		
Education	-0.22	-0.09		
Other	-0.20	-0.20	-0.52	
Total	-0.16	-0.16	-0.60	-0.20
Long Term				
Commuting	-0.14	-0.23	-0.41	-0.63
HB business	-0.07	-0.20	-0.30	-0.61
NHB business	-0.17	-0.26	-0.12	-0.53
Education	-0.40	-0.41	-0.57	-0.76
Other	-0.15	-0.29	-0.52	-0.85
Total	-0.19	-0.26	-0.29	-0.74

WRT = "With Respect To" HB = "Home Based" NHB = "Not Home Based"

Table 8 **Overall results: Various elasticities** (Goodwin, Dargay and Hanly, 2003)

Dependent Variable	Short term	Long term
Fuel consumption (total)		
Mean elasticity	-0.25	-0.64
Standard deviation	0.15	0.44
Range	-0.01, -0.57	0, -1.81
Number of estimates	46	51
Fuel consumption (per vehicle)		
Mean elasticity	-.08	-1.1
Standard deviation	N/A	N/A
Range	-.08, -.08	-1.1, -1.1
Number of estimates	1	1
Vehicle kilometres (total)		
Mean elasticity	-0.10	-0.29
Standard deviation	0.06	0.29
Range	-0.17, -0.05	-0.63, -0.10
Number of estimates	3	3
Vehicle kilometres (per vehicle)		
Mean elasticity	-0.10	-0.30
Standard deviation	0.06	0.23
Range	-0.14, -0.06	-0.55, -0.11
Number of estimates	2	3
Vehicle stock		
Mean elasticity	-0.08	-0.25
Standard deviation	0.06	0.17
Range	-0.21, -0.02	-0.63, -0.10
Number of estimates	8	8

Whelan (2007) identifies various factors that affect vehicle ownership, including household demographics, income and location. Giuliano and Dargay (2006) compare UK and US travel patterns. They find that UK residents own fewer automobiles and make fewer and shorter motor vehicle trips due to a combination of lower real incomes, higher vehicle fees (particularly fuel taxes) and better travel options (better walking and cycling conditions, better public transport services, and more local shops). Based on a major review of elasticity studies Goodwin, Dargay and Hanly (2004) conclude that:

- Fuel consumption elasticities are greater than traffic elasticities, mostly by factors of 1.5 to 2.
- Long run elasticities are greater than short run, mostly by factors of 2 to 3.
- Income elasticities are greater than price, mostly by factors of 1.5 to 3.

They conclude that if the real (inflation adjusted) price of fuel rises by 10% and stays at that level, the result is a dynamic process of adjustment such that the following occur:

- Traffic volume falls about 1% within a year, increasing to a 3% reduction in the longer run (about 5 years or so).
- Fuel consumption falls about 2.5% within a year, increasing to a 6% longer run reduction.
- Efficiency of fuel use rises by about 1.5% within a year, and around 4% in the longer run.
- Total vehicle ownership falls by less than 1% in the short run and 2.5% in the longer run.

The also conclude that if real income goes up by 10%, the following occurs:

- Number of vehicles, and the total amount of fuel they consume, will both rise by nearly 4% within about a year, and by over 10% in the longer run.
- Traffic volume (i.e., total vehicle travel) increases about 2% within a year and 5% in the longer run, indicating that the additional vehicles are driven less than average mileage.

DKS (2003) provides information on the impacts of various TDM programs, including various pricing strategies.

Table 9 **Vehicle Travel Elasticities** (Moore & Thorsnes, 1994)

Cost Component	Short Run Effect	Long Run Effect
Out-of-Pocket Price		
Fuel (work)	- Low	- Low to Medium
Fuel (non-work)	- Medium	- Medium to High
Highway tolls	- Medium	- High
Parking fees	-Low	- High
Time Costs		
Riding time	- Low	- Medium
Parking search	- Low	- High
Congestion	- Low	- High
Cost of Alternatives		
Transit fare	+ Low	+ Low
Transit access time	+ Low	+ Low

Elasticities: Low = 0 to 0.5; Medium = 0.5 to 1.0; High = 1.0+

Burt and Hoover (2006) found the following vehicle travel elasticities. This indicates, for example, that each 1% increase in the portion of national population living in urban areas reduces per capita annual light truck mileage by about 5.0% and car travel by about 2.4%.

Table 10 **Light Duty Vehicle Travel Demand Coefficients** (Burt and Hoover, 2006)

Factor	Light Truck Travel	Car Travel
The share of national population living in urban areas	–4.984	–2.413
Vehicles per person of driving age	1.097	1.010
Real per capita disposable income	0.721	0.705
Vehicle-kilometres traveled per person of driving age (lagged one period)	0.163	0.220
The price of gasoline relative to the price of local transit	–0.195	–0.080
The lane-kilometres of road network per person of driving age	0.490	0.267

Louis Berger Group (2004) provides recommended elasticity values for vehicle travel with respect to numerous transportation and land use factors including regional accessibility, land use density and mix, lane-miles, travel time, transit service, sidewalks and other pedestrian facilities.

Santos and Catchesides (2005) evaluate the equity and travel impacts of fuel taxes using U.K. consumer and travel survey data. They find the most price sensitivity among lower-income urban households, who show an elasticity of -0.93 (each 1% increase in fuel price causes a -0.93% reduction in vehicle mileage), and the lowest price sensitivity among middle-income rural residents, who show an elasticity of -0.75. Income elasticity range from -0.63 for lower-income urban households to -0.07 for the richest rural residents. Their analysis indicates the following factors affecting vehicle travel:

- *Real cost per mile:* Real cost per mile has a negative and statistically significant effect on mileage, such that an increase in the real cost per mile causes a drop in mileage.
- *Real household income:* Real income has a positive and statistically significant effect on mileage, but the rate of increase of mileage declines with income.
- *Age of head of household:* Age has a positive and statistically significant effect on mileage, but the rate of increase of mileage declines with age.
- *Number of children:* The number of children in the household has a positive and significant effect on mileage.
- *Employment status of head of household:* All categories have lower mileage compared to full-time workers, although the effect is statistically significant only for the retired.
- *Occupational class:* Professionals have increased mileage, and skilled manual workers reduced mileage, compared to an unskilled manual worker. The difference for non-manual workers is not statistically significant.
- *Availability of public transport:* Available and frequent public transport services have a statistically significant negative impact on mileage.
- *Population density:* Households in the least densely populated areas have significantly increased mileages compared to those in the most densely populated areas.

Bento, et al (2003) identify the following factors affecting household vehicle travel, based on a comparison of 113 U.S. cities:

Table 11 **Factors Affecting Household Vehicle Travel** (Bento, et al, 2003)

	Annual VMT		Annual VMT
Additional working adult male	6,070	10% increase in education	1,239
Additional working adult female	4,779	10% increase in income	588
Additional working child	8,461	10% increase in central location	-281
		10% increase in accessible city shape	-84
		10% increase in road density	127
		10% increase in bus service	-1
		10% increase in rail service	-40
		10% increase in jobs-housing imbalance	107
		10% increased distance to nearest bus stop	151

This table summarizes how various factors affect average household vehicle mileage in U.S. cities. Employment and income have the greatest impacts, but land use factors can also affect vehicle travel.

Using a detailed travel survey integrated with a sophisticated land use model, Frank, et al. (2008) found that a 10% increase in fuel or parking costs reduced automobile mode split by 0.7%, and increased demand for carpooling by 0.8%, transit by 3.71%, biking by 2.7% and walking by 0.9%.

Individual Elasticities

The elasticities of different types of transportation prices found in various studies are discussed below.

Vehicle Operating (Out-of-Pocket) Expenses

This refers to the travel effects of vehicle operating expenses (i.e., variable monetary costs), including fuel, parking fees and road tolls. Button estimates the elasticity of driving with respect to out-of-pocket costs for various trips, shown in Table 12. Oum, Waters, and Yong (1992) estimate the elasticity of vehicle travel with respect to price is -0.23 in the short run and -0.28 in the long run. Oum, Van Ooststroom and Yoon (1996) found the elasticity of automobile travel in the Netherlands to range between -0.02 and -0.28. De Borger, et al, (1997) find elasticities for urban peak travel in Belgium to be -0.384 for automobile and -0.35 for public transit, with higher values for off-peak travel.

Table 12 **Elasticity Estimates for Various Trip Types** (Button, 1993)

Trip Type	Elasticity of Road Travel with Respect to Out of Pocket Expenses
Urban shopping	-2.7 to -3.2
Urban commuting	-0.3 to - 2.9
Inter-urban business	-0.7 to -2.9
Inter-urban leisure	-0.6 to -2.1

Small and Winston (1999) find that the price sensitivity of a particular motor vehicle's use increases over time and depends on whether or not it is a household's only vehicle, as shown in Table 6b. This has important implications for analyzing the effects that pricing can have on the use of vehicles that have desirable attributes, such as increased fuel efficiency or reduced pollution emissions.

Parking Price

Motorists tend to be particularly sensitive to parking price because it is such a direct charge ("Parking Pricing," VTPI, 2005). Compared with other out-of-pocket expenses, parking fees are found to have a greater effect on vehicle trips, typically by a factor of 1.5 to 2.0 (USEPA, 1998). For example, a $1.00 per trip parking charge is likely to cause the same reduction in vehicle travel as a fuel price increase averaging $1.50 to $2.00 per trip.

Several studies (K.T. Analytics, 1995; Shaw, 1997; Vaca and Kuzmyak, 2005) provide detailed reviews of parking price elasticities. Vaca and Kuzmyak (2005) summarizes studies from North America and Europe on the effects of parking price changes on travel behavior, taking into account demographic factors and travel conditions, and type of trip; including changes in the magnitude and structure of prices, elimination of employee parking subsidies, rideshare vehicle parking discounts and park-and-ride facility pricing.

Kuzmyak, Weinberger and Levinson (2003) describe how parking supply affects parking and travel demand, but this may actually reflect price impacts (reduced parking supply increases prices). These studies indicate that the elasticity of vehicle trips with regard to parking prices is typically in the –0.1 to –0.3 range, with significant variation depending on demographic, geographic, travel choice and trip characteristics. Pratt (1999, p. 13-40) finds significantly higher elasticities (-0.9 to -1.2) of parking price with regard to commercial parking gross revenues, since motorists can respond to higher prices by reducing their parking duration or changing to cheaper locations and times, as well as reducing total vehicle trips. Similarly, in a study of downtown parking meter price increases, Clinch and Kelly (2003) find that the elasticity of parking frequency is smaller (–0.11) than the elasticity of vehicle duration (-0.20), indicating that some motorists respond to higher fees by reducing how long they stay.

Table 13 **Parking Price Elasticities** (TRACE, 1999, Tables 32 & 33)

Term/Purpose	Car Driver	Car Passenger	Public Transport	Slow Modes
Trips				
Commuting	-0.08	+0.02	+0.02	+0.02
Business	-0.02	+0.01	+0.01	+0.01
Education	-0.10	+0.00	+0.00	+0.00
Other	-0.30	+0.04	+0.04	+0.05
Total	*-0.16*	*+0.03*	*+0.02*	*+0.03*
Kilometres				
Commuting	-0.04	+0.01	+0.01	+0.02
Business	-0.03	+0.01	+0.00	+0.01
Education	-0.02	+0.00	+0.00	+0.00
Other	-0.15	+0.03	+0.02	+0.05
Total	*-0.07*	*+0.02*	*+0.01*	*+0.03*

This table indicates how parking fees affect travel patterns for various types of trips. For example, a 10% increase in commuter parking prices will reduce automobile trips and parking demand by 0.8%, and increase car passenger trip, public transport travel and slow mode travel (Walking and Cycling) by 0.2% each.

TRACE (1999) provides detailed estimates of the elasticity of various types of travel (car-trips, car-kilometers, transit travel, walking/cycling, commuting, business trips, etc.) with respect to parking price under various conditions (e.g., level of vehicle ownership and transit use, type of trip, etc.). Table 13 summarizes long-term elasticities for relatively automobile-oriented urban regions.

Hess (2001) assesses the effect of free parking on commuter mode choice and parking demand in Portland's (Oregon) CBD. He found that where parking is free, 62% of commuters drive alone, 16% carpool and 22% ride transit; with a $6.00 daily parking charge 46% drive alone, 4% carpool and 50% ride transit. The $6.00 parking charge results in 21 fewer cars driven for every 100 commuters, a daily reduction of 147 VMT per 100 commuters and an annual reduction of 39,000 VMT per 100 commuters.

Hensher and King (2001) model the price elasticity of CBD parking, and predict how an increase in parking prices in one location will shift cars to park at other locations and drivers to public transit (Table 14). Harvey (1994) finds that airport parking prices range from -0.1 for less than a day to -2.0 for greater than 8 days.

Table 14 **Parking Elasticities** (Hensher and King, 2001, Table 6)

	Preferred CBD	Less Preferred CBD	CBD Fringe
Car Trip, Preferred CBD	-0.541	0.205	0.035
Car Trip, Less Preferred CBD	0.837	-0.015	0.043
Car Trip, CBD Fringe	0.965	0.286	-0.476
Park & Ride	*0.363*	*0.136*	*0.029*
Ride Public Transit	*0.291*	*0.104*	*0.023*
Forego CBD Trip	0.469	0.150	0.029

This table shows elasticities and cross-elasticities for changes in parking prices at various Central Business District (CBD) locations. For example, a 10% increase in prices at preferred CBD parking locations will cause a 5.41% reduction in demand there, a 3.63% increase in Park & Ride trips, a 2.91% increase in Public Transit trips and a 4.69% reduction in total CBD trips.

One survey found that about 35% of drive-alone commuters would likely switch modes in response to $20 per month parking fees, even if offset by a transportation voucher (Kuppam, Pendyala and Gollakoti, 1999). This study found that mode shifting increases for lower income, and if transit, ridesharing and sidewalks are available. Trip Reduction Tables in Comsis Corporation, 1993 predict travel reductions resulting from parking fees and other commuter financial incentives. The table below shows an example from these tables ("Trip Reduction Tables," VTPI, 2005).

Table 15 **Commute Trip Reductions from Daily Parking Charges** (Comsis Corp. 1993)

	$1	$2	$3	$4
Suburb	6.5%	15.1%	25.3%	36.1%
Suburban Center	12.3%	25.1%	37.0%	46.8%
Central Business District	17.5%	31.8%	42.6%	50.0%

This table illustrates the reduction in automobile commute trips likely to result from a given daily parking fee at worksites. (1993 U.S. dollars)

Harvey and Deakin (1998) model the effect of parking fee on commuters in four California regions, as summarized in Table 16. It indicates, for example, that in the South Coast (Los Angeles) region, a $3 (1991 U.S. dollars) daily parking fee would reduce total vehicle trips by about 2.8%, but congestion delay would decline by a much larger amount (8.5%), because most of the travel reduction occurs during peak traffic periods.

Table 16 **Employee Parking Fees, Year 2010** (Harvey and Deakin, 1998, Table B.7)

Region	Price	VMT	Trips	Delay	Fuel	ROG	Revenue
Bay Area	$1.00	-0.8%	-0.9%	-2.7%	-1.0%	-0.8%	$473
	$3.00	-2.1%	-2.4%	-7.0%	-2.4%	-2.3%	$1,399
Sacramento	$1.00	-1.0%	-1.1%	-2.5%	-1.1%	-1.1%	$142
	$3.00	-2.6%	-2.8%	-6.5%	-2.7%	-2.8%	$419
San Diego	$1.00	-0.9%	-1.0%	-2.5%	-1.0%	-0.9%	$271
	$3.00	-2.4%	-2.6%	-7.0%	-2.5%	-2.5%	$800
South Coast	$1.00	-0.9%	-1.1%	-2.9%	-1.1%	-1.0%	$1,408
	$3.00	-2.5%	-2.8%	-8.5%	-2.7%	-2.6%	$4,151

Price = minimum daily parking fee for SOV commuters. *VMT* = change in total vehicle mileage. *Trips* = change in total vehicle trips. *Delay* = change in congestion delay. *Fuel* = change in fuel consumption. *ROG* = a criteria air pollutant. *Revenue* = annual revenue in millions of 1991 dollars. See report for additional notes.

Parking fees affect trip destinations as well as vehicle use. An increase in parking prices can reduce use of parking facilities at a particular location, but this may simply shift vehicle travel to other locations. Increased parking prices may result in spillover parking problems, as motorists find nearby places to park for free illegally ("Parking Management," VTPI, 2005). However, if parking prices increase throughout an area, there is effective enforcement of parking regulations, and there are good travel alternatives, parking price increases can reduce total vehicle travel. For some types of trips, pricing can affect parking duration, such as how long shoppers stay at a store.

The use of parking price elasticities can be confusing since most parking is currently free, so it is meaningless to measure percentage increases from zero price. The table below summarizes the commute mode shifts occurring at worksites that changed from free to priced parking. Other case studies find similar impacts. Shifting from free to priced parking typically reduces drive alone commuting by 10-30%, particularly if implemented with improvements in transit service and rideshare programs and other TDM strategies.

Table 17 **Changes in Workplace Travel Due to Parking Pricing**

	Canadian Study			Los Angeles Study		
	Before	After	Change	Before	After	Change
Drive Alone	35%	28%	*-20%*	55%	30%	*-27%*
Carpool	11%	10%	*+9%*	13%	45%	*+246%*
Transit	42%	49%	*+17%*	29%	22%	*-24%*
Other	12%	13%	*-8%*	3%	3%	*0%*

(Feeney, 1989, cited in Pratt, 1999)

Farrell, O'Mahony and Caulfield (2005) survey university employees to determine how they would respond to parking pricing and cash out. They found that most employees would reduce their automobile trips in response to a €5 daily fee, and one third would reduce their trips in response to parking cash out. Shiftan (1999) surveyed motorists driving to a commercial district in Haifa, Israel to determine how they would respond to higher fees. Of 200 motorists surveyed there, 78% currently parked for free (67% on-street, 11% at employee off-street parking lots). Their predicted reduction in vehicle trips is summarized below. Non-work trips tended to be more price-sensitive than work trips.

New Israeli Shekels (NISs)/U.S. dollars per hour	Parking Demand Decline
5 NIS/$1.00	29%
10 NIS/$1.00	50%
10 NIS/$1.00	58%

Washbrook, Haider and Jaccard (2006) surveyed Vancouver, British Columbia region commuters to determine how they would respond to various incentives. Table 18 shows how various road and parking fees would affect their drive alone rates. For example, with unpriced roads and parking, 83% of commuters drive alone, but this declines to 75% if there is a CA$1.00 ($0.64 US) parking charge and a CA$1.00 daily road toll. A $9.00 ($5.72 US) parking fee and a $9.00 road toll together reduce automobile commute mode split to 17%, which equals a total reduction in drive alone demand of 80%.

Table 18 **Automobile Commute Mode Split** (Washbrook, Haider and Jaccard, 2006)

Road Toll	Free Parking	$1 Parking	$3 Parking	$6 Parking	$9 Parking
$0	83%	80%	74%	62%	49%
$1	78%	75%	68%	55%	42%
$3	68%	65%	56%	43%	30%
$6	56%	52%	43%	31%	21%
$9	50%	46%	37%	26%	17%

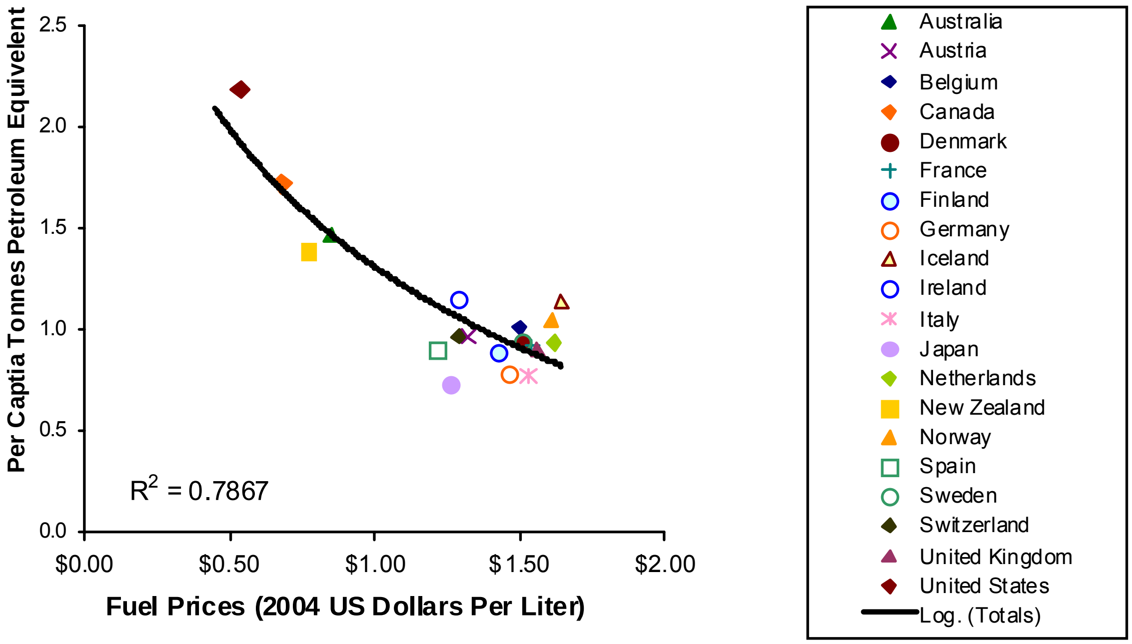
This table indicates the automobile commute mode split that can be expected from various combinations of road tolls and parking fees in the Vancouver region.

Shoup (1992) finds that charging employees for parking reduces solo commuting by 20-40%. A study by ICF (1997) indicates that a $1.37 to $2.73 increase in parking fees (1993 U.S. dollars) reduces auto commuting 12-39%, and if matched with transit and rideshare subsidies, can reduce total auto trips by 19-31%. Parking supply can affect travel behavior by affecting parking convenience, parking price and walkability (Morrall and Bolger, 1996). Increased parking supply tends to increase automobile commuting and reduce transit and ridesharing (Mildner, Strathman and Bianco, 1997). How parking prices are structured also affects travel patterns. Large discounts for long-term parkers (e.g., lower-priced monthly leases) encourages automobile commuting, while pricing that discounts short-term use (e.g., "First-Hour-Free" rates) favor shoppers and business trips. Rate increases of $1-2 per day directed at commuters are found to reduce long-term parking demand by 20-50%, although much of this may consist of shifts to other parking locations rather than alternative modes (Pratt, 1999).

Fuel Consumption With Respect to Fuel Price

Fuel price increases tend to cause fuel consumption to decline, in the short-term by reducing total vehicle mileage and traffic speeds, and shifting travel to more fuel-efficient vehicles in multi-vehicle households, and in the long-term by increasing vehicle fuel economy[1] and more accessible land use patterns (Institute for Transport Studies 2004; Sterner 2006; Lipow 2008; CBO 2008; Sivak and Schoettle 2009; UKERC 2009).

Figure 3 **Fuel Price Versus Per Capita Transport Energy Consumption** (VTPI 2007)



As fuel prices increase, per capita transportation energy consumption declines.

Motorists in countries with higher fuel prices tend to drive more fuel efficient vehicles, drive fewer annual miles and rely more on alternative modes, as illustrated in Figure 3.

Table 19a **Fuel Price, Vehicle Travel and Economy** (Garrison & Levinson, 2006, p. 264)

	Fuel Price	Annual Mileage	Fuel Economy	Fuel Consumption
	per liter	Veh-Kms Per Capita	liters per 100 kms	Annual liters
United States	*$0.39 (100%)*	*19,099 (100%)*	*10.0 (100%)*	*1,910 (100%)*
Japan	$0.96 (246%)	8,032 (42%)	8.0 (80%)	643 (34%)
France	$1.06 (272%)	14,629 (77%)	7.0 (70%)	1,024 (54%)
Germany	$0.99 (254%)	12,475 (65%)	8.0 (80%)	998 (52%)
Sweden	$1.11 (285%)	14,611 (77%)	9.8 (98%)	1,432 (75%)
UK	$1.35 (346%)	17,187 (90%)	8.0 (80%)	1,375 (72%)
Canada	$0.54 (138%)	15,578 (82%)	9.8 (98%)	1,527 (80%)

Countries with higher fuel prices tend to have lower per-capita vehicle mileage and higher fuel economy, resulting in lower total fuel consumption. Percentage values are relative to the U.S.

[1] *Fuel economy* refers to fuel consumption rates per mile or kilometer. *Fuel efficiency* refers to fuel consumption per horsepower, which may increase vehicle performance without improving fuel economy.

Tables 19a and 19b also compare fuel prices and per capita annual vehicle travel and transportation energy consumption for various countries. Motorists in countries with low fuel prices tend to use improvements in vehicle energy *efficiency* (power per unit of fuel consumed) to increase vehicle performance (power and size) rather than improving *fuel economy* (distance traveled per unit of fuel consumed) (Lutsey and Sperling 2005).

Table 19b **Fuel Price, Consumption and Vehicle Travel** (VTPI 2007)

Country	Fuel Prices		Annual Transport Energy Use		Annual Vehicle Travel	
	US Cents Per Liter		Petrol Equivalent Tonnes/Cap.		Kms/Cap.	
		To U.S.		*To U.S.*		*To U.S.*
Australia	$0.85	*54%*	1.47	*67%*	NA	
Austria	$1.32	*85%*	0.96	*44%*	NA	
Canada	$0.68	*44%*	1.72	*79%*	15,169	*66%*
Czech Republic	$1.08	*69%*	0.60	*27%*	7,516	*33%*
Denmark	$1.51	*97%*	0.94	*43%*	13,058	*57%*
France	$1.54	*99%*	0.91	*42%*	12,977	*56%*
Finland	$1.42	*91%*	0.88	*40%*	12,865	*56%*
Germany	$1.46	*94%*	0.78	*36%*	10,186	*44%*
Greece	$1.14	*73%*	0.73	*33%*	3,812	*17%*
Hungary	$1.30	*83%*	0.38	*18%*	6,428	*28%*
Iceland	$1.64	*105%*	1.14	*52%*	16,217	*70%*
Ireland	$1.29	*83%*	1.14	*52%*	NA	
Italy	$1.53	*98%*	0.77	*35%*	15,453	*67%*
Japan	$1.26	*81%*	0.73	*34%*	6,602	*29%*
Korea	$1.35	*87%*	0.72	*33%*	NA	
Netherlands	$0.59	*38%*	0.93	*43%*	9,961	*43%*
New Zealand	$1.62	*104%*	1.38	*63%*	NA	
Norway	$0.77	*49%*	1.05	*48%*	12,301	*53%*
Poland	$1.61	*103%*	0.30	*14%*	5,256	*23%*
Russian Fed.	$0.45	*83%*	NA		-	*0%*
Spain	$1.21	*224%*	0.90	*41%*	9,270	*40%*
Sweden	$1.51	*280%*	0.94	*43%*	11,619	*50%*
Switzerland	$1.29	*239%*	0.96	*44%*	12,409	*54%*
Turkey	$1.44	*267%*	0.19	*9%*	2,305	*10%*
United Kingdom	$1.56	*289%*	0.90	*41%*	11,614	*50%*
United States	$0.54	*100%*	2.18	*100%*	23,095	*100%*

This table compares transportation fuel prices, energy consumption, vehicle travel and traffic fatalities of various countries. Italic values show each factor relative to those in the U.S.

Using 1982-1995 U.S. data, Agras and Chapman (1999) find short-term fuel price elasticities of -0.15 for vehicle mileage and 0.12 for fuel economy, summing to an overall short-run gasoline price elasticity of –0.25, and long-run elasticities of –0.32 for vehicle travel and 0.60 for fuel economy, summing to –0.92 in the long run. This means that a 10% fuel price increase typically reduces driving 1.5% and improves fuel economy by 1.2% in the short-run, and over the long run mileage declines 3.2% and fuel efficiency increase 6%, leading to a 9.2% overall reduction in fuel consumption.

Glaister and Graham (2000) review international studies on fuel price and income impacts on vehicle travel and fuel consumption. They find short run elasticities from –0.2 to –0.5, and long run elasticities from –0.24 in the U.S. (ranging from –0.24 to –0.8) up to –1.35 in the OECD overall (ranging from –0.75 to –1.35). They identify factors that affect fuel price elasticities including functional form, time span, geography and what other factors are included in a model (such as vehicle ownership), and find that long-term gasoline demand appears to be getting more elastic. They conclude that short-run elasticities are –0.2 to –0.3, and long-run elasticities are –0.6 to –0.8. Summarizing international research, Goodwin (1992) estimates gasoline price elasticity to be -0.27 in the short run and -0.7 in the long run. He predicts that a 10% vehicle fuel price increase will have the following effects:

- In the short run vehicle travel declines about 1.5% and fuel consumption 2.7%, due in part to shifts to more fuel efficient vehicles in multi-vehicle households and reduced speeds.
- In the long run vehicle travel declines 3-5%, split between reduced car ownership and per-vehicle use. Petroleum consumption declines 7% or more, due in part to the purchase of more fuel-efficient vehicles.

In a major review, Goodwin, Dargay and Hanly (2003) conclude that a durable, 10% real (inflation adjusted) fuel price increase causes the following adjustment process:

A. Vehicle travel declines by approximately 1% within about a year and about 3% in the longer run (about five years).
B. Fuel consumption declines approximately 2.5% within a year and 6% in the longer run.

Fuel consumed declines more than vehicle travel because motorists purchase more fuel-efficient vehicles and drive more carefully. As a result, price increase cause:

C. Vehicle fuel efficiency increases approximately 1.5% within a year and approximately 4% over the longer run.
D. Total vehicle ownership declines less than 1% in the short run and 2.5% in the longer run.

The results indicate that fuel price affect vehicle purchase decisions, which affects total vehicle travel. However, many studies only assess vehicle ownership, per vehicle mileage or traffic, but not at the same time or using the same data. Their analysis suggests that (A) and (B) effects are more robust than (C) and (D) effects.

Dargay (1992) reports higher fuel price elasticities averaging -0.67 when price increases and decreases are calculated separately. Sterner et al (1992) found relatively high fuel elasticities in North America, greater than -1.0. DeCicco and Gordon (1993) calculate the medium-run U.S. vehicle fuel price elasticity to be -0.3 to -0.5. Eltony (1993) finds the Canadian fuel price elasticity to be approximately -0.3 in the short term and rises to approximately 1.0 after a decade. Hagler Bailly (1999) conclude that the fuel price elasticity for gasoline is –0.15 in the short run and –0.6 in the long run, with separate estimates for air, freight and transit transport. Table 20 summarizes the price elasticities of various types of transportation fuel. Using 1980-2000 U.S. data, Zupan (2001) finds little relationship between fuel price and VMT in the short-term, but a relationship is found if price changes are evaluated with a 6-month lag, indicating that approximately 25% of VMT changes can be accounted for by fuel price.

Table 20 **Estimated Fuel Price Elasticities** (Hagler Bailly 1999)

	Short Run Elasticity			Long Run Elasticity		
	Low	Base	High	Low	Base	High
Road Gasoline	-0.10	-0.15	-0.20	-0.40	-0.60	-0.80
Road Diesel - Truck	-0.05	-0.10	-0.15	-0.20	-0.40	-0.60
Road Diesel – Bus	-0.05	-0.10	-0.15	-0.20	-0.30	-0.45
Road Propane	-0.10	-0.15	-0.20	-0.40	-0.60	-0.80
Road CNG	-0.10	-0.15	-0.20	-0.40	-0.60	-0.80
Rail Diesel	-0.05	-0.10	-0.15	-0.15	-0.40	-0.80
Aviation Turbo	-0.05	-0.10	-0.15	-0.20	-0.30	-0.45
Aviation Gasoline	-0.10	-0.15	-0.20	-0.20	-0.30	-0.45
Marine Diesel	-0.02	-0.05	-0.10	-0.20	-0.30	-0.45

This table summarizes Canadian price elasticities for various vehicle fuels.

Meta-analysis by Espey (1996) evaluated price and income elasticity estimates in 101 U.S. gasoline demand studies. It found the gasoline price-elasticity of averages -0.26 short-run (one year or less), and -0.58 the long-run (longer than 1 year). Among the explanatory variables considered in the meta-analysis included functional form, lag structure, time span, and geographic scope. Including vehicle ownership in gasoline demand studies was found to result in lower estimates of income elasticity, data sets which pool U.S. and foreign data result in larger (absolute) estimates of both price and income elasticity, and the small difference between static and dynamic models suggests that lagged responses to price or income changes are relatively short. This study found that elasticity estimates appear relatively robust across estimation techniques.

Sipes and Mendelsohn (2001) surveyed motorists concerning their response to fuel price increases. They find an elasticity of -0.4 to -0.6 in the short-run and -0.5 to -0.7 in the long run, with greater price sensitivities for larger and poorer households. Kennedy and Wallis (2007) calculate that the price elasticity of fuel in New Zealand is –0.15 in the short run (less than two years) and –0.20 in the medium run (2-4 years).

Analyzing 1971-1997 OECD energy and price data, Gately and Huntington (2001) find the long-run price elasticities of 64% for petroleum and 24% for all energy. They report a long-run income-elasticity of 55-60% for oil and energy, indicating that 3% GDP growth would increase energy use less than a 2%, all things equal (i.e., constant prices). Sterner (2006) estimates the long-term vehicle fuel price elasticity to be -0.8, and calculates the carbon emission reductions that would have resulted if during the last three decades all OECD countries had high fuel taxes (about 44%), and the additional emissions if all countries had low fuel taxes (about 40%). Wadud, Graham and Noland (2008) find heterogeneity in price and income elasticities for different demographic and income groups; elasticities are higher in multi-vehicle, multi-wage earner, urban households, and are lower in single car, single (or no) wage earner, and rural household.

North American fuel price elasticities declined between 1980 and 2005 (CBO 2008). Using U.S. state-level data, Hughes, Knittel and Sperling (2006) found short-run fuel price elasticities from -0.21 to -0.34 during 1975-80, but only -0.034 to -0.077 during 2001-06. Using somewhat more comprehensive data Small and Van Dender (2005 and 2007) found the gasoline price elasticities were -0.09 in the short run and -0.40% in the long run during the 1997 to 2001 period, about half the values observed from 1966 to 1996. They implied that these trends will continue, resulting in ever declining price sensitivity. However, those results likely reflect unique factors during those years, including declining real fuel prices, demographics (peak Baby Boom driving years), and sprawl-encouraging development policies. Recent studies suggest that fuel price elasticities increased after 2006. In 2007 and 2008, per capita fuel consumption and vehicle travel declined, suggesting that fuel prices are high enough to significantly affect consumer behavior (CERA 2006; Williams Derry 2008). Komanoff (2008) estimates that the short-run U.S. fuel price elasticity reached a low of -0.04 in 2004, but this increased to -0.08 in 2005, -0.12 in 2006 and -0.16 in 2007.

This probably reflects a number of factors, particularly the growing share of total household budgets devoted to fuel. For example, in 2004, when gasoline averaged $1.88 per gallon, an average household that drives 20 miles per gallon (mpg) vehicles 20,000 annual miles spent about $1,900 annual on fuel, about 3.3% of total household expenditures. Purchasing a less efficient vehicle, that gets 15 mpg, or a more automobile-dependent location that requires 30,000 annual miles, increases these costs several hundred dollars annually, but still seemed affordable to many households. In July 2008, when fuel averages about $4.10 per gallon, a household must pay $4,100 for 20,000 miles at 20 mpg, nearly as much as was previously spent by the highest fuel consuming households (15 mpg, 30,000 annual miles), and driving a less efficient vehicle or high annual mileage adds thousands of dollars to annual fuel costs, as indicated in Table 21.

Table 21 **Fuel Costs as Portion of Household Income, 2004 and 2008**

	2004			2008		
Fuel Price	$1.88 per gallon			$4.10 per gallon		
Fuel Economy	30 mpg	20 mpg	15 mpg	30 mpg	20 mpg	15 mpg
10,000 annual miles	$627 (1.4%)	$940 (2.2%)	$1,253 (2.9%)	$1,367 (2.8%)	$2,050 (4.2%)	$2,733 (5.6%)
20,000 annual miles	$1,253 (2.9%)	$1,880 (3.3%)	$2,507 (5.8%)	$2,733 (5.6%)	$4,100 (8.5%)	$5,467 (11.3%)
30,000 annual miles	$1,880 (4.3%)	$2,820 (6.5%)	$3,760 (8.7%)	$4,100 (8.5%)	$6,150 (12.7%)	$8,200 (16.9%)

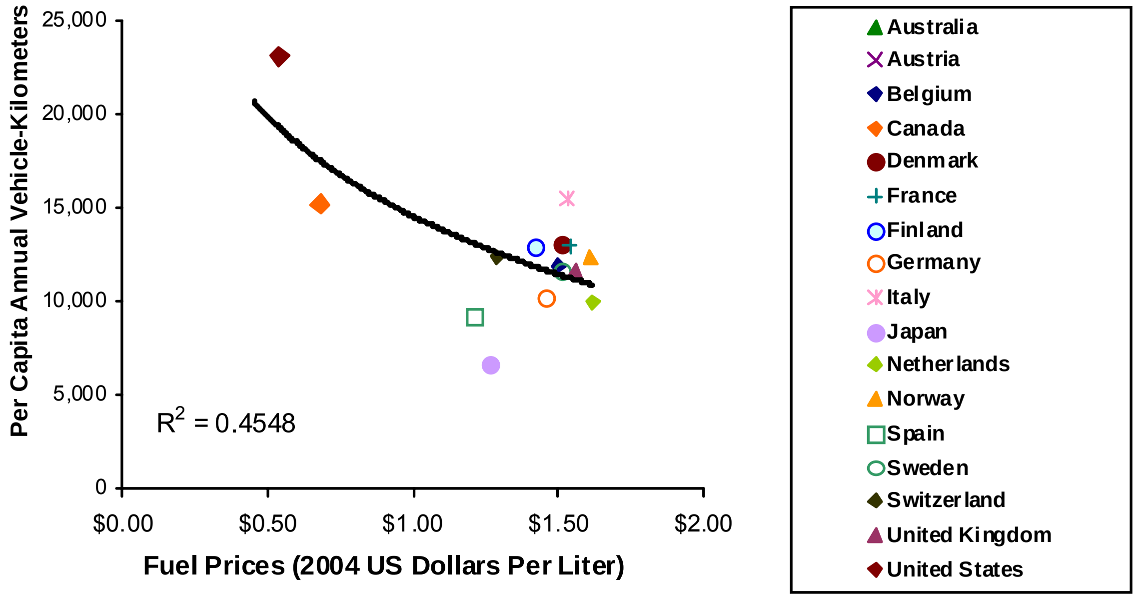
This table compares fuel expenditures as a portion of average household budgets in 2005, when vehicle fuel prices averaged $2.30, and 2008 when fuel prices averaged $4.10.

Research by Enerdata (2009) indicates that each 1% reduction in global oil demand reduces oil prices by 1.6 to 1.8% over a 10 year timeframe, and by 1.2 to 1.3% over a 20-year timeframe. As a result, some of the projected energy savings that result from technical strategies that increase vehicle fuel efficiency (such as fuel efficiency standards) will be offset by increased fuel consumption due to reduced energy prices.

Vehicle Travel With Respect to Fuel Price

As mentioned above, about a third of the fuel savings that result from increased fuel prices consist of reductions in vehicle mileage.

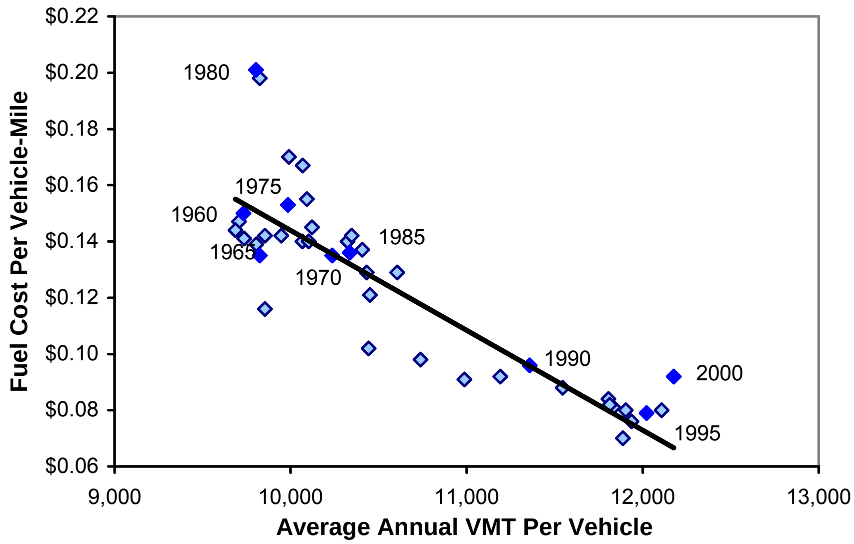
Figure 4 **Fuel Price Versus Per Capita Vehicle Travel** (VTPI 2007)



Higher fuel prices tend to reduce per capita vehicle travel.

Figures 4 and 5 illustrate how changes in real fuel prices (adjusted for inflation and currency exchange) affect per capita annual vehicle travel.

Figure 5 **Fuel Costs Versus Annual Vehicle Mileage** (BTS 2001)



Per capita vehicle mileage tends to increase when real (inflation-adjusted) per-mile fuel costs decline. For a spreadsheet with the source data of this graph, click here: [FuelTrends]

Schimek (1997) finds the elasticity of vehicle travel with respect to fuel price in the U.S. to be -0.26. These results are consistent with international research (Johansson and Schipper 1997). One study finds that a $0.40 to $2.00 increase in fuel prices would reduce Puget Sound region vehicle trips by 1.2-6.7%, and vehicle mileage by 1.4-7.2% (PSRC 1994). INFRAS (2000) cites estimates of the long-term elasticity of vehicle use with respect to fuel price to typically average about –0.3.

TRACE (1999) provides detailed estimates of the elasticity of various types of travel (car-trips, car-kilometers, transit travel, walking/cycling, commuting, business trips, etc.) with respect to fuel price under various conditions (level of vehicle ownership, transit use, type of trip, etc.). Table 22 summarizes fuel price elasticities of kilometers traveled in areas with high vehicle ownership (more than 450 vehicles per 1,000 population).

Table 22 **Elasticities WRT Fuel Price** (TRACE 1999, Tables 8 & 9)

Term/Purpose	Car Driver	Car Passenger	Public Transport	Slow Modes
Trips				
Commuting	-0.11	+0.19	+0.20	+0.18
Business	-0.04	+0.21	+0.24	+0.19
Education	-0.18	+0.00	+0.01	+0.01
Other	-0.25	+0.15	+0.15	+0.14
Total	*-0.19*	*+0.16*	*+0.13*	*+0.13*
Kilometers				
Commuting	-0.20	+0.20	+0.22	+0.19
Business	-0.22	+0.05	+0.05	+0.04
Education	-0.32	+0.00	+0.00	+0.01
Other	-0.44	+0.15	+0.18	+0.16
Total	*-0.29*	*+0.15*	*+0.14*	*+0.13*

Slow Modes = Walking and Cycling WRT = With Respect To

This table shows the estimated elasticities and cross-elasticities of urban travel in response to fuel or other vehicle operating costs. For example, a 10% fuel price increase is predicted to reduce automobile trips by 1% and increase transit ridership by 2%.

A Congressional Budget Office study (CBO 2008) found that increased fuel prices reduce urban highway traffic speeds and volumes. For each 50¢ per gallon (20%) gasoline price increase, traffic volumes on highways with parallel rail transit service declined by 0.7% on weekdays and 0.2% on weekends, with comparable increases in transit ridership, (no traffic reductions where found on highways that lack parallel rail service), and reduces median uncongested highway traffic speeds about one percent.

Harvey and Deakin (1998) model the travel impacts of a fuel tax increase in four major urban regions in California. Table 23 summarizes their results for the year 2010. It indicates, for example, that in the South Coast (Los Angeles) region, an additional $2.00 per gallon tax would reduce total vehicle trips by about 12.5%, but congestion delay would decline by a much larger amount (28.5%). Kennedy and Wallis (2007) calculate that the elasticity of vehicle travel with respect to fuel price in New Zealand is -0.12 in the short run (less than two years) and -0.24 in the long-run (5+ years).

Table 23 **Impacts of Fuel Tax Increase, Year 2010** (Harvey and Deakin 1998, B.8)

Region	Tax Increase	VMT	Trips	Delay	Fuel	ROG	Revenue
Bay Area	$0.50	-3.6%	-3.4%	-8.5%	-8.8%	3.5%	$1,332
	$2.00	-11.7%	-11.3%	-25.5%	-30.6%	11.6%	$4,053
Sacramento	$0.50	-4.1%	-3.9%	-7.0%	-9.3%	4.0%	$414
	$2.00	-13.2%	-12.7%	-22.0%	-31.8%	13.0%	$1,245
San Diego	$0.50	-3.9%	-3.5%	-8.0%	-9.1%	3.8%	$747
	$2.00	-12.5%	-12.0%	-23.0%	-31.1%	12.3%	$2,257
South Coast	$0.50	-4.2%	-3.5%	-9.5%	-9.3%	4.1%	$3,724
	$2.00	-13.0%	-12.5%	-28.5%	-31.6%	12.8%	$11,235

Tax Increase = additional fuel taxes applied in addition to current taxes. VMT = change in total vehicle mileage. Trips = change in total vehicle trips. Delay = change in congestion delay. Fuel = change in fuel consumption. ROG = a criteria air pollutant. Revenue = annual revenue in millions of 1991 U.S. dollars. See report for additional notes and data.

One result of the elasticity of vehicle travel with respect to vehicle operating costs is the *rebound effect*, which refers to the additional vehicle travel that results from increased vehicle fuel efficiency. For example, increasing vehicle fuel economy from 20 to 30 miles per gallon (MPG) reduces per-mile fuel costs by 33%, from 10¢ to 6.7¢ per mile when fuel is $2.00 per gallon and from 20¢ to 13.3¢ per mile at $4.00 per gallon. This effect is typically estimated at 10-30% over the long run (the effect is likely to be increase as fuel prices increase relative to incomes or production costs), so each 10% fuel economy gain increases vehicle mileage 1-3%, resulting in 7-9% net fuel savings (UKERC 2007).

Small and Van Dender (2005 and 2007) cross sectional data from U.S. states from 1966-2001 to estimate rebound effects. Their model accounts for endogenous changes in fuel efficiency, distinguishes between autocorrelation and lagged effects, includes a measure of the stringency of fuel-economy standards, and interacts the rebound effect with income. They estimate rebound effects of 4.7% in the short run and 22.0% over the long run with values that declined with income: with variables at 1997- 2001 levels they become 2.6% and 12.1%. However, recent studies suggest that fuel price elasticities are increasing as fuel costs increase relative to incomes (Cortright 2008).

The elasticity of air travel with respect to ticket price is about -1.0, and fuel costs represent about 10% of total operating costs, so doubling fuel costs or comparable fees would reduce air travel mileage about 10% (Davidson, Wit and Dings, 2003). Santos and Catchesides (2005) evaluate the equity and travel impacts of UK fuel taxes. They find the highest price elasticities among lower-income urban households (-0.93), and the lowest among middle-income rural residents (-0.75). Income elasticities range from -0.63 for lower-income urban households to -0.07 for the richest rural residents.

Fuel Tax Survey (www.rideshare.511.org/research)
A survey of 1,520 San Francisco area commuters for the *511 Rideshare* program in June 2004 (after a fuel price jump) had the following results:

Have increased gas prices changed how you commute to work?

	Number	Percent
Yes	559	37%
No	961	63%

If your commute behavior has changed in the last four months, what mode of transportation do you use now? For the 557 Respondents who answered yes to question 1.

Mode	Number	Percent
Carpool	264	48%
Public Transit	141	25%
Telecommute	13	2%
Bicycle	18	3%
Walk	5	1%
Other	50	9%

Have increased gas prices changed your other (non-commute) travel behavior?

	Number	Percent
Yes	925	61%
No	589	39%

As gas prices increase are carpooling and transit more appealing modes of transportation for you?

	Number	Percent
Yes	1,363	91%
No	143	9%

If you currently drive alone, what price would gas have to reach for you to switch to an alternative mode of transit?

	Number	Percent
$3 per gallon	352	26%
$4 per gallon	139	10%
$5 per gallon	58	4%
Will not switch	89	8%
Already switched	692	52%

Respondents who have not already switched

	Number	Percent
$3 per gallon	352	55%
$4 per gallon	139	22%
$5 per gallon	58	9%
Will not switch	89	14%

INRIX (2008) evaluated the effects of fuel price increases on U.S. vehicle travel and traffic congestion, using the "Smart Dust Network" of GPS-enabled vehicles which report roadway travel conditions. They also surveyed consumers concerning the effects of fuel prices on their travel behavior. The results indicate that increased gas prices in the first half of 2008 significantly reduced VMT and highway traffic congestion.

- Two-thirds of consumers indicated that increased gas prices caused them to decrease the amount of driving they do, including 23% reporting a significant decrease.
- 72% of those who reported a decrease of driving said they combined several trips into one to conserve fuel and 69% indicated they took fewer trips as a result of increased gas prices.
- If gasoline prices rise (again) to $4.50/gallon, more than half (54%) of all automobile owners said that they would find it worthwhile to reduce their frequency or distance of vacations by car.
- Females (69%) were significantly more likely than males (63%) to report a decrease in driving as a result of higher gas prices.
- The reduction in discretionary driving significantly reduced traffic congestion.
- Many cities exhibiting high correlation in congestion reduction from the fuel price increase are types of areas that are most impacted by vacation or leisure travel (i.e., driving destination sites) such as Las Vegas, Miami, Daytona Beach, and Orlando.
- The largest decrease in congestion is at those times that are most impacted by vacation driving, specifically Friday PM, not Monday AM.
- National peak hour travel times were down in the first half of 2008 for every hour and for every day of the week.

Road Pricing and Tolls

Road Pricing means that motorists pay a toll for using a particular roadway or driving in a particular area ("Road Pricing," VTPI, 2005). There is growing interest in *Congestion Pricing*, which refers to tolls that are higher during peak periods and lower during off-peak periods in order to reduce traffic congestion. Evans, Bhatt and Turnbull (2003) and Lake and Ferreira (2002) provide summaries of recent road pricing experience and their price elasticities. Matas and Raymond (2003) summarizes previous estimates of toll road elasticities, and develop a model of toll road demand using data from toll roads in Spain, 1980-1998. They find that demand varies depending on several factors, including economic activity (GDP), tourist activity, fuel prices, and travel conditions on parallel roads. Short-term toll road price elasticities range from -0.21 to -0.83, a somewhat higher and broader range than indicated in previous studies. They find that elasticities are greater where there are uncongested parallel roads.

Since February 2003 a congestion pricing fee (initially £5 and raised to £8 in 2005) has been charged for driving in downtown London during weekdays, which reduced private automobile traffic in the area by 38% and total vehicle traffic (including buses, taxis, and trucks) by 18%, a greater reduction than planners predicted indicating a higher price elasticity than economists expect, as described in Litman, 2003.

Hirschman, et al. (1995) find that New York area bridge and tunnel toll elasticities for automobiles average -0.1. Harvey (1994) finds similar results on San Francisco area bridge tolls, and higher values (-0.2) for trucks. Mekky found toll elasticities are as high as -4.0 for Toronto's Highway 407, and that traffic volumes and trip lengths decline significantly if tolls exceed 10¢ per vehicle kilometer (1999). When tolls were reduced from $1.75 to $1.00 (-43%) on the Dulles Greenway (to the Washington DC Dulles Airport), vehicle traffic increased from about 10,000 to 26,000 trips per day (80%), indicating a price elasticity of –1.9 (UTM, 1996). A study by the New Jersey Turnpike found relatively low toll elasticities (around –0.2) for small price increases (UTM, 2000).

Holguín-Veras, Ozbay and de Cerreño (2005) investigated the response of automobile and truck travel to E-ZPass tolls, which provide discounts for off-peak travel. The results indicate modest shift from peak to off-peak periods. The car short-term elasticities range from –0.31 to –1.97 for weekday and –0.55 and –1.68 for weekends depending on the time of the day. Arentze, Hofman and Timmermans (2004) used a public survey to determine traveler response to congestion pricing incentives. They found that for commute trips, route and departure time changes are most likely to occur, while shifts to public transit and working at home are less likely. For non-commute trips, shifts to cycling also occur. This study indicates the price elasticity of overall vehicle travel is -0.13 to -0.19, and -0.35 to -0.39 for a particular congested road that is priced, taking into account shifts in route and time. A state-preference survey of suburban automobile long-distance commuters indicates that financial incentives are the most effective strategy for reducing automobile trips (Washbrook, 2002). A CA$5.00 (US$3.00) per round-trip road toll is predicted to reduce automobile commuting by 25%, and a CA$5.00 parking fee would reduce automobile commuting by 20%.

Odeck and Svein Brathan (2008) found that elasticities average -0.54 in the short run and -0.82 in the long run at 19 Norwegian toll roads. They found that the public generally has negative attitudes toward tolls, but become more favorable when people understand how revenues will be used. A survey of Tappan Zee Bridge users found that most travelers would respond to congestion pricing by changing travel timing, route or mode (Adler, Ristau & Falzarano, 1999). Luk (1999) estimates that Singapore toll elasticities are –0.19 to –0.58, with an average of –0.34. Singapore may be unique, because car ownership is restricted to higher-income residents which tend to make travel less sensitive to price, but this may be offset by the city's excellent public transit service, which may make car travel more price sensitive than other cities.

The *Traffic Choices Study*, placed tolling meters in the vehicles of about 275 Puget Sound (Seattle, Washington) area volunteer households between July 2005 and March 2006, to see how motorists change their travel behavior (number, mode, route, and time of vehicle trips) in response to road pricing (PSRC 2005). The project observed driving patterns before and after hypothetical tolls were charged for the use of all the major freeways and arterials in the Seattle metropolitan area.

Each participant was given a $1,016 debit account. A meter similar to those used in taxis was installed in their car and, with the help of global positioning satellites that keep track of where and when they drive, it subtracts a toll that varies depending on the time of day and the route. For instance, if participants drove on Interstate 405 on a weekday between 4 p.m. and 7 p.m. – peak commuting hours –50 cents a mile was subtracted from their account. If they make the same trip using city streets after 7 p.m. the computer subtracted only 5 cents a mile. That means the 17-mile trip to the Greenwood neighborhood cost as much as $8.50 during peak periods, as little as 85¢ during evenings, and there are no tolls between 10 p.m. and 5 a.m. The dash-board meter keeps track of what each trip costs.

Participating motorists made small-scale adjustments in travel in response to this price incentive, including changes in trip time, route, frequency and distance. Overall, this price structure reduced total vehicle travel about -0.12, although impacts varied due to various factors. For example, the elasticity of Home-to-Work travel averaged approximately -0.04, but was a much higher -0.16 for workers with the best public transit service available.

Harvey and Deakin (1997) model the effect of congestion pricing on transportation impacts in four major urban regions in California. Table 24 summarizes their results for the year 2010. It indicates, for example, that in the South Coast (Los Angeles) region, an a congestion fee averaging 19¢ per mile driven in congested conditions would reduce total vehicle trips by about 3.3%, but congestion delay would decline by 32%.

Table 24 **Congestion Pricing Impacts, Year 2010** (Harvey and Deakin 1998, Table B.6)

Region	Avg. Fee	VMT	Trips	Delay	Fuel	ROG	Revenue
Bay Area	13¢	-2.8%	-2.7%	-27.0%	-8.3%	-6.9%	$2,274
Sacramento	8¢	-1.5%	-1.4%	-16.5%	-4.8%	-3.9%	$443
San Diego	9¢	-1.7%	-1.6%	-18.5%	-5.4%	-4.2%	$896
South Coast	19¢	-3.3%	-3.1%	-32.0%	-9.6%	-8.1%	$7,343

Avg. Fee = average congestion fee per mile applied to vehicle travel on congested roads. VMT = change in total vehicle mileage. Trips = change in total vehicle trips. Delay = change in congestion delay. Fuel = change in fuel consumption. ROG = a criteria air pollutant. Revenue = annual revenue in millions of 1991 dollars. See report for additional notes and data.

Road pricing impacts and benefits depend on the price structure. Ubbels and Verhoef (2006) predict that road pricing in The Netherlands would reduce car trips by 6% to 15%. A flat kilometre fee primarily affects social trips and tends to cause total trips to decline and shifts to nonmotorized modes. A peak-period fee primarily affects commute trips, and tends to cause a combination of shifts in time and mode, and working at home. May and Milne (2000) used an urban traffic model to compare the impacts of cordon tolls, distance pricing, time pricing and congestion pricing. They found significant differences in the effectiveness that particular size fee would have in achieving TDM objectives. The table below shows the estimated price level required to achieve a 10% reduction in regional vehicle trips. They conclude that time-based pricing provides the greatest overall benefits, followed by distance-based pricing, congestion pricing and cordon pricing.

Table 25 **Estimated Fee To Reduce Vehicle Trips 10%** (May and Milne 2000)

Type of Road Pricing	Fee Required to Reduce Trips 10%
Cordon (pence per crossing)	45
Distance (pence per kilometer)	20
Time (pence per minute)	11
Congestion (pence per minute delay)	200

Mileage and Emission Charges

Harvey and Deakin (1998) model the effect of a 2¢ per vehicle-mile fee on transportation impacts in four major urban regions in California. Table 26 summarizes their results for the year 2010. It indicates, for example, that in the South Coast (Los Angeles) region, a 2¢ per mile fee would reduce total vehicle trips by 4.1%, but congestion delay would decline by 10.5%. INFRAS (2000) estimates kilometer fees have elasticities of –0.1 to –0.8, depending on the trip purpose, mode and price level.

Table 26 **Impacts of 2¢ Per Mile Fee, Year 2010** (Harvey and Deakin 1998, B.9)

Region	VMT	Trips	Delay	Fuel	ROG	Revenue
Bay Area	-3.9%	-3.7%	-9.0%	-4.1%	-3.8%	$1,122
Sacramento	-4.4%	-4.1%	-7.5%	-4.4%	-4.3%	$349
San Diego	-4.2%	-4.0%	-8.5%	-4.2%	-4.1%	$629
South Coast	-4.3%	-4.1%	-10.5%	-5.2%	-4.2%	$3,144

VMT = change in total vehicle mileage. Trips = change in total vehicle trips. Delay = change in congestion delay. Fuel = change in fuel consumption. ROG = a criteria air pollutant. Revenue = annual revenue in millions of 1991 U.S. dollars. See report for additional notes and data.

Table 27 shows the predicted change in travel by income class, based on 1991 dollars. The last column adjusts average reductions to 2006 dollars. This indicates an elasticity of vehicle travel with respect to VMT fees to be -0.2 to -0.25 (Deakin & Harvey, 1998).

Table 27 **VMT Fee Travel Reduction by Income Quintile** (USEPA 1998, Table B21)

VMT Fee	Q1	Q2	Q3	Q4	Q5	Overall	2006
1¢	-7.0	-4.2	-2.6	-1.5	-0.5	-2.3	-1.6
2¢	-13.3	-8.2	-5.1	-3.1	-1.0	-4.5	-3.1
3¢	-19.1	-12.0	-7.5	-4.6	-1.6	-6.6	-4.6
4¢	-24.3	-15.6	-10.0	-6.2	-2.2	-8.7	-6.0
5¢	-29.1	-19.1	-12.4	-7.7	-2.8	-10.7	-7.4
6¢	-33.5	-22.4	-14.7	-9.3	-3.5	-12.6	-8.7
7¢	-37.4	-25.6	-17.0	-10.8	-4.1	-14.5	-10.0
8¢	-41.0	-28.7	-19.2	-12.4	-4.8	-16.3	-11.2
9¢	-44.2	-31.5	-21.4	-13.9	-5.5	-18.0	-12.4
10¢	-47.2	-34.3	-23.5	-15.4	-6.3	-19.7	-13.6

A quintile is one-fifth of the population. Values are based on 1991 dollars, except the last column, labeled 2006, which takes into account inflation between 1991 and 2006.

O'Mahony, Geraghty and Humphreys (2000) found that congestion fees averaging €6.40 per trip for 20 volunteer motorists reduced peak period trips 21.6% and total trips 5.7%, peak mileage 24.8% and total mileage 12.4%. Table 28 indicates impacts of two types of emission fees: a per-mile charge based on each vehicle model-year average emissions, and a fee based on actual emissions measured when a vehicle is operating. Distance based emission charges averaging about 0.5¢ per mile are estimated to reduce VMT by 1-7% and emissions by 14-35% (ICF, 1997). The in-use pricing options has much greater emission reducing impacts, because it discourages driving of gross-emitting vehicles.

Table 28 **Impacts of Emission Charges, Year 2010** (Harvey and Deakin 1998, B.10)

Region	Fee Basis	VMT	Trips	Delay	Fuel	ROG	Revenue
Bay Area	Vehicle Model	-2.2%	-1.9%	-3.5%	-3.9%	-5.4%	$384
	Vehicle Use	-1.6%	-1.4%	-2.5%	-6.6%	-17.7%	$341
Sacramento	Vehicle Model	-2.6%	-2.3%	-4.5%	-4.0%	-5.7%	$116
	Vehicle Use	-2.3%	-2.1%	-5.0%	-7.4%	-20.2%	$102
San Diego	Vehicle Model	-2.5%	-2.2%	-3.5%	-4.1%	-5.5%	$211
	Vehicle Use	-1.9%	-1.7%	-3.5%	-7.1%	-19.5%	$186
South Coast	Vehicle Model	-2.5%	-2.3%	-5.5%	-3.9%	-5.5%	$1,106
	Vehicle Use	-2.1%	-1.9%	-6.0%	-7.2%	-18.9%	$980

Vehicle Model Fee = a per-mile fee based on vehicle model and year. Vehicle Use Fee = a fee based on measured tailpipe emissions of individual vehicles using electronic instrumentation. VMT = change in total vehicle mileage. Trips = change in total vehicle trips. Delay = change in congestion delay. Fuel = change in fuel consumption. ROG = a criteria air pollutant. Revenue = annual revenue in millions of 1991 U.S. dollars. See report for additional notes and data.

Generalized Costs

Generalized cost refers to combined monetary and time costs of travel. For example, the generalized cost of automobile travel includes vehicle operating and monetized passenger travel time, and the generalized cost of transit travel include fares and monetized passenger travel time values. Generalized cost values are used in transport models.

These are usually determined empirically for a specific community based on local travel behavior and user survey data. A typical value is –0.5 (NHI, 1995). Booz, Allen, Hamilton (2003) estimate the generalized cost of travel in the Canberra, Australia region to be –0.87 for peak, -1.18 for off-peak, and –1.02 overall (peak and off-peak combined). TRL (2004) calculates generalized cost elasticities to be –0.4 to –1.7 for urban bus transit, -1.85 for London underground, and -0.6 to –2.0 for rail transport. Lee (2000) estimates the elasticity of vehicle travel with respect to Total Price (including fuel, tolls, parking fees, vehicle wear and travel time, which is equivalent to generalized costs) is –0.5 to –1.0 in the short run, and –1.0 to –2.0 over the long run.

Travel Time

In general, increased speed and reduced delay (by congestion or transfers) tends to increase travel distance, and increased relative speed for a particular mode tends to attract travel from other modes on a corridor. Some research supports the *constant travel time budget* hypothesis, which means the amount of time people devote to travel tends to remain constant (typically averaging 70-90 daily minutes), implying the elasticity of travel with respect to speed is 1.0 (Mokhtarian and Chen, 2004). Leading U.K. transport economists concluded the elasticity of travel volume with respect to travel time is -0.5 in the short term and -1.0 over the long term (SACTRA, 1994), so increasing traffic speeds 20% typically increases traffic volumes 10% in the short term and 20% over the long term. Another study found the elasticity values for vehicle travel with respect to travel time shown in Table 29. Pratt (1999) estimates the effects of service speed, frequency and reliability on public transit use, including the effects of HOV facilities.

Table 29 **Vehicle Travel Elasticities With Respect to Travel Time** (Goodwin 1996)

	Short Run	Long Run
Urban Roads	-0.27	-0.57
Rural Roads	-0.67	-1.33

TRACE (1999) provides detailed estimates of the elasticity of various types of travel (car-trips, car-kilometers, transit travel, walking/cycling, commuting, business trips, etc.) with respect to car travel times under various conditions (e.g., level of vehicle ownership and transit use, type of trip, etc.). Table 30 summarizes elasticities of kilometers traveled with respect to travel time in areas with high vehicle ownership (more than 450 vehicles per 1,000 population). Litman (2005 and 2007) discusses the valuation of travel time costs, including adjustments for qualitative factors such as comfort and convenience.

Table 30 **Long Run Travel Elasticities With Respect to Car Travel Time** (TRACE 1999)

Term/Purpose	Car Driver	Car Passenger	Public Transport	Slow Modes
Commuting	-0.96	-1.02	+0.70	+0.50
Business	-0.12	-2.37	+1.05	+0.94
Education	-0.78	-0.25	+0.03	+0.03
Other	-0.83	-0.52	+0.27	+0.21
Total	-0.76	-0.60	+0.39	+0.19

This table summarizes the effects of changes in car travel time on travel demand for other modes for various types of trips. (Slow Modes = walking and cycling)

Dowling Associates (2005) estimate the elasticity of travel with respect to travel time for various modes and time periods, based on Portland, Oregon data. For example, it indicates that each 1% increase in AM Peak Drive Alone travel time reduces vehicle travel 0.225% and increases demand for Shared Ride travel 0.037% and transit 0.036%.

Table 31 **Travel Time Elasticities and Cross Elasticities** (Dowling Asso. 2005)

		Am Peak			Pm Peak		
		DA	SR	TR	DA	SR	TR
AM Peak	DA	-0.225	0.030	0.010	-0.024	0	0
	SR	0.037	-0.303	0.032	0	-0.028	0
	TR	0.036	0.030	-0.129	0	0	-0.007
PM Peak	DA	-0.124	0	0	-0.151	0.015	0.005
	SR	0	-0.109	0	0.019	-0.166	0.016
	TR	0	0	-0.051	0.018	0.015	-0.040
Off-Peak	DA	-0.170	0	0	-0.069	0	0
	SR	0	-0.189	0	0	-0.082	0
	TR	0	0	-0.074	0	0	-0.014

DA = Drive Alone, SR = Shared Ride, TR = Transit
This table indicates the change in demand by three modes from changes in travel time by that mode and other modes during morning peak, afternoon peak and off-peak periods.

Frank, et al. (2008) find that relative that the travel time between different modes significant affects mode choice. Increasing drive alone commute time by 10% was associated with increases in demand for transit by 3.1%, bike demand by 2.8% and walk demand by 0.5%. Transit riders are found to be more sensitive to changes in travel time, particularly waiting time, than to cost of transit fares. Increasing transit in-vehicle travel times for non-work travel by 10% was associated with a 2.3% decrease in transit demand, compared to a 0.8% reduction for a 10% fare increase. Non-work walking trips increased in more walkable areas with increased density, mix and intersection density. Increasing auto travel time for non-work trips by 10% was associated with a 2.3% increase in transit ridership, a 2.8% increase in bicycling, and a 0.7% increase in walking. Walking and biking are used for shorter trips, such as travel to local stores and mid day tours from worksites if services are nearby.

Various studies have used the elasticity of travel with respect to travel time to calculate the amount of induced travel that results from roadway improvements that increase travel speeds and reduce delays, particularly expansion of congested urban roadways (Litman, 2001). Schiffer, Steinvorth and Milam (2005) summarize recent publications on this subject in the transportation modeling literature.

Vehicle Price and Income
A number of studies have examined how vehicle ownership and use are affected by price and income (Jansson 1989; Golob 1989). The elasticity of vehicle ownership with respect to price is estimated to be -0.4 to -1.0, meaning that a 10% increase in total vehicle costs reduces vehicle ownership by 4-10%. This is based on various studies, including analysis by Goodwin, Dargay and Hanly (2003) showing that a 10% increase in fuel prices reduces vehicle ownership 1.0 in the short-run and 2.5% over the long-run, and fuel represents about 25% of total vehicle costs. McCarthy (1996) estimates the price elasticity of vehicle purchases at –0.6 to –0.87. Glaister and Graham (2000) conclude that the long-run elasticity of vehicle fuel consumption with respect to income is 1.1 to 1.3, and the long-run elasticity of vehicle travel with respect to income is 1.1 to 1.8, with lower short-run values.

Generally, as people become wealthier vehicle ownership increases, but at a declining rate (Schafer and Victor 2000). Per capita automobile ownership and mileage tend to increase rapidly over the range of $3,000 to $10,000 (2002 U.S. dollars), when vehicle ownership increases twice as fast as per-capita income, but at higher income levels growth rates levels off and eventually reach saturation ("Travel Elasticities," VTPI 2005; IEA 2004; Dargay, Gately and Sommer 2007). Dargay (2007) finds asymmetry in vehicle ownership: household vehicle ownership increases as households become wealthier and have more adult workers, but are less likely to reduce their vehicle ownership as incomes and workers decline.

Kopits and Cropper (2003) find that vehicle ownership nearly levels off at about $16,000 (2003 dollars) per capita annual income, and some researchers suggest that above a certain level (estimated at $21,000 U.S. by Talukdar), automobile ownership levels may even decline slightly (Newman and Kenworthy, 1998). Karlaftis and Golias (2002) find that the purchase of a household's first vehicle is primarily dependent on socioeconomic factors (as income increases, so does the ownership of a vehicle), but the purchase of second and third vehicles is primarily dependent on the quality of travel alternatives (walking and transit service) in their community (if urban driving is faster and cheaper than transit, households will tend to own more automobiles). Small and Van Dender (2005 and 2007) found that the "rebound" effect of fuel costs on annual vehicle travel declines significantly with income.

In a major review of price elasticity, Goodwin, Dargay and Hanly (2003) conclude that if real income goes up by 10%:

- The number of vehicles, and the total amount of fuel they consume, will both go up by nearly 4% within about a year, and by over 10% in the longer run.
- The volume of traffic does not grow in proportion: 2% within a year and about 5% in the longer run, since much of that increase is in reduced fuel efficiency.

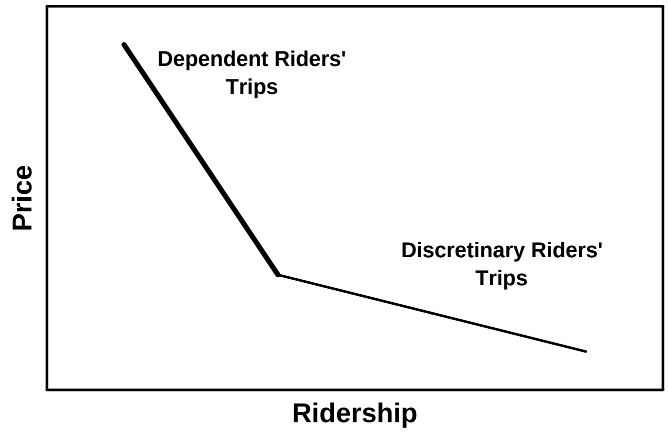
Transit Elasticities

Several factors can affect public transit elasticities (Pratt 1999; Litman 2002; Nash 2002; FTA 2002; Wardman and Shires 2003; TRL 2004; Pratt and Evans 2004; McCollom and Pratt 2005; Taylor et al. 2009):

- *User Type.* Transit dependent riders are generally less price sensitive than "discretionary" or "choice" riders (people who have the option of using an automobile for that trip). Certain demographic groups, including people with low incomes, non-drivers, people with disabilities, high school and college students, and elderly people tend to be more transit dependent. In most communities transit dependent people are a relatively small portion of the total population but a large portion of transit users, while discretionary riders are a potentially large but more price sensitive market segment.
- *Trip Type.* Non-commute trips tend to be more price sensitive than commute trips. Elasticities for off-peak transit travel are typically 1.5-2 times higher than peak period elasticities, because peak-period travel largely consists of commute trips.
- *Geography.* Large cities tend to have lower price elasticities than suburbs and smaller cities, which probably reflects the greater number of transit-dependent residents in such areas.
- *Type of Price Change.* Transit fares, service quality (service speed, frequency, coverage and comfort) and parking pricing tend to have the greatest impact on transit ridership. Fuel price tends to have relatively little impact. Elasticities appear be somewhat higher for higher fare levels (i.e., when the starting point of a fare increase is relatively high).
- *Direction of Price Change.* Transportation demand models often apply the same elasticity value to both price increases and reductions, but there is evidence that some changes are non-symmetric. Fare increases tend to cause a greater reduction in ridership than the same size fare reduction will increase ridership. A price increase or transit strike that induces households to purchase an automobile may be somewhat irreversible, since once people become accustomed to driving they often continue using that option.
- *Time Period.* Price impacts are often categorized as short-term (typically, within one year), medium-term (within five years) and long-term (more than five years). Elasticities increase over time, as consumers take price changes into account in more decisions (such as where to live or work). Long-term transit elasticities tend to be two or three times as large as short-term elasticities.
- *Transit Type.* Bus and rail often have different elasticities because they serve different markets, although how they differ depends on specific conditions.

Elasticity values depend on what portion of the demand curve is being measured. Price sensitivity is relatively low for transit travel demanded by dependent riders and relatively high for discretionary riders' demand, as illustrated in Figure 6. We can say that there is a "kink" in the demand curve (Clements 1997). In general, basic transit that primarily serves transit dependent riders is in the less elastic portion of the demand curve, while service that attracts discretionary transit users is in the more elastic portion of the demand curve.

Figure 6 **A Kink In the Demand Curve**



Transit dependent riders tend to be less price sensitive than discretionary riders. Elasticity values tend to be significantly lower for the portion of the demand curve representing transit dependent travelers and higher for travel by discretionary riders.

Transit dependent riders represent a major share of current ridership for most transit systems, while discretionary rider represent a large potential market. Price changes may have relatively little impact on ridership for a basic transit system that primarily serves transit dependent users, but to attract significantly more riders and reduce automobile travel, fares will need to decline and service quality improve significantly to attract more price-sensitive, discretionary riders.

Many of the original studies that current elasticity values are based on were performed decades ago, when per capita drivers licenses, automobile ownership and real incomes were lower, and so transit dependency was higher. This suggests that transit elasticities have probably increased over time, and are likely to be somewhat higher than older, standard values.

Transit Elasticity Studies
Several publications summarize public transit elasticity estimates, including Pham and Linsalata (1991); Oum, Waters, and Yong (1992); Goodwin (1992); Luk and Hepburn (1993); Pratt (1999); Dargay and Hanly (1999), TRACE (1999), Nash (2002), Booz Allen Hamilton (2003), Wardman and Shires (2003), and TRL (2004); Taylor et al. 2009.

A frequently used rule of thumb, known as the *Simpson – Curtin* rule, is that each 3% fare increase reduces ridership by 1% (equivalent to an arc elasticity of –0.35 to –0.42). However, this has been widely criticized as being outdated and simplistic.

Ubillos and Sainz (2004) developed a nested logit model to evaluate the price, time and service frequency elasticities of transit travel by Bilboa, Portugal university students. They found relatively high sensitivity to bus fare, rail service frequency and overall service quality, and so conclude that a combination of increased rail service and reduced bus fares would increase ridership to help reduce traffic congestion and pollution.

Holmgren (2007) used meta-regression to explain the wide variation in elasticity estimates obtained in previous demand studies. He calculated short-run U.S. elasticities with respect to fare price (−0.59), level of service (1.05), income (-0.62), price of petrol (0.4) and car ownership (−1.48). The analysis indicates that commonly-used elasticity estimates treat transit service quality as an exogenous variable, which reduces analysis accuracy, and recommends that demand models include car ownership, price of petrol, own price, income and some measure of service among the explanatory variables, and that the service variable be treated as endogenous.

Taylor, et al. (2009) evaluated how various geographic, demographic, pricing and transit supply factors affect per capita transit ridership rates in U.S. cities. They found a relatively high aggregate (all types of transit) fare elasticity of -0.51, and a service elasticities with respect to vehicle hours of 1.1 to 1.2.

Table 32 shows transit fare elasticity values published by the American Public Transportation Association, and widely used for transit planning and modeling in North America. This was based on a study of the short-term (less than two years) effects of fare changes in 52 U.S. transit systems during the late 1980s.

Table 32 **Bus Fare Elasticities** (Pham and Linsalata 1991)

	Large Cities (More than One Million Population)	**Smaller Cities** (Less than One Million Population)
Average for All Hours	-0.36	-0.43
Peak Hour	-0.18	-0.27
Off-Peak	-0.39	-0.46
Off-peak Average	-0.42	
Peak Hour Average	-0.23	

This table summarizes U.S. transit fare elasticities published by the American Public Transit Association, which are widely used in North America.

Dargay and Hanly (1999) studied the effects of UK transit bus fare changes over several years using sophisticated statistical techniques to derive the elasticity values summarized in Table 33. They found that demand is slightly more sensitive to rising fares (-0.4 in the short run and –0.7 in the long run) than falling fares (-0.3 in the short run and –0.6 in the long run), and tends to be more price sensitive at higher fare levels. The cross-elasticity of bus patronage to automobile operating costs is negligible in the short run but increases to 0.3 to 0.4 over the long run, and the long run elasticity of *car ownership* with respect to transit fares is 0.4, while the elasticity of *car use* with respect to transit fares is 0.3.

Table 33 **Bus Fare Elasticities** (Dargay and Hanly 1999, p. viii)

Elasticity Type	Short-Run	Long-Run
Non-urban	-0.2 to –0.3	-0.8 to –1.0
Urban	-0.2 to –0.3	-0.4 to –0.6

This table shows elasticity values from a UK study.

Based on extensive research, TRL (2004) calculates that bus fare elasticities average around –0.4 in the short-run, -0.56 in the medium run, and 1.0 over the long run, while metro rail fare elasticities are –0.3 in the short run and –0.6 in the long run. Bus fare elasticities are lower (-0.24) during peak than off-peak (-0.51). Bresson, et al. (2003) used a dynamic model to calculate transit price elasticities in British and French cities. They found relatively high fare elasticities of -0.3 to -0.5 in the short-run, and -0.6 to -0.7 in the long-run, and relatively high service elasticities. Nijkamp and Pepping (1998) found elasticities of transit ridership with respect to transit fares in the –0.4 to –0.6 range in a meta-analysis of European transit elasticity studies. Dargay, et al, (2002) compared transit elasticities in the UK and France between 1975 and 1995. They found that transit ridership declines with higher fares and incomes (although not in Paris), and increases with increased transit service kilometers, and these elasticities increased during that period. The table below summarizes their findings.

Table 34 **Transit Elasticities** (Dargay, et al. 2002, table 4)

	England		France	
	Log-Log	Semi-Log	Log-Log	Semi-Log
Income				
Short Run	-0.67	-0.69	-0.05	-0.04
Long Run	-0.90	-0.95	-0.09	-0.07
Fare				
Short Run	-0.51	-0.54	-0.32	-0.30
Long Run	-0.69	-0.75	-0.61	-0.59
Transit VKM				
Short Run	0.57	0.54	0.29	0.29
Long Run	0.77	0.74	0.57	0.57
Annual Fare Elasticity Growth Rate		1.59%		0.66%

This table shows mean elasticity values based on 1975 to 1995 data.

With a log-log function, elasticity values are the same at all fare levels, whereas with a semi-log function elasticity value increases with higher fares. Log-log functions are most common and generally easiest to use. Semi-log values reflect an exponential function and can be used for predicting impacts of fares that approach zero, that is, if transit services become free, but are unsuited for very high fare levels, in which case semi-log may result in exaggerated elasticity values. For typical fare changes, between 10% and 30%, log-log and semi-log functions provide similar results. The table below summarizes transit elasticity estimates, based on a review of previous studies.

Table 35 **Factors Affecting Transit Ridership** (Kain & Liu 1999)

Factor	Elasticity
Regional employment	0.25
Central city population	0.61
Service (transit vehicle miles)	0.71
Fare price	-0.32

This table shows the elasticity of transit use with respect to various factors. For example, a 1% increase in regional employment is likely to increase transit ridership by 0.25%, while a 1% increase in fare prices will reduce ridership by 0.32%, all else being equal.

Lee, Lee and Park (2003) surveyed motorists to determine what factors affect their willingness to shift to public transit. They have low fare elasticities so reducing fares is unlikely to attract many people out of cars. Car users are more sensitive to parking fees, travel time and crowding, indicating that improved transit service can increase transit ridership by discretionary users. Table 36 summarizes estimates of transit fare elasticities for different user groups and trips types, illustrating how various factors affect transit price sensitivities. For example, it indicates that car owners have a greater elasticity (-0.41) than people who are transit dependent (-0.10), and work trips are less elastic than shopping trips.

Table 36 **Transit Fare Elasticities** (Gillen 1994, pp. 136-37)

Factor	Elasticity
Overall transit fares	-0.33 to –0.22
Riders under 16 years old	-0.32
Riders aged 17-64	-0.22
Riders over 64 years old	-0.14
People earning <$5,000	-0.19
People earning >$15,000	-0.28
Car owners	-0.41
People without a car	-0.10
Work trips	-0.10 to –0.19
Shopping trips	-0.32 to –0.49
Off-peak trips	-0.11 to –0.84
Peak trips	-0.04 to –0.32
Trips < 1 mile	-0.55
Trips > 3 miles	-0.29

This table shows elasticities disaggregated by rider and trip factors.

Booz Allen Hamilton (2003) used stated preference survey data to estimate own and cross-elasticities for various costs (fares, travel time, waiting time, transit service frequency, parking fees) modes (automobile, transit, taxi) and trip types (peak, off-peak, work, education, other) in the Canberra region. They developed generalized costs and travel time cost values, including estimates of the relative cost of walking and waiting time for transit users. Table 37 shows their estimated price and cross fare elasticities. Bresson, et al (2004) calculate the cross elasticity of transit demand relative to vehicle ownership and fuel price.

Table 37 **Australian Travel Demand Elasticities** (Booz, Allen Hamilton 2003)

Mode	Peak	Off-Peak	Total
Bus	-0.18	-0.22	-0.20
Taxi	0.03	0.08	0.07
Car	0.01	0.01	0.01

This table shows elasticity and cross-elasticity values. It means, for example, that a 10% peak-period transit fare increase (decrease) will reduce (increase) peak-period transit ridership by 1.8%, and will increase (reduce) taxi travel by 0.3% and car travel by 0.1%.

Fearnley and Bekken (2005) summarize elasticity research and calculate the ratio of short- to long-run effects, as summarized in Table 38.

Table 38 **Transit Elasticities** (Fearnley and Bekken 2005)

	Short-run Elasticity	Long-run Elasticity	Long-Run/Short-Run
Service Level, Local Public Transport	0.43	0.75	1.84
Fare Level, Local Public Transport	-0.44	-0.76	1.92
Fare Level, Train/Metro	-0.61	-0.98	1.59
Average Ratio long-run/short-Run			*1.84*

Mattson (2008) analyzed the effects of rising fuel prices on transit ridership in U.S. cities from 1999 through 2006. He found longer-run elasticities of transit ridership with respect to fuel price are 0.12 for large cities, 0.13 for medium-large cities, 0.16 for medium-small cities, and 0.08 for small cities. For large and medium-large cities, the response is fairly quick, mostly occurring within one or two months after the price change, while for medium and small cities, the effects take five to seven months.

Rail and bus elasticities often differ. In major cities, rail transit fare elasticities tend to be relatively low, typically in the –0.18 range, probably because higher-income residents depend on such systems (Pratt 1999). For example, the Chicago Transportation Authority found peak bus riders have an elasticity of -0.30, and off-peak riders -0.46, while rail riders have peak and off-peak elasticities of -0.10 and -0.46, respectively. However, fare elasticities may be relatively high on routes where travelers have viable alternatives, such as for suburban rail systems. Table 39 summarizes travel demand elasticities used in Australia, based on a review of national and international studies.

Table 39 **Australian Travel Demand Elasticities** (Luk & Hepburn 1993)

Elasticity Type	Short-Run	Long-Run
Petrol consumption and petrol price	-0.12	-0.58
Travel level and petrol price	-0.10	
Bus demand and fare	*-0.29*	
Rail demand and fare	*-0.35*	
Mode shift to transit and petrol price	*+0.07*	
Mode shift to car and rail fare increase	*+0.09*	
Road freight demand and road/rail cost ratio	-0.39	-0.80

This table shows elasticity values adopted by the Australian Road Research Board.

Several TDM strategies involve transit fare reductions. Commuter Transit Benefit programs, in which employers encourage and sometimes subsidize transit passes, are effective at increasing ridership (*Commuter Check*, www.commutercheck.com). Deep Discount transit passes can encourage occasional riders to use transit more frequently (Oram and Stark 1996) or avoid ridership losses if implemented when fares are increasing. Many Campus Transport Management programs include free or discounted transit fares. Not all transit travel increases represent automobile travel reductions, some are shifts from walking, cycling and ridesharing or increases in total personal travel.

Vanpool Elasticity Studies

York and Fabricatore (2001) estimate the price elasticity of vanpooling at about 1.5, meaning that a 10% reduction in vanpool fares increases ridership by about 15%. For example, if vanpool fares that are currently $50 per month are reduced to $40 (a 20% reduction), ridership is likely to increase by about 30% (20% x 1.5).

Analysis by Wambalaba, Concas and Chavarria (2004) and Concas, Winters and Wambalaba (2005) indicate that the elasticity of vanpool ridership with respect to fees is -2.6% using a 1997 data set and -14.8% using a less statistically robust 1999 data set, that is, a one dollar decrease (increase) in vanpool fares is associated with a 2.6% to 14.8% increase (decrease) in the predicted odds of choosing vanpool with respect to drive alone. The same study found the elasticity of vanpooling with respect to price to be -0.61 (1997) and 13.4% (1999), meaning that for each 10% increase in vanpool price there is a 6% to 13% decrease in vanpool choice with respect to auto. Using a nested logit model the study found the elasticity of vanpooling with respect to fares to be -1.14.

Cross Elasticities

Cross-elasticity refers to the changes in demand for a good that results from a change in the price of a substitute good. This includes changes in automobile travel due to transit fare changes, changes in transit ridership due to changes in automobile operating costs, and changes in one type of transit (such as bus) in response to price changes in another type of transit (such as rail). Lago et al. (1992) found the mean cross-elasticity of auto travel demand with respect to bus fares is 0.09 (±0.07), and 0.08 (±0.03) with respect to rail fares. Hensher developed a model of elasticities and cross-elasticities between various forms of transit and car use, illustrated in Table 40.

Table 40 **Direct and Cross-Share Elasticities** (Hensher 1997, Table 8)

	Train Single Fare	Train Ten Fare	Train Pass	Bus Single Fare	Bus Ten Fare	Bus Pass	Car
Train, single fare	-0.218	0.001	0.001	0.057	0.005	0.005	0.196
Train, ten fare	0.001	-0.093	0.001	0.001	0.001	0.006	0.092
Train, pass	0.001	0.001	-0.196	0.001	0.012	0.001	0.335
Bus, single fare	0.067	0.001	0.001	-0.357	0.001	0.001	0.116
Bus, ten fare	0.020	0.004	0.002	0.001	-0.160	0.001	0.121
Bus, pass	0.007	0.036	0.001	0.001	0.001	-0.098	0.020
Car	0.053	0.042	0.003	0.066	0.016	0.003	-0.197

This table indicates how various changes in transit fares and car operating costs affects transit and car travel demand. For example, a 10% increase in single fare train tickets will cause a 2.18 reduction in the sale of those fares, and a 0.57% increase in single fare bus tickets. This is based on a survey of residents of Newcastle, a small Australian city.

Currie and Phung (2008) found that in Australia, the cross elasticity of transit ridership with respect to fuel prices are 0.22, with higher values for high quality transit including Australian Rail/ BRT, and for longer-distance travel, and lower values for basic bus service and shorter-distance trips.

TRACE (1999) provides detailed estimates of transit ridership with respect to fuel and parking prices for various types of travel and conditions (see data in sections on fuel and parking price elasticities). It estimates that a 10% rise in fuel prices increases transit ridership 1.6% in the short run and 1.2% over the long run (this declining elasticity value is unique to fuel, due to motorists purchasing more efficient vehicles when fuel prices increase). This project made the following conclusions:

- For the cross elasticities we find more variation than for the own elasticities, partly due to the fact that the elasticities depend on the market shares of the modes in each study.
- The fuel price elasticity of public transport traveller trips (all purposes, long run) averages about 0.1. There are no clear differences between purposes and time-of-day. Short-term cross elasticities are not necessarily higher than the long-term counterparts.
- For the average fuel price elasticity of public transport traveller kilometres we find a value of around 0.1. There are no clear differences by purpose and time-of-day. Short-term elasticities are a bit higher here than long-term elasticities.
- The average car time elasticity of public transport traveller trips (all purposes, long run) is 0.4. There are no clear differences with respect to purpose and time-of-day.
- The car time elasticity of public transport traveller kilometres (all purposes, long run) is 0.4, which is greater than the cost sensitivity. This elasticity is higher for commuting and higher for the short term (destination choice effect, see above).

METS Transit Demand Model

METS (MEtropolitan Transport Simulator) is a simulation model of transport supply and demand. It uses default values that simulate transport in London, but it can be modified for any large urban region. It is updated regularly. METS was built in the early 1980s to evaluate the effects of London transit fare changes. In 1981 fares were reduced on buses and the tube by a third, and a simpler ticketing scheme was introduced, which produced an 11% increase in transit use and a 6% reduction in car use. The policy was challenged in the courts and declared illegal, with the result that fares rose by over 90% a year later, causing a 15% reduction in transit use and 14% increase in car travel. However, after another court case in 1983, the GLC was able to cut fares by 23%, and introduce further ticketing simplifications, which caused a 11% increase in transit use and a 9% reduction in car. The following table summarizes these changes:

Table 41 **Fares Fare**

	Oct 1981	Mar 1982	May 1983
Change in average Fares (%)	-31	+93	-23
Change in bus and tube use (%)	+11	-15	+11
Change in commuting to London by car (%)	-6	+14	-9

Source: Graying and Glaister 2000, page 10, from an original in Lindsay and Fairhurst (1984).

Later, the federal government took away much of the local authority's power to set transit policy and required local authorities to conduct cost-benefit analyses of public transport subsidies, taking into account the benefits from lower fares and faster journeys. Only if these benefits exceed cost are subsidies allowed. The METS model was developed to help local authorities to do this. It is a large computer program which represents London's transport system as a series of inter-related equations. For example, there is an equation that describes the demand for bus trips as a function of the cost of the journey and the costs of alternative modes such as cars or the tube, and similar equations for the tube, trains, cars and taxis. Table 42 summarizes elasticities used in the METS model.

Table 42 **METS Cost Elasticities**

	Car	Bus	Underground
Car	-0.30	0.09	0.057
Bus	0.17	-0.64	0.13
Underground	0.056	0.20	-0.50

Source: Grayling and Glaister p.35.

Each row tells us how demand for that form of transport changes as costs (fares and travel time) change. Look at the top row. The first number indicates that the own-price elasticity of demand for car journeys is -0.3, so a 10% rise in car costs will reduce car use 3%. The second number in the first row (0.09) is the cross-price elasticity of demand for car use with respect to bus costs: a 10% increase in bus costs would cause a 0.9% increase in car use. The third number (0.057) is the cross-price elasticity of car use with respect to Underground costs: car users seem less responsive to changes in tube costs than bus costs. From the second row, second column, you can see that buses are rather more responsive to own-cost changes (an own-price elasticity of -0.64, so a 10% cost increase causes a 6% fall in use), and from the third row that the Underground elasticity, at -0.5, is somewhere in-between cars and buses. Note that all the own-cost elasticities are absolutely less than -1, which implies that total revenues should rise if fares go up. Elasticities are calculated from the National Travel Survey (an annual survey of transport use), and results from fare policy changes, such as those described earlier.

Much of the complexity in METS comes from the need to accurately measure costs. The costs of making a journey are not just the price of the bus ticket or of your car's petrol. Your time is worth something, too. Travel time is measured relative to hourly wage rates.

For more information on the METS model see:

Tony Grayling and Stephen Glaister (2000), *A New Fares Contract for London*, Institute for Public Policy Research (www.ippr.org.uk), ISBN 1 86030 100 2.

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Tackling Traffic Congestion: More about the METS Model, Virtual Learning Arcade (http://www.bized.co.uk/virtual/vla/transport/resource_pack/notes_mets.htm) and (www.bized.co.uk/virtual/vla/transport/index.htm)

Parking Pricing Impacts on Transit

Several studies indicate that parking prices (and probably road tolls) tend to have a greater impact on transit ridership than other vehicle costs, such as fuel, typically by a factor of 1.5 to 2.0, because they are paid directly on a per-trip basis. Hensher and King (1998) calculate elasticities and cross-elasticities for various forms of transit fares and automobile travel in the Sydney, Australia city center.

Transit Service

Service elasticity refers to how much transit ridership increases (decreases) in response to an increase (reduction) in transit vehicle-mileage, vehicle-hours or frequency. Of course, many factors affect service elasticities, including demographic factors (i.e., the portion of the population that is transit dependent or lower-income), geographic factors (i.e., population density, employment density and pedestrian accessibility), service quality (i.e., speed, comfort and schedule information) and fare price. New transit quality of service indices that better account for these factors may be used in the future to better define transit service elasticity factors (Transit Evaluation).

Evans (2004) provides information on the effects of various types of service improvements on transit ridership. The elasticity of transit use to service expansion (e.g. routes into new parts of a community) is typically in the range of 0.6 to 1.0, meaning that each 1% of additional service (measured in vehicle-miles or vehicle-hours of service) increases ridership by 0.6-1.0%, although much lower and higher response rates are also found (from less than 0.3 to more than 1.0). The elasticity of transit use with respect to transit service frequency (called a *headway elasticity*) averages 0.5. There is a wide variation in these factors, depending on the type of service, demographic and geographic factors. Higher service elasticities often occur with new express transit service, in university towns, and in suburbs with rail transit stations to feed. It usually takes 1 to 3 years for ridership on new routes to reach its full potential.

Pratt (1999) finds that completely new bus service in a community that previously had no public transit service typically achieves 3 to 5 annual rides per capita, with 0.8 to 1.2 passengers per bus mile. Improved schedule information, easy-to-remember departure times (for example, every hour or half-hour), and more convenient transfers can also increase transit use, particularly in areas where service is less frequent.

Mackett (2000 and 2001) identifies a number of positive incentives that could reduce short (under 5 mile) car trips, including improved transit service, improved security, reduced transit fares, pedestrian and cycling improvements. Of those, transit improvements are predicted to have the greatest potential travel impacts.

Transit ridership tends to be more responsive to service improvements than to fare reductions (Pratt concludes that “ridership tends to be one-third to two-thirds as responsive to a fare change as it is to an equivalent percentage change in service”), and most responsive to combinations of service improvements and fare reductions.

Transit Elasticities Summary

No single transit elasticity value applies in all situations: various factors affect price sensitivities including type of user and trip, geographic conditions and time period. Transit dependent people are generally less price sensitive and discretionary riders more price sensitive. As per capita wealth, drivers, vehicles and transport options increase, transit elasticities are likely to increase. Commonly used transit elasticity values are based on studies performed 10-30 years ago, when real incomes where lower and a greater portion of residents were transit dependent. These studies primarily reflect short-term impacts. The resulting elasticity values are lower than what would accurately predict medium and long-term changes under current conditions in most North American urban areas. Available evidence suggests that the elasticity of transit ridership with respect to fares is about –0.3 to –0.5 in the short run (first year) and increases to about –0.6 to –0.9 over the long run (five to ten years). Table 43 summarizes transit elasticity values.

Table 43 **Transit Elasticity Values**

	Market Segment	Short Term	Long Term
Transit ridership WRT transit fares	Overall	–0.2 to –0.5	–0.6 to –0.9
Transit ridership WRT transit fares	Peak	–0.15 to –0.3	–0.4 to –0.6
Transit ridership WRT transit fares	Off-peak	–0.3 to –0.6	–0.8 to –1.0
Transit ridership WRT transit fares	Suburban Commuters	–0.3 to –0.6	–0.8 to –1.0
Transit ridership WRT transit service	Overall	0.50 to 0.7	0.7 to 1.1
Transit ridership WRT auto operating costs	Overall	0.05 to 0.15	0.2 to 0.4
Automobile travel WRT transit costs	Overall	0.03 to 0.1	0.15 to 0.3

This table summarizes estimates of transit elasticities. These values can be used to predict how various types of changes in prices and service are likely to affect transit ridership and travel behavior.

These are affected by the following factors:

- Transit price elasticities are lower for existing (transit dependent) riders than for new (discretionary) riders, and lower in urban areas than for suburban commuters.
- Elasticities are about twice as high for off-peak and leisure travel as for peak-period and commute travel.
- Transit price elasticities are relatively high for efforts to shift automobile travel to transit as a demand management strategy (i.e., a relatively large fare reduction is needed to attract motorists), although improved transit services or increased automobile operating costs through road or parking pricing are likely to increase the impacts of fare reductions.
- Discretionary ridership is often more responsive to service quality (speed, frequency and comfort) than fares.
- Packages of incentives that include fare reduction or discounted passes, increased service and improved marketing can be particularly effective at increasing ridership.
- Cross-elasticities between transit and automobile travel are relatively low in the short run (0.05), but increase over the long run (probably to 0.3 and perhaps as high as 0.4).
- Due to variability and uncertainty it is preferable to use a range rather than single point values for elasticity analysis as much as possible.

Taxi Service Elasticities

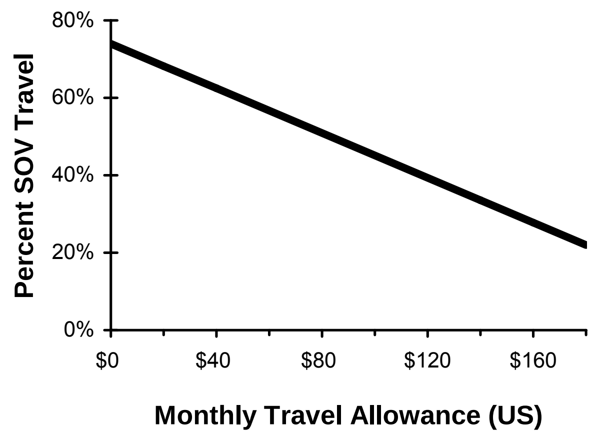
Schaller (1999) finds that in New York City, the elasticity of taxi demand with respect to fares is –0.22, the elasticity of service availability with respect to fares is 0.28, and the elasticity of service availability with respect to total supply of service is 1.0. Based on these values he concludes that fare increases tend to increase total industry revenues and service availability, and that the number of taxi licenses can often be expanded without reducing the revenue of existing operators.

Commute Trip Reduction Programs

Models are now available which can predict the travel impacts of a specific Commute Trip Reduction program, taking into account the type of program and worksite. These include the *CUTR_AVR Model* (www.cutr.usf.edu/tdm/download.htm), the *Business Benefits Calculator* (BBC) (www.commuterchoice.gov) and the *Commuter Choice Decision Support Tool* (www.ops.fhwa.dot.gov/PrimerDSS/index.htm).

The figure below illustrates the effect such economic incentives typically have on single occupant vehicle (SOV) commuting.

Figure 7 **Effect of Economic Incentives on SOV Rates** (Rutherford 1995)



SOV travel decline as economic incentives for other modes increase.

The VTPI Trip Reduction Tables provide more information on the impacts that financial incentives can have on commute travel under various circumstances. Table 44 is an example. It shows the effects of a transit subsidy on commute trips for various worksite settings, taking into account location (suburban, activity center, central business district [CBD]), and whether carpooling or transit are favored as alternative modes. For example, a $1 (in 1993 U.S. dollars) per day transit subsidy provided to employees at a transit-oriented activity center is likely to reduce commute trips by 10.9%, while in a rideshare-oriented Central Business District, the same subsidy only causes a 4.7% trip reduction.

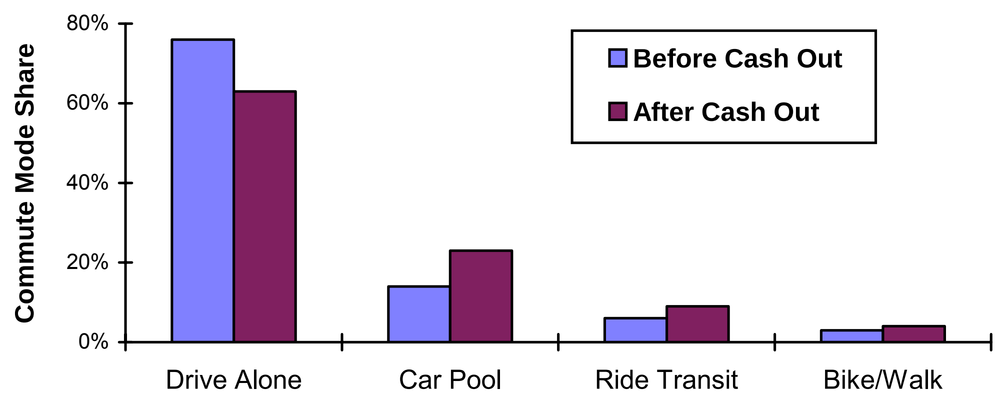
Table 44 **Percent Vehicle Trips Reduced by Daily Transit Subsidy** ("Trip Reduction Tables," VTPI 2005, based on Comsis Corporation 1993)

Worksite Setting	$0.50	$1	$2	$4
Low density suburb, rideshare oriented	0.1	0.2	0.6	1.9
Low density suburb, mode neutral	1.5	3.3	7.9	21.7
Low density suburb, transit oriented	2.0	4.2	9.9	23.2
Activity center, rideshare oriented	1.1	2.4	5.8	16.5
Activity center, mode neutral	3.4	7.3	16.4	38.7
Activity center, transit oriented	5.2	10.9	23.5	49.7
Regional CBD/Corridor, rideshare oriented	2.2	4.7	10.9	28.3
Regional CBD/Corridor, mode neutral	6.2	12.9	26.9	54.3
Regional CBD/Corridor, transit oriented	9.1	18.1	35.5	64.0

This table can be used to predict how transit subsidies are likely to affect automobile commute trips. See Trip Reduction Tables for more information.

Solo driving declined 17% after parking was *cashed out* (employees could choose cash instead of subsidized parking), as illustrated in Figure 8. Travel impacts tend to increase over time: one employer reported that solo commuting continued to decline each year for three years after cashing out was introduced as employees found more opportunities to reduce their driving (Shoup 1997). Transit vouchers tend to have similar effects (Oram Associates 1995; Schwenk 1995).

Figure 8 **Cashing Out Impacts on Commute Mode** (Shoup 1997)



This figure illustrates the effects Parking Cash Out had on commute mode choice.

Travel impacts are affected by the magnitude of the benefit and the quality of travel choices. Mode shifts tend to be greatest if current transit use is low. In New York City, where transit commute rates are already high, transit benefits only increased transit use 16% to 23%, while in Philadelphia, transit commuting increased 32% (Schwenk, 1995). Similarly, only 30% of employees who received transit benefits who work in San Francisco increased their transit use, while 44% of those in other parts of the region commuted by transit more (Oram Associates, 1995). These probably represent the lower range of mode shifts since they are marketed primarily as an employee benefit and are therefore most attractive to firms with high current levels of transit commuting.

Mode Shifts

Increases in vehicle operating charges (fuel, parking, tolls, etc.) tend to reduce vehicle use, as described previously. Some of this travel simply disappears, due to fewer and shorter trips, and use of mobility substitutes such as telework and delivery services. A portion of reduced automobile use consists of shifts to other travel modes. Which changes occur depends on factors such as the type of trip, the travel route, the quality of travel alternatives, and the type of traveler. In general, shorter distance, non-work trips tend to shift to walking and cycling, while longer trips tend to shift to transit (particularly for urban destinations) and ridesharing (particularly for suburban commutes).

A disincentive to driving (say, higher parking fees or a road toll in urban areas) generally causes 20-60% of automobile trips to shift to transit, while other trips will shift to nonmotorized modes, ridesharing, or be avoided altogether when travelers consolidate errands or shift destinations. Conversely, when bus service is improved, typically 10-50% of the added trips will substitute for automobile trips, with higher shifts for longer-distance trips. For example, if improved regional bus service attracts 1,000 additional riders, perhaps 500 of them will substitute for car passenger-trips, resulting in 333 fewer automobile vehicle-trips (assuming 1.5 passengers per automobile). Other new bus passengers will consist of people who would have gone to a different destination, or not traveled at all.

Pratt (1999) and Kuzmyak, Weinberger and Levinson (2003) provide information on the mode shifts that result from various incentives, such as transit service improvements. They find that commercial center parking supply has a major impact on transit ridership: each 1% increase in downtown parking supply reduces transit ridership by 0.77% (Kuzmyak, Weinberger and Levinson, 2003, p. 18-18), although this probably reflects confounding factors, such as walkability and transit service quality, not just parking supply. Table 45 provides one example. Also see Pratt, Table 10-22 and Kuzmyak, Weinberger and Levinson, Table 18-34.

Table 45 **Mode Shifts By New Transit Users** (Pratt 1999, Table 9-10)

Riders Attracted By Increased Bus Frequency		Riders Attracted By Increased Commuter Rail Frequency	
Prior Mode	Percentage	Prior Mode	Percentage
Own Car	18-67%	Own Car	64%
Carpool	11-29%	Carpool	17%
Train	0-11%	Bus	19%
Taxi	0-7%		
Walking	0-11%		

The Congressional Budget Office found that a 20% gasoline price increase reduces traffic volumes on highways with parallel rail transit service by 0.7% on weekdays and 0.2% on weekends, with comparable increases in transit ridership, but find no traffic reductions on highways that lack parallel rail service (CBO, 2008).

The Transit Performance Monitoring System (TPMS) surveys provide a variety of information on transit ridership (FTA, 2002). More than half (56%) of transit passengers report that if transit service were unavailable they would have traveled by automobile, either as a driver or passenger. Below is what survey respondents would do if transit service were unavailable:

Drive	23%
Ride with someone	22%
Taxi/Train	12%
Not make trip	21%
Walk	18%
Bicycle	4%

Below are results of an on-board survey that asked transit riders what they would do if transit was unavailable. In this case, between 25% and 58% of total transit trips displace a motor vehicle trip (depending on the portion of "Ride with someone" responses would involve an additional vehicle trip). Other surveys find similar results. The amount of substitution is likely to be higher in more automobile dependent areas, and lower in multi-modal areas where travelers have a greater variety of mobility options, including walking and cycling.

Table 46 **Alternatives To Transit Travel** (Volusia County Public Transit 1999)

How would you make this trip if not by bus?	Frequency
Ride with someone*	626 (33%)
Walk	369 (19%)
Wouldn't make trip	262 (14%)
Taxi*	245 (13%)
Drive*	147 (8%)
Bicycle	161 (8%)
Paratransit service*	57 (3%)
Other	56 (3%)
Total	*1,923 (100%)*

* Increases automobile trips.

In a survey of 2000 motorists driving to a Haifa, Israel commercial district, Shiftan (1999) found that parking demand would be reduced 29% by a US$1.00 per hour fee, and 50% by a US$1.50 per hour fee. Of those who change, 40% would change mode (to walking, taxi or public transportation), 31% would change destination, about 8% would change how long they park, and 8% would cancel the trip. For commuters, nearly all of the reduction results from mode shifting. For non-work trips, about a third of the reduction results from mode shifting, half results from changing time (and therefore reducing the amount of time they are charged to park), and there are small shifts in destination or trip generation.

Shoup (1997) found that the Parking Cash Out programs he studied caused a 13-point reduction in drive alone, a 9-point increase in carpooling, a 9-point increase in transit use, and a 1-point increase in walk/bike commuting. In another example, after Canadian fuel prices increased about 15% in 2001, a survey by the federal Competition Bureau found that about a quarter of motorists reported shifting some travel from driving to alternative modes. Of those, 46% took transit, 36% walked, 24% bicycled, and 20% used ridesharing.

The TravelSmart program in the city of Perth, Australia used TDM Marketing and a variety of incentives to encourage residents to use alternative travel modes. The goal of the program is to encourage residents to increase the portion of total trips made by environmentally friendly modes (walking, cycling and public transit) from 10% to 25% of trips by 2029. This goal is considered feasible, based on detailed market research and transportation surveys. Before-and-after surveys of pilot projects found the following results (Transport WA, 2001):

Trips By	**Change**
Car-as-driver	Down 14%
Public transit	Up 17%
Cycling	Up 61%
Walking	Up 35%
Car mileage	Down 17%

A survey by Mackett (2001) of UK residents evaluated the potential of shifting short trips (less than 8 kms) from driving to alternative modes. Survey respondents indicated that 31% to short vehicle trips could be shifted to bus, 31% to walking, 7% to bicycle and 3% to taxi; respondents often indicated more than one possible alternative mode for particular trips.

Freight Elasticities

The price elasticity of freight transport (measured in ton-miles) in Denmark is calculated to be –0.47, while the elasticity of freight traffic (measured in truck-kilometers) is –0.81, and the elasticity of freight energy consumption is only about –0.1 according to a study by Thomas Bue Bjørner (1999). A 10% increase in shipping costs reduces truck traffic by 8%, but total shipping volume by only 5%. Some freight is shifted to rail, while other freight is shipped using existing truck capacity more efficiently.

Hagler Bailly (1999) estimate the long-run price elasticity of rail and truck freight transport at –0.4, with a wide range depending on the type of freight. Small and Winston summarize various estimates of freight elasticities, as summarized in the table below.

Table 47 **Freight Transport Elasticities** (Small & Winston 1999, Table 2-2)

	Rail	Truck
Aggregate Mode Split Model, Price	-0.25 to –0.35	-0.25 to –0.35
Aggregate Mode Split Model, Transit Time	-0.3 to –0.7	-0.3 to –0.7
Aggregate Model from Tanslog Cost Function, Price	-0.37 to –1.16	-0.58 to –1.81
Disaggragate Mode Choice Model, Price	-0.08 to -2.68	-0.04 to –2.97
Disaggragate Mode Choice Model, Transit Time	-0.07 to –2.33	-0.15 to –0.69

These elasticities vary depending on commodity group.

References and Resources for More Information

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Comparative Evaluation between Elevated

&

Underground Metro

For

Charkop-Bandra-Mankhurd Route

SEPTEMBER 2009

Evaluation Report

By

I.I.T. - BOMBAY

Indian Institute of Technology, Bombay

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Transportation System Engineering
Department of Civil Engineering

CONTENTS

LIST OF MAPS

ABOUT IIT BOMBAY

The Indian Institute of Technology (IIT) Bombay, set up by an Act of Parliament, was established in 1958, at Powai. Today the Institute is recognized as one of the centers of academic excellence in the country. Over the years, there has been dynamic progress at IIT Bombay in all academic and research activities, and a parallel improvement in facilities and infrastructure, to keep it on par with the best institutions in the world. Institutes in positions of excellence grow with time. The ideas and ideals on which such institutes are built evolve and change with national aspirations, national perspectives, and trends world - wide. IIT Bombay, too, is one such institution.

IIT Bombay, under Civil engineering department conducts an elaborate post-graduate and Doctorial course in Transport engineering.

IIT Bombay is actively involved in varieties of Industrial Research and Consultancy projects and co-ordinates with sponsored research and industrial consultancy projects.

The project of Comparative Evaluation between Elevated and Underground Metro for Charkop Bandra Mankhurd (Metro-2) is taken by IIT Bombay under **DRD/ CE/ SLD-3/2008-2009.**

ABOUT THE AUTHOR

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His vast experience for over four decades in Transport Engineering has contributed his expertise in many projects across the country.

This report is prepared in Sept 2009.
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LIST OF ABBREVATIONS

CBM	Charkop-Bandra-Mankhurd
CTS	Comprehensive Transport Study
DMRC	Delhi Metro Rail Corporation
DPR	Detailed Project Report
EIRR	Economic Internal Rate of Return
FIRR	Financial Internal Rate of Return
GR	Government Revolution
GOM	Government of Maharashtra
MCGM	Municipal Corporation of Greater Mumbai
MMRDA	Mumbai Metropolitan Regional Development Authority
MRTS	Mass Rapid Transit Systems
MUIP	Mumbai Urban Infrastructure Project
NPV	Net Present Value
O & M	Operation and Maintenance
PHFD	Peak Hour Flow Diagram
PPP	Public Private Participation
SP	Social Perception
VAG	Versova-Andheri-Ghatkopar
VOC	Vehicle Operating Cost
VOT	Vehicle Operating Time

LIST OF TABLES

CHAPTER 1

EXECUTIVE SUMMARY

The scope of this Report is to study the proposed Metro Line II as proposed by MMRDA for Charkop-Bandra-Mankhurd route, in the context of overall Master Plan for the city of Mumbai. The study also evaluates options for Underground Metro and its impact on the Integrated Transport Plan for the citizen of a developed and congested city like Mumbai.

The attached proposal of Underground Metro is one of the alternatives of a study plan between Jogeshwari and Bandra-Kurla-Complex stretch of the route.

This study report does not touch upon many aspects of Metro Rail Project such as rolling stock, rail yards at both ends, Finance resource, Tax exemptions, Operation & Maintenance, Validity of Contracts for PPP, BOT, etc. general administration of the metro rail and so on.

1.1 Mumbai Metro

As per GR of 4^{th} May 2006 Line I is proposed between Colaba- Mahim-Charkop. But the same is modified on 14^{th} November 2006 to Charkop-Bandra-Mankhurd. According to ridership the first option would have been better justified from the planning point of view as well as for convenience of the commuters because ridership envisaged between Bandra to Mankhurd is meager 16% even after 20 years.

However, the Elevated Metro Line II - Charkop-Bandra-Mankhurd is proposed as a part of the Phase I of the construction of MRTS System in Mumbai by the MMRDA under a Public Private Participation (PPP) model.

The key benefits generally expected from the Metro projects include:

- Reduction in traffic congestion on roads within the city by offering an alternate transport route.
- Reduction in congestion within the city will also help in increasing traffic speeds and reduces journey travel time.
- Give a boost to the development of the project corridor area.
- Provision of a comparatively more comfortable and convenient travel enroot the journey
- Improve the quality of the air and environment by possible reduction in the private vehicles on roads.

1.2 Demerits of Elevated Metro :

These are divided into seven groups and are analyzed in the Report:

Group A	Technical Issues
Group B	Legal
Group C	Social/Quality of Life
Group D	Other Infrastructure
Group E	Environment
Group F	Cost, Finance & Economics
Group G	Integrated Transport Plan

1.3 Data Collection

This task involves conduct of various surveys to collect data regarding traffic and travel characteristics of the region.

1.4 Pilot Survey

A Pilot Survey is an essential pre-requisite for any field survey based Research Project to get first hand information regarding feasibility through a questionnaire in terms of its flow, readability, understanding and time taken.

1.5 The various objectives of Traffic survey conducted for the study are listed below

- **Classified Traffic Volume Count Survey**
  To assess and estimate the traffic intensity (Average Daily Traffic), Hourly Variation and Traffic Composition.

- **Classified traffic volume count at Intersections capturing all movements**
  To appreciate the traffic characteristics on major/critical Intersections.

- **Road Network Inventory Survey**
  Accessibility and Mobility are largely defined by network characteristics. The road network inventory survey aims to gather all physical characteristics of the network in order to assess network capacities and other characteristics affecting ease of movement.

- **Journey Time Survey**
  Mobility as defined by network characteristics is manifested in journey speed and delay characteristics.

- **Airport Traffic and Terminal Survey**
  Traffic volume counts on roads approaching the airport for impact assessment.

- **Parking Survey**
  The main objective of the parking survey is to assess parking demand at various locations.

- **Commuters Opinion Survey**
  This survey would include interviewing commuters on sample basis to have information on personal details, trip characteristics, opinion on service and their suggestions towards improvement.

1.6 Economic Advantages and Costs of Underground Metro and its Benefits

Description of economic benefits and costs of the Underground Metro requires the identification of the changes brought out by it in the transport sector of the economy.

Most importantly, the diversion of current passenger traffic from road to Metro is not much. As a result, there will be a less reduction than envisaged in the number of buses, passenger cars and other vehicles carrying passengers on roads with the introduction of the Metro.

In Elevated Metro there will be reduction in capacity of roads from 3 lanes to 2 lanes, which will remain same in case of Underground Metro. As per result congestion and pollution on road side will be less in Underground metro.

Investment in the Underground Metro could result in the reduction on road user cost. There will be reductions in motor vehicles' operation and maintenance charges to both the government and the private sector. The citizens of Mumbai will gain substantially with the introduction of the Underground Metro service. It saves travel time due to a reduction of congestion on the roads combined with lower travel time of the Metro. There will be health and other environmental benefits to the public due to reduced pollution from the transport sector of Metro.
The savings at current prices on account of:

- Less number of vehicles on road with MRTS Implemented
- Decongestion Effect
- Time for all passengers using Metro and Roads
- Land Acquisition Cost

- Pulling down the Structures and displacement of Residents.
- Savings in Shifting of Utilities Services
- Accidents
- Vehicle Operating Cost (VOC) due to decongestion for residual traffic
- The cost of Road Infrastructure
- Reduction in Pollution
- Savings in Foreign Exchange due to reduced Fuel Consumption

1.7 Why Underground Metro for Suburbs:

Although this evaluation report indicates necessity for Underground Metro between Jogeshwari and Bandra Stretch for the sake of detailed study.

However the Government must invest in implementing Underground Metro throughout the complex city like Mumbai. Where vehicular roads are overused and real estate development dominates city’s built forms.

Many aspects of this evaluation report may be taken as reference on similar cities across the country.

CHAPTER 2

COMPARATIVE EVALUATION OF ELEVATED AND UNDERGROUND METRO

2.1 INTRODUCTION AND STUDY NEEDS:

The elevated metro from Charkop – Bandra-Mankhurd is proposed as a part of the phase I of the construction of MRTS system in Mumbai by the MMRDA under a Public Private Participation (PPP) model. This report contains a technical study to evaluate the elevated metro vis-à-vis the underground system to make a rational decision, considering the all kinds of impacts on the quality of life of the people of Mumbai as well as those affected directly by the elevated alignment of the said metro. Therefore the decision on whether the metro needs to be elevated or underground should be based on the improvement in the overall quality of life of the people of Mumbai.

2.2 THE ISSUES FOR CONSIDERATION:

The following issues are taken into account while preparing the technical report:

a. Reviewing the Merits and Demerits of an Elevated System vis-à-vis an Underground MRTS System.

b. Cost Benefit Analysis of Elevated Rail vis-à-vis an underground rail. The point should cover all costs for both the system
   - Construction Cost
   - Infrastructure Cost
   - Land Acquisition Cost
   - Rehabilitation and Resettlement Cost
   - Litigation Cost
   - Cost of Delays due to legal or other obstacles
   - Environment Cost
   - Social Cost
   - Economic Cost
   - Including impact of increase in FSI requiring additional infrastructure and resulting in intensive densification along the entire length of the corridor.

2.3 STUDY AREA :

Metro II (Charkop-Bandra-Mankhurd) corridor falls within Municipal Corporation of Greater Mumbai (MCGM). This corridor mainly connects the Western Region with the business oriented areas of Bandra, etc. The MCGM area thus has been designated as study area. The area of MCGM is 438 sqkm. and population 12.81 millions for the year 2005. The other details of the study area are furnished in the subsequent sections.

The estimated population and employment for various horizon periods were based on the following assumptions and developmental scenarios contemplated based on CTS report of MMRDA.

- Population growth (1991-2001) applied at census sections (88 no's), based on aggregate level (island city, western & eastern suburb)

- Employment distribution at census sections in proportion to that observed in 1998 economic census

- Redevelopment of textile mill land

- Employment concentration at Bandra - Kurla complex

- Employment growth potential at Andheri (E), SEEPZ, MIDC

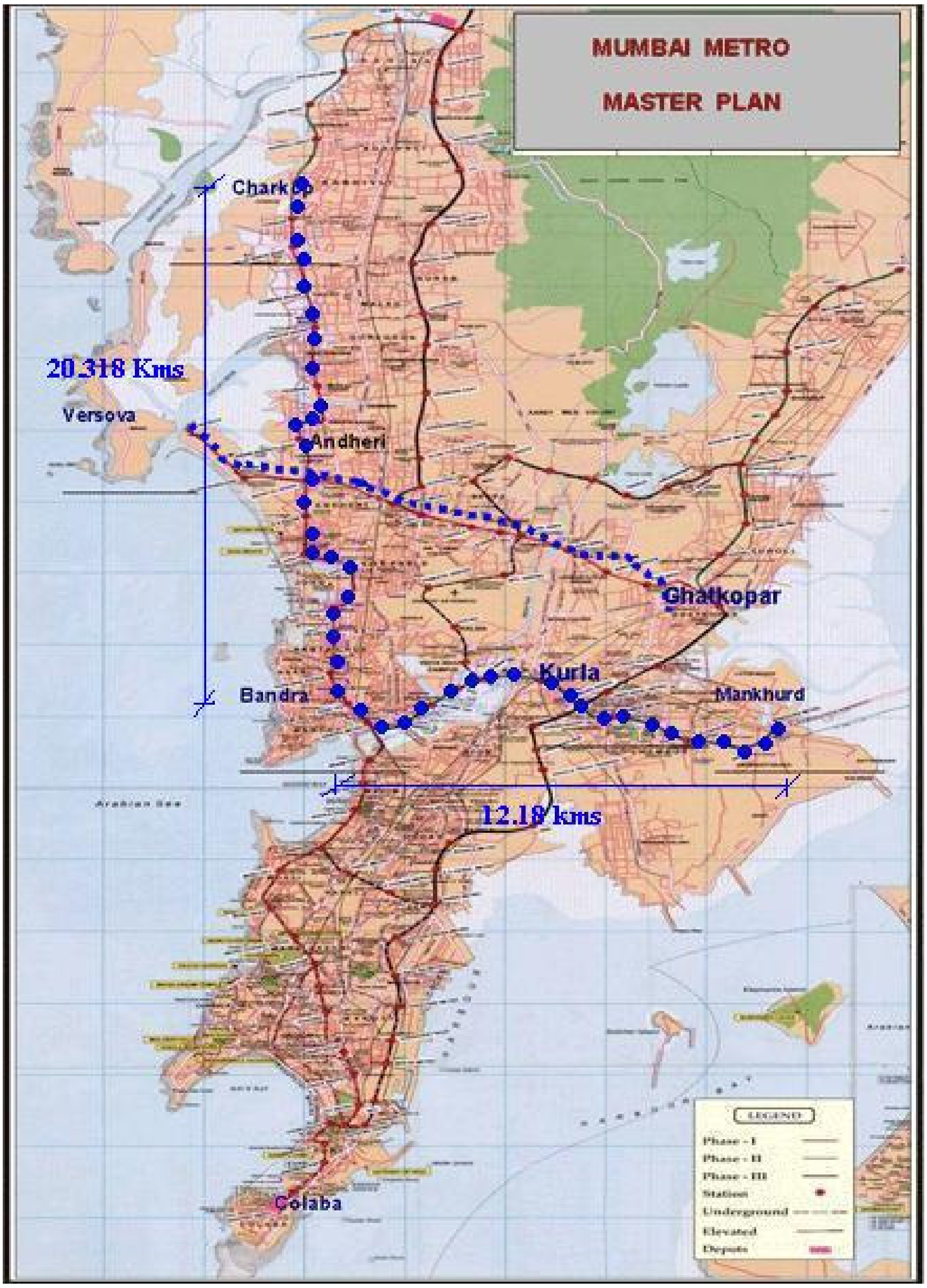


FIG. 2.3.1 METRO - PHASE-I LINE - 2 (CHARKOP - BANDRA TO MANKHURD)

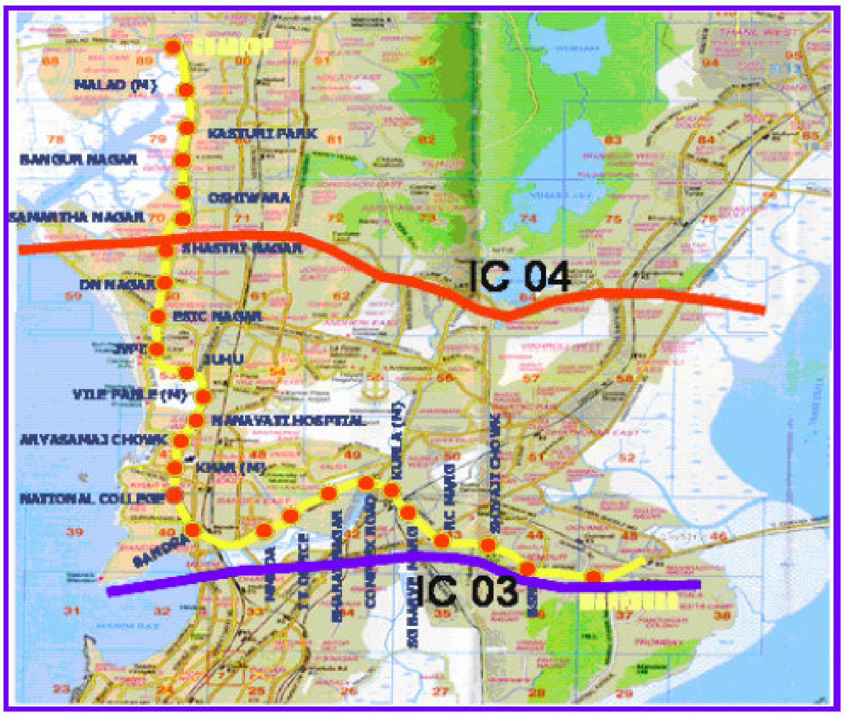


FIG. 2.3.2 MAP SHOWING INTERNAL CORDON LOCATION 3,4

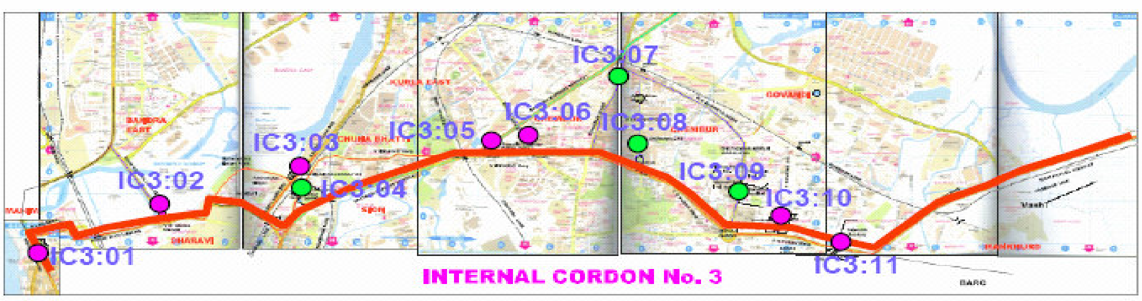


FIG. 2.3.3 MAP SHOWING DETAILS OF INTERNAL CORDON NO. 3

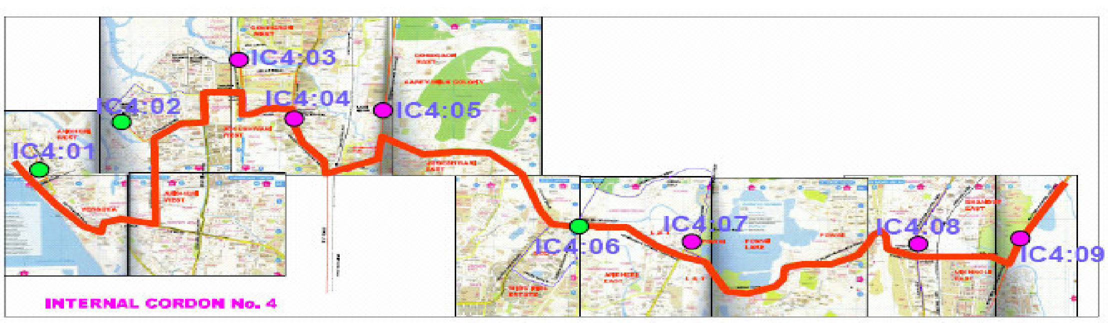


FIG. 2.3.4 MAP SHOWING DETAILS OF INTERNAL CORDON NO. 4

2.4 TRAFFIC DATA AND LEVEL OF CONGESTION

TABLE 2.4.1 CLASSIFIED TRAFFIC VOLUMES ON INTERNAL CORDON 3 AND 4

Sr.No.	Name of code	Name of the Road	Cars	Two wheelers	Autos	Taxis	Buses	Cycles	Hcv	Lcv	others	Total Vehicles
1	IC3:01	Mahim Causeway	70458	44513		43713					11668	170352
2	IC3:02	Sion Bandra Link Road	52740	22021	34353	18329					20246	147689
3	IC3:03	LBS Road, near Naik Road	14756	9217	15644						16615	56232
4	IC3:04	Duncan Causeway Road	1610	1843	2909	1005					1062	8429
5	IC3:05	Eastern Express Highway	46901	24678					5832	13988	39938	131337
6	IC3:06	S G Barve Marg, U Bappa Chowk	4758	7645	28242						8962	49607
7	IC3:07	R C Road	8143	9682	23631						5608	47064
8	IC3:08	Sarasvati Marg, Lad Chowk	5629	4448	7687		647				1982	20393
9	IC3:09	Patil Marg, near Patil Industrial Estate	4000	2945	5998						1547	14490
10	IC3:10	B S Devashi Marg	2254	2285	4288						1449	10276
11	IC3:11	Sion Panvel Highway	35288	16270	15409						19990	86957
12	IC4:01	Yari Road	2722	3559	6428						2623	15332
13	IC4:02	(BMC Road	4426	1083	2119						736	8364
14	IC4:03	Link Road, Oshiwara	22356	19976	27984		3003				7651	80970
15	IC4:04	S V Road	10193	17035	29833						8912	65973
16	IC4:05	Western Express Highway	63557	48086	61699						30756	204098
17	IC4:06	Moral Mahroshi Road	1949	4442	3187			644			709	10931
18	IC4:07	Saki Vihar Road)	5598	5291	8354		1176				3020	23439
19	IC4:08	LBS Marg	9699	13768	17644		3902				5789	50802
20	IC4:09	Eastern Express Highway	41492	20002	13000				8747	3854	8287	95382

(Source: CTS for MMR Draft Final Report Vol.II April 2008)

Above table shows traffic volumes of roads which falls on inner cordon 3 and 4. Traffic volume is function of width of the road, pavement condition, road geometry and which is directly related to the free flow speed and journey speed. Above matrix of 24 hours count shows that most of the roads are congested.

Table 2.4.2 Details of Road Links and Their Characteristics

Link Type	No. of lanes	Divided/ Undivided	Type of flow	Capacity Per Direction (PCU/hr)	Free flow speed (km/h)	Speed @ Capacity (km/h)
1	One Lane	Undivided	One-Way	1650	30	15
2	Two Lane	Undivided	One-Way	3200	40	15
3	Three Lane	Undivided	One-Way	4350	40	15
4	Four Lane	Undivided	One-Way	5300	50	18
5	Five Lane	Undivided	One-Way	6200	50	18
6	Six Lane	Undivided	One-Way	7000	55	20
7	Three Lane	Divided	One-Way	4350	40	15
8	Four Lane	Divided	One-Way	4950	50	18
9	**Six Lane**	**Divided**	**Two-Way**	**7000**	**45**	**18**
11	Two Lane	Undivided	Two-Way	1100	35	15
12	Three Lane	Undivided	Two-Way	1500	35	15
13	Four Lane	Undivided	Two-Way	2150	40	18
14	Five Lane	Undivided	Two-Way	2600	40	18
15	Six Lane	Undivided	Two-Way	3200	45	18
16	Three Lane	Divided	Two-Way	1650	40	18
17	Four Lane	Divided	Two-Way	2600	50	18
18	Six Lane	Divided	Two-Way	3800	50	18
19	Eight Lane	Divided	Two-Way	6200	55	20

(Source: CTS for MMR Draft Final Report Vol.II April 2008)

The alignment of the metro line two for C-B-M route is proposed on 4-lane and 6-lane roads. The present journey speed on this road is about 15 kmph. The post construction will permanently reduce to 2 lane and 4 lane respectively thus reducing speed to about 10 kmph. During the construction minimum 2.5 lanes (9 metres width) will be barricaded that results further congestion and will reduce journey speed to 12 kmph.

2.5. IMPORTANT STATISTICS OF THE PROPOSED ELEVATED METRO CORRIDOR BY MMRDA

2.5.1 General :

Gauge (Nominal)	1435 mm.
Route Length (between dead ends) Elevated	31.87 Km.
Number of stations Elevated	27 Nos.

2.5.2 Traffic Forecast :

	2011	2021	2031
Daily Boarding (Lakhs)	12.75	18.77	22.16
PKM (Lakhs)	95.3	139.8	164.7
Average trip length	7.5	7.4	7.4

2.5.3 Designed speed **80 kmph**

2.5.4 Construction Methodology :

Elevated Viaduct consisting prestressed concrete ” Box ” shaped Girders on Single Pier with pile / Open Foundation.

2.5.5 Total Estimated Cost + Taxes **Approx. Rs. 8,200 Crores**

(Source:http://w.w.w.mmrdamumbai.org/projects)

2.5.6 Financial Indices :

Financial Indices of MRTS Phase-I Network with this corridor is:

EIRR	18.64%
FIRR	7.39%

2.6 IMPACT OF POPULATION DISTRIBUTION BETWEEN CITY AND SUBURBS

POPULATION DISTRIBUTION BETWEEN CITY AND SUBURBS

	City	Western Suburbs	Eastern Suburbs
(1981)	(39.84 %)	(34.71%)	(25.49%)
2001	27.92%	42.77%	29.31%
2011	24.88%	44.66%	30.46%
2021	22.38%	46.15%	31.47%
2031	20.40%	47.20%	32.20%

POPULATION IN CITY DECLINES TO MERE 20% WHILE INCREASES IN WESTERN SUBURBS TO 50%

The density of population in the city is declining whereas Western Suburbs & Eastern Suburbs are rapidly expanding, mainly because of increased FSI, SRA Projects and rapid real estate development in the suburbs. This has resulted in shrinking of open spaces, failure of infrastructure and deteriorating quality of life especially in the Western Suburbs.

2.6.1 Employment Scenario

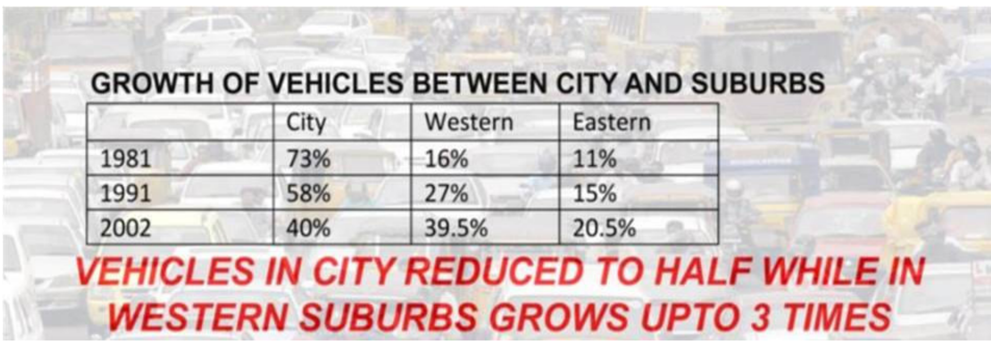
	City	Western Suburbs	Eastern Suburbs	Total
1981	Rs. 11.00 Lacs	Rs. 2.40 Lacs	Rs. 1.90 Lacs	Rs. 15.30 Lacs
1998	Rs. 15.90 Lacs (14.5 % growth)	Rs. 6.50 Lacs (27% growth)	Rs. 3.80 Lacs (50% growth)	Rs. 26.20 Lacs
	60% share	**25% share**	**15% share**	

2.6.2 Peak Hour Boarding/Alighting

	City	Western Suburbs	Eastern Suburbs
2011	Rs. 1.54 Lacs	(Rs. 0.73 Lacs)	Rs. 0.54 Lacs
2031	Rs. 1.89 Lacs (13 % growth)	Rs. 1.57 Lacs (21% growth)	Rs. 0.64 Lacs (11.8% growth)
	46% share	**38% share**	**16% share**

2.7 GROWTH OF VEHICLES BETWEEN CITY AND SUBURBS

Alongwith the pattern of population, the growth of vehicles – private & public – created imbalance between city and suburbs.
These figures indicate growing pressure on roads in the suburbs in last decades, which lead to traffic congestion in the entire suburbs. It is evident when one travels from city to suburbs at any time of the day. As such under MUIP, 9 flyovers are planned on alignment route alone.


GROWTH OF VEHICLES BETWEEN CITY AND SUBURBS

	City	Western	Eastern
1981	73%	16%	11%
1991	58%	27%	15%
2002	40%	39.5%	20.5%

VEHICLES IN CITY REDUCED TO HALF WHILE IN WESTERN SUBURBS GROWS UPTO 3 TIMES

2.8 SOCIAL COST BENEFIT ANALYSIS

- Our experience for construction of mega projects at ground in highly congested areas shows that life almost becomes standstill a hell during the construction period up to minimum 5 years. The vehicle operating cost mounts extremely high due to barricading, existing road width up to 9 meters. This reduced road width leads to congestion and tremendous delays.

- The necessity/need for any mega transportation / infrastructure project is felt from urgent social mobility needs of the society.

- The cost and benefits of different alternatives are calculated considering social cost benefit analyses which are based on the detailed calculations attached in the appendix.

- Calculation of benefits is much complex and challenging. That is the reason it is criticized that government organizations resort to only financial analysis forgetting social needs / aspirations of the citizen of the city, particularly of the residents in the influence zone.

- In the highly congested corridors, the social benefits outweigh for the underground metro compared to the elevated metro.

  This is obvious on the account of very high direct and indirect cost savings of Underground metro compared to Elevated metro.

CHAPTER 3

DEMERITS OF ELEVATED METRO: C-B-M ROUTE

There are several Demerits of Elevated Metro in C-B-M Route. These demerits are sourced mainly from the DPR of September 2007 For better evaluation they are presented into 7 different groups as under :

GROUP A - TECHNICAL ISSUES :

3.1 Even before Elevated line – I (VAG Route) is commissioned, the worst impact for line-II (CBM Route) noticed when it crosses at D.N. Nagar Station at 24.99 mtr. (chainage 9020 to 9537) from road level. This double elevation of combined D.N. Nagar Station as well as via ducts in either direction is structural monstrosity at one of the busiest intersections.

Similarly at S.G. Barve Marg station which is at 22.08 mtrs. (chainage 25565 to 26194) for crossing a flyover over Eastern Express Highway.

In fact the entire 32 km. route is lifted to average 10.mtr. level instead of normal 6.00 mtr. level because of VAG route.

3.2 Vile Parle Station on S.V. Road adjoining high security runway of Juhu Airport is impossible at +16.74 level (chainage 13224). Even if the station is removed, the elevated via duct at +12.43 mtr. will be prohibited by Airport Authority. At this stretch maximum height upto tip of the building allowed by Airport Authority is 12.3 mtr. because of Air funnel whereas top of coach will be over 16.00 mtr. from road level.

3.3 54% of the length of alignment is on Curves. In other words over 17 km. of elevated metro rail falls on curves, thus the speed planned at 80 kmph shall be restricted immensely. Further these curves are at 140 locations, of which as many as 38 locations are less than 500 m radius and at 8 prime locations at 90^o, requiring land acquisition, displacement of people, public amenities, etc.

These curves are unavoidable evil for any rail which are prone to derailment, high maintenance costs and accidents. It is a known fact that many times via duct support needs portal frame structure to negotiate peculiar curves which may not align with the Right of Way.

These curves are also accident prone and high on maintenance costs.

GROUP B - LEGAL

3.4 There is no evidence of option consideration of Underground Metro before finalizing Elevated Metro for CBM route. In fact it is construed as discrimination of citizens between city and suburbs.

3.5 Order passed by GOM on 30th July'09 has not considered a single petition from over 8500 submitted in response to Draft Order dated 1st November'08

3.6 Order passed by GOM on 17th August 2009 clearly violates MMRDA's own directive and allows commercial exploitation upto 4000 sqm. over platform of each of the 27 elevated stations. Average level of these Commercial spaces will be at 20.00 mtrs. from roads on the C-B-M route and needs dedicated car parks over 70 nos.

3.7 No coordination with MCGM – the main regulatory authority for approval, completion, etc. of plans of private properties as yet.

3.8 Non applying of Airport Authority regulation as per item 3.2 above.

3.9 Flouting of CRZ norms as no permission obtained as yet from the government inspite of 40% of rail yard passes through CRZ areas.

3.10 Ignoring of CFO norms - ROW and open spaces are not as per prevailing CFO regulations.

GROUP C - SOCIAL/QUALITY OF LIFE :

Any infrastructure project should improve quality of life of its citizen. In total contradiction CBM route will deteriorate the entire urban fabric of Suburban Mumbai.

It is evident from the pattern of density, vehicular traffic. Right of ways of arterial roads and ridership. etc. The Western & Eastern Suburbs is experiencing deteriorating qualify of life especially considering Air pollution, sound levels, fuel consumption, road accidents, etc.

As per the DPR – EIRR alone, during construction period of 5 years of Elevated metro will be a huge financial loss.

3.11 As per the table no. 2.4.2 (page 15) Elevated Metro Station reduces the motorable width of Roads to over 30%. This will deteriorate traffic and congestion on roads.

3.12 About 7000 sqm. of Footpaths are acquired to accommodate Elevated Station. Thus a vital link between vehicular traffic and private properties will endanger pedestrians.

3.13 The massive structure of elevated metro stations at (approx. 25 mtr. wide x 150 mtr. long) every kilometer distance shall change the skyline because it will be enforced in the middle of crowded arterial roads with virtually no open space. The impact will be the worst in terms of quality of life for several generations to follow.

GROUP D - OTHER INFRASTRUCTURE

3.14 The three main Arterial Roads i.e. Linking Road, S.V. Road and Link Road are strangulated forever. As such these are the only Arterial roads connecting Western Suburbs to entire city. Similarly part of Sion-Panvel Road will be obstructed for traffic moving towards New Bombay and beyond.

3.15 MMRDA itself has planned 7 flyovers in Western Suburbs and 2 flyovers in Eastern Suburbs (Ref. Item 2.7) for ease of traffic on roads where alignment is proposed. Instead all 9 Flyovers are scrapped to accommodate Elevated Metro Rail.

3.16 7000 sqm. of footpaths shall be removed to make place for stairs, lifts and escalators for Elevated stations as mentioned in item 3.12

3.17 Andheri Pumping Station, Santacruz Police Station and few MHADA projects at Bandra will be displaced amongst others. Thus citizen will be deprived of many vital amenities.

3.18 There is no clue whatsoever about existing bus routes and Bus stops. Within a stretch between Andheri and Bandra alone about 60 bus stops will be displaced thus the prevailing Bus service will be absolutely chaotic during pre-construction and post-construction of Elevated Metro.

3.19 Utility Responsibility and Several Departments

There are 13 major Organisations/Departments such as MCGM, PWD, RTO, MHADA, Railways, etc. under whose responsibilities varieties of utilities are running either underground, surface or overhead.

Some of the critical utilities like sewerage, water supply, water treatment plants, HT/LT Lines, gas lines, traffic signals, telephone and data cables, railway crossings, etc. will have to be diverted, altered or removed.

It is pertinent to note that in our prevailing system each of the 13 organisations are functioning independently. It's going to be a mammoth task for any authority of coordinating these organization / depts., leave aside implementing their services cohesively.

The huge cost and time required for diversion/replacement needs to be accounted in detail.

32 kms. of sewer lines, 12.5 km. of water lines and 11 kms. of gas lines will have to be re-laid amongst other essential utilities in over-congested arterial roads as under :

DETAILS OF SEWER LINES (at 2 to 3 mtrs. depth)

No. of Locations	To be shifted	Non-standard Foundation
45 locations	32,300 Rmt.	--
54 locations	--	1,650 Rmt.

DETAILS OF WATER PIPE LINES (at 1 to 2 mtrs. depth)

No. of Locations	To be shifted	Non-standard Foundation
29 locations	12,570 Rmt.	--
88 locations	--	2,750 Rmt.

DETAILS OF MAHANAGAR GAS PIPE LINES (at 1 mtr. depth)

No. of Locations	To be shifted	Non-standard Foundation
36 locations	11,050 Rmt.	--
41 locations	--	11,060 Rmt.

3.20 As per the break-up of lands permanently required is 46.98 Ha which includes 2.35 Ha from private ownership.

It is observed that these lands are the minimum land required for access to a station or for the footings of the viaduct. It appears that there is no computation of appurtenant land which will be inevitable to acquire subsequently.

There is no mention, where the user from 44.63 Ha of Government land shall be relocated and its impact to the citizens such as Santacruz Police Station, Andheri Pumping Station, etc.

Moreover the acquisition of private lands seems to be grossly underestimated considering over-developed properties on narrow ROWs.

GROUP E - ENVIRONMENT

3.22 One of the worst impacts is uprooting of 948 trees from 1950 existing trees of several generations. A meager amount of Rs. 1000/- per tree is estimated as loss to the citizen is absurd. These trees are priceless. Even planting ten time more trees in remote location is no solution.

3.23 Sound Pollution

It is expected that Elevated Metro Rail will have 85 to 90 db (A). The noise pollution emitted by the trains on account of engine noise, wheel rail interaction, D.G. sets, train speed and irritant constant announcement over PA systems at all stations, apart from noise of mass movement of commuters.

3.24 Fuel Loss:

The vehicle operating cost and pollution costs will have its direct impact on Fuel Loss of Buses, cars, taxis, autos, etc. not only during construction but forever. In addition it will generate huge amount of air and dust pollution.

3.25 It is presumed that the Elevated Metro is more economical and therefore a viable project. It's a known fact that no Metro Project even if it is elevated is profitable in any part of the world. Even in Kolkata and Delhi it is hugely subsidized by respective State Governments.

3.26 As per the DPR analysis under EIRR, Socio-economic cost will be incurred during the construction phase alone :

DPR specifies actual loss of amount on following costs :

a)	Vehicle Operating Cost	Rs. 732.79 crores per anum
b)	Decongestion Cost	Rs. 41.40 crores per anum
c)	Passenger Time Cost	Rs. 507.98 crores per anum
d)	Pollution Cost	Rs. 129.71 crores per anum
e)	Accident Cost	Rs. 2.40 crores per anum
		Rs. 1414.28 crores per anum

Thus for 5 years of construction duration, citizens will loose over Rs. 7,070 crores. It is not clear who shall compensate this huge cost apart from inconvenience to entire suburbs !

3.27 As per the DRP the overhead/maintenance cost will be higher in 2021 and 2031 as under :

MAINTANENCE COST		
	20 Km. Underground Metro in City	**32 Km. Elevated Metro in Suburbs**
2021	80.89 Crores **(4.04 Crores/km.)**	188.00 Crores **(5.875 Crores/Km.)**
2031	131.76 Crores **(6.60 Crores/km.)**	307.00 Crores **(9.60 Crores/Km.)**

GROUP G - INTERGRATED TRANSPORT PLAN

3.28 All options for optimizing and interconnection various modes of transport are clipped forever.

3.29 All options of wide footpaths and separating pedestrian lanes are lost forever.

3.30 All options of cycling tracks connecting short distances to playgrounds, schools, markets, etc. are vanished forever.

3.31 The BRTS (Bus Rapid Transport System) and feeder bus routes to Metro station will not be possible.

3.32 Elevated metro will be a huge liability to expand Metro rail itself in all future routes.

CHAPTER 4

DEMERITS OF UNDERGROUND METRO

4.1 It is generally perceived that the cost of Underground Metro costs double than Elevated.

(In the proposed CBM Route this notion is not applicable because only the cost of civil work for stations, via ducts, HVAC system and partially Electrical cost will be affected).

4.1.2 COMPARATIVE COST SUMMARY BETWEEN CITY AND SUBURBS

MAHIM-COLABA ROUTE		
For Underground	17.3 km.	14 Stations
	+	+
For Elevated	2.1 km.	2 Stations
	19.4 km.	16 Stations
TOTAL COST	Rs. 10,315 Crores **OR Rs. 531 Crores/km.**	
For Underground	8.2 km.	8 Stations
	+	+
For Elevated	12.3 km.	8 Stations
	20.5 km.	16 Stations
TOTAL COST	Rs. 7,529 Crores **OR Rs. 369 Crores/ km.**	

CHARKOP-BANDRA-MANKHURD ROUTE		
For Elevated	31.87 km +	27 Stations
TOTAL COST	Rs. 8,250 Crores **OR Rs. 260 Crores/ km.**	
*For Underground	11.50 km.	11 Stations
	+	+
For Elevated	20.50 km.	16 Stations
	32.00 km.	27 Stations
TOTAL COST (as per Aug 2009)	Rs. 9,708 Crores **OR Rs. 303 Crores/km.**	

*(As per study – Jogeshwari/Bandra)

4.2 The other attribute is the time. ***(This demerit will not affect the citizen, especially during construction. Infact it will overcome of one of the demerits of Elevated Metro of coordination issue as mentioned in item 3.19)***

CHAPTER 5

BRIEF STUDY APPROACH

Following activities come under scope of work of the study.

- Data Collection
- Simulation/ Modeling
- Formulation of a transport strategy
- Public consultation process
- Comparative Evaluation

Sections below detail out each of the above activities in terms of various tasks and their contents and scope.

5.1 DATA COLLECTION

This task involves conduct of various surveys to collect data regarding traffic and travel characteristics of the region.

5.2 PILOT SURVEY

A pilot survey is an essential prerequisite for any field survey based research project to get first hand information regarding feasibility of questionnaire in terms of its flow, readability, understanding and time taken, and also the get a clear view of the field issues and logistics that are likely to be faced.

5.3 THE VARIOUS TRAFFIC SURVEYS CONDUCTED FOR THE STUDY ARE LISTED BELOW:

5.3.1 Classified Traffic Volume Count Survey

The objective of the survey is to assess and estimate the traffic intensity (Average Daily Traffic), Hourly Variation and Traffic Composition.

5.3.2 Major Roads along the Route

The Alignment from North to South & East traverses along all Major Roads as indicated. Please note that at 5 out of 13 stretches of ROW is less than 25 mtrs. width.

These critical stretches are congested and experiencing the burden of TDR including deteriorating infrastructure.

Sno	Chainage(m)		Name of the Road	Stretch		ROW (m)
	From	To		From	To	
1	0	6,700	Goregaon Linking Road	Charkop	Behram Baug Bus Stand	36.6
2	7,375	9,250	Kamal Karapant Walawalkar Rd	Behram Baug Bus Stand	Param Vir Chakra Lt. Col A.B. Tarapore Chowk	18.3
3	9,250	9,650	D.P. Road (New Link Road)	Param Vir Chakra Lt. Col A.B. Tarapore Chowk	Jivan Nagar Road	27.45
4	9,650	12,000	Guru Nanak Das Road	Jivan Nagar Road	Sports Club	30.5
5	12,000	12,900	Vaikunth Lal Mehta Road	Sports Club	B.Bhuta Chowk	36.6
6	12,900	14,700	S.V. Road	B.Bhuta Chowk	Red Sea Classic	24
7	14,850	15,000	Juhu Road	S.V. Road	Arya Samaj Chowk	16
8	15,150	17,900	Guru Nanak Das Road	Arya Samaj Chowk	Gurunanak Chowk	20
9	17,900	18,500	Vithal Bhai Patel Road	Bandra Rly. Station	Gurunanak Chowk	16
10	19,836	20,886	Bandra Kurla Complex Road	Open Theatre	E Block Road	30
11	21,486	23,186	Bandra Kurla Complex Road	Bank of Baroda	ICICI Bank	36
12	24,686	25,886	S.G. Burve Marg	Kurla West	S.G. Barve Marg	31
13	25,986	29,486	Trombay Marg	Trombay Marg	Bharat Sanchar Nigam Limited	33

5.3.3 Classified traffic volume count at Intersections capturing all movements

The objective of the survey is to appreciate the traffic characteristics on major/critical Intersections. The survey would result in having Peak Hour Flow Diagram (PHFD) at surveyed intersections/junctions. The results of this survey would primarily be utilized in working out circulation, geometric improvement, capacity augmentation plans and to validate trip assignment model.

5.3.4 Road Network Inventory Survey

Accessibility and Mobility are largely defined by network characteristics. The road network inventory survey aims to gather all physical characteristics of the network in order to assess network capacities and other characteristics affecting ease of movement.

5.3.5 Journey Time Survey

Mobility as defined by network characteristics is manifested in journey speed and delay characteristics.

5.3.6 Airport Traffic and Terminal Survey

Traffic volume counts on roads approaching the airport for impact assessment.

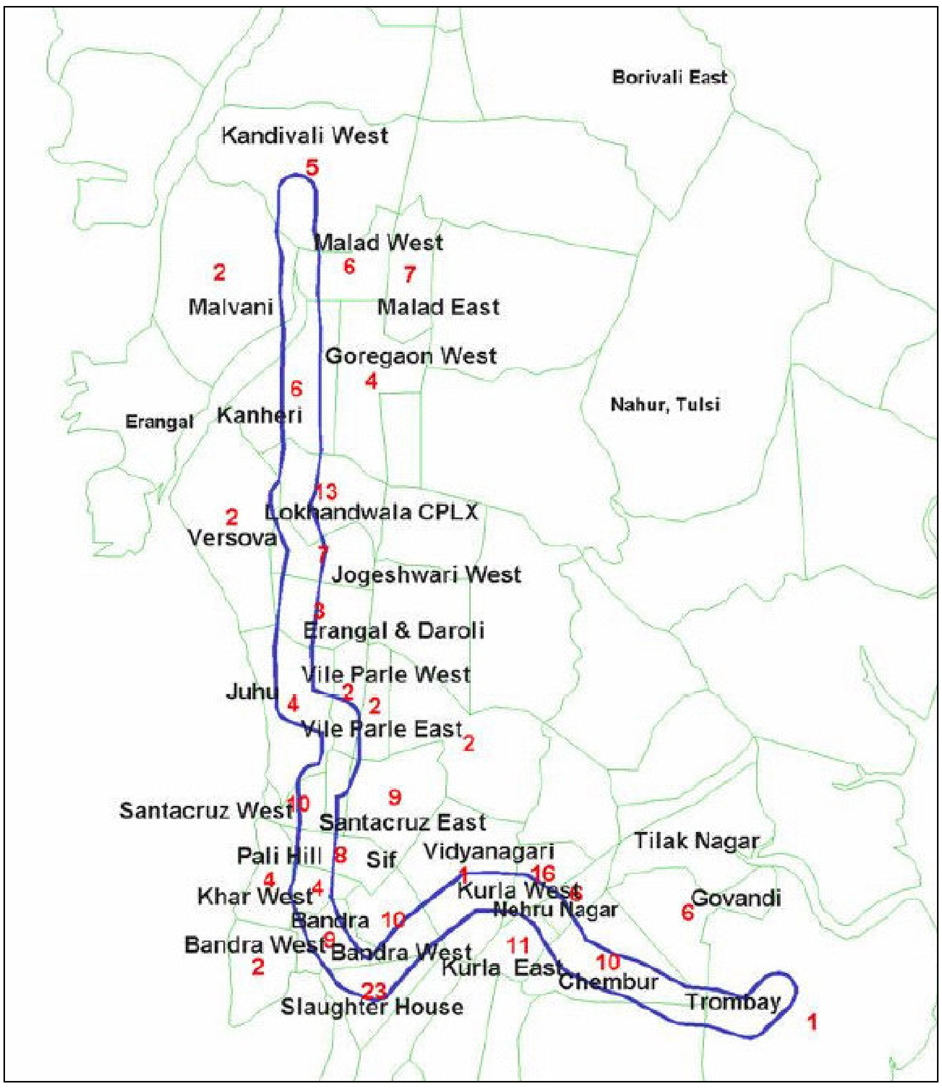
5.3.7 Parking survey

The main objective of the parking survey is to assess parking demand at various locations.

5.4 COMMUTERS OPINION SURVEY:

Social Perception survey of the residents of different societies in the influence area of the Metro corridor

This survey would include interviewing commuters on sample basis to have information on personal details, trip characteristics, opinion on service and their suggestions towards improvement. We Targeted 500 Samples with influence region of 250 meters either side of proposed metro line. Sample size mapping as per Population density is shown in figure below:



5.5 SAMPLE SIZE AS PER POPULATION DENSITY

ID	Name	Population	Area	Density	*Sample Size*
87	Kurla West	1,87,037	0.69	2,70,072.08	***16***
71	Goregaon West	1,32,192	1.81	72,918.18	***4***
72	Kanheri	2,00,714	1.89	1,06,034.65	***6***
68	Lokhandwala CPLX	3,15,053	1.42	2,22,175.32	***13***
57	Jogeshwari West	1,11,350	2.62	42,542.02	***3***
58	Vile Parle East	24,127	0.58	41,747.34	***2***
62	Jogeshwari West	1,23,616	0.95	1,29,605.91	***8***
61	Erangal & Daroli	56,367	1.04	54,130.17	***3***
63	Versova	1,17,173	2.61	44,927.45	***3***
59	Vile Parle West	23,190	0.6	38,918.41	***2***
60	Juhu	1,54,756	1.86	83,149.52	***5***
50	Santacruz West	85,269	0.47	1,80,615.69	***11***
92	Govandi	1,90,462	1.7	1,12,302.60	***7***
89	Nehru Nagar	50,989	0.5	1,01,579.55	***6***
94	Trombay	1,95,390	9.01	21,685.84	***1***
93	Chembur	3,36,398	1.98	1,69,687.59	***10***
88	Kurla East	1,20,070	0.6	1,99,415.22	***12***
56	Santacruz East	2,33,255	1.51	1,54,774.78	***9***
53	Sif	1,06,900	0.72	1,48,524.76	***9***
51	Khar West	31,809	0.39	80,976.49	***5***
55	Vidyanagari	64,600	2.29	28,227.35	***2***
39	Slaughter House	3,85,966	0.96	4,00,166.69	***24***
52	Bandra West	1,64,738	0.97	1,69,343.43	***10***
49	Pali Hill	56,080	0.77	72,900.33	***4***
47	Bandra	1,29,357	0.78	1,66,859.03	***10***
48	Bandra West	37,805	0.98	38,629.68	***2***
41	Pali Hill	28,295	0.42	67,910.27	***4***
43	Worli	1,13,363	0.85	1,33,825.22	***8***
79	Kandiwali	4,34,855	4.03	107827.15	***5***
74	Malad Waet	1,19,555	1	119449.30	***6***
77	Malvani	1,55,370	3.89	39924.90	***2***
75	Malad East	1,48,111	1.02	145097.00	***7***
					219

5.6 ANALYSIS OF SOCIAL PERCEPTION SURVEY OF MUMBAI METRO -2

Metro line II - Once if Underground metro comes into operation the hidden advantages are more, it will be economical if we consider those advantages and convert it into cost of Underground metro.

After explaining the merits and demerits of both kind of metros and how their quality of life will change if metro comes and it's operation, most of the respondents co-operated in carrying out the Social perception Survey.

Survey sheet has designed and as a starting point pilot survey has been done, after pilot survey as per respondents behavior and based on their suggestions final survey sheet has been modified. For this, trained professionals have done the survey at various locations around.

The respondents sample comprised mostly households but 15% commercial establishments to represent city wide coverage. The survey team interviewed 70 respondents. It is observed that around 90% of people want Underground metro to sustain their quality of life. If Underground metro is implemented then they are willing to pay on an average two times more than the Elevated metro fare.

SP SURVEY SHEET DESIGN

6.1 Social Perception (SP) Survey for Proposed Elevated / Underground Metro II CBM Route in Suburban Mumbai :

A. SOCIO-ECONOMIC BACKGROUND

1. Place of Residence — Area

   Locality

2. Place of Work — Name of Establishment

   Area

   Locality

3. Sex   4. Age

5. Designation

6. Monthly Income in Rupees

7. No. of Members in Family

8. Details of Family Members (Use codes Provided below)

Sno.	Relation with HOH* (code)	Age (Yrs)	Gender (M/F)	Marital Status (Y/N)	Education (Code)	Occupation (Code)

*HOH = Head of the Household

Relation with HOH 1-Self 2-wife 3-Husband 4-Son 5-Daughter 6-Other

Education 1-SSC 2-HSC 3-Graduation 4-Post graduation

Occupation 1-Retired 2- Public Sector 3-Private Sector 4-Business

9.	Vehicle Ownership in the Family	No. of Cars	
		No. of Motorised 2-Wheelers	
		No. of Bicycles	

10.	Are you provided with a vehicle by your employer	Car/2-Wheeler/Company bus

11.	What amount do you receive from your employer specially for your travel to expenses?	Rs.		Per month

12	Are you a pass holder ?		Bus Weekly Pass	Rs.		Train Weekly Pass	Rs.	
	No Pass		Bus Mthly Pass	Rs.		Train Mthly Pass	Rs.	

B. Details of Normal Mode of Travel to Work

13. What is your daily parking cost at your workplace?

Existing Travel Characteristics By Household members upto 4 Nos.																					
Leg No.	Leg Description	Mode of Travel				Time (Mins.)								Travel Cost (Rs.)				Level of Discomfort			
						Waiting + Transfer				Travel											
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1	Residence to 1st Halt																				
2	1st Halt to 2nd Halt																				
3	2nd Halt to 3rd Halt																				
4	3rd Halt to 4th Halt																				
Total																					

Codes for Mode	Walk = 1	Cycle=2	Two Wheeler = 3	Car = 4	Auto = 5	Six seater=6
	Bus=7	Train =8	Company Bus/Car = 9		Car Pool = 10	

Level of Discomfort	A/C Seat =1	Comfortable A/C Standing = 2	Non-A/C Seat = 3	Non- A/C Standing = 4	Non A/C Standing in Crowd = 5
	Very Low	Low	Moderate	High	Very High

C. Social Valuation and Perception

Please record the preferences of the respondents for the following statements on the basis of the following rankings:

1- Immensely Improved   2-Improved   3-Neutral   4- Worsen   5-Immensely worsen

Metro-2 Corridor				
Attributes	**Elevated Metro**		**Underground Metro**	
	Construction Phase	Operational Phase	Construction Phase	Operational Phase
Riding Quality				
Safety				
Accident Scenerio				
Travel Time Savings				
Quality of Life				

1- Immensely Increase   2-Increase   3-Neutral   4- Decrease   5-Immensely decrease

Attributes	**Elevated Metro**		**Underground Metro**	
	Construction Phase	Operational Phase	Construction Phase	Operational Phase
Air Pollution				
Noise Pollution				
Congestion and Delays				
Parking Problems				
Helath Problems				
Property Prices				

In case of Underground Metro, cost will increase 2 or 2.5 times of Elevated Metro. In this case Are u ready to pay extra fare, if yes how many times more u can pay,

1.25   1.5   1.75   2   2.5

The **SP survey** consists (Travel Survey and social perception for Proposed Elevated or Underground Metro 2 Corridor in Mumbai) total three sheets. Sheet A contains socio-economic background of respondent, sheet B contains details of their travel to work, sheet C contains social valuation and perception of the people towards Metro-2. In detail sheet C has more influencing attributes like riding quality, safety, accident scenario, travel time savings and **quality of life at both construction and operational phase**. Rating has been done on a scale of 1 to 5 to fill these attributes, 1 being immensely improved and 5 being immensely worsen. Some more important attributes to **affect the quality of life like air pollution, noise pollution, congestion and delays, parking problems, health problems, property prices have been included** These also have been included in the survey sheet both at the time of construction phase and operational phase. To fill these attributes also rating have been given on a scale of 1 to 5, 1 being immensely increase and 5 being immensely decrease.

6.2 Development of SP model: ALOGIT is a computer program for studying and forecasting consumer choices. ALOGIT exploits the ability of 'logit' models to explain and predict many aspects of consumer behavior, giving insight into the reasons for behavior, the main variables determining the choices made by consumers and allowing forecasts to be made of what they will choose in the future.

6.3 Analysis of Survey Data

```
Metro SP Model:
Last input data item in transformations or utilities    16
0 transformation codes; maximum 5000
Maximum Iterations 10
Convergence criterion is  .10E-01  Option 3
INFORMATION: No explicit specification - base file read with default format
report of user selections
0 Observations rejected because item 2012 = 1.00
DATA INPUT COMPLETED
from data file : m.dat
Total observations read from file    :   42
Observations rejected by user tests  :    0
Observations rejected automatically  :    0
Observations accepted for processing :   42
Sum of weights of observations :        42.00
SPECIFICATION OF MODEL and DATA STATISTICS
Alternative   1: chosen   31.4 of available   42.0 observations
Coefficient      RQ    +    SA    +   TTS    +    Ap    +    NP
Number (Con)    1 (F)     2 (F)     3 (F)     4 (F)     5 (F)
Start Value    .0000     .0000     .0000     .0000     .0000
Data Item    *Data0003  *Data0004  *Data0005  *Data0006  *Data0007
% Non-Zero     100.0     100.0     100.0     100.0     100.0
Mean (N-Z)      1.57      2.24      1.71      3.29      2.90
C. of V. %      31.5      33.5      36.6      23.3      27.9
Coefficient      CD    +    PP
Number (Con)    6 (F)     7 (F)
Start Value    .0000     .0000
Data Item    *Data0008  *Data0009
% Non-Zero     100.0     100.0
Mean (N-Z)      4.05      3.43
C. of V. %      19.4      34.4
```

Alternative 2: chosen 10.6 of available 42.0 observations
Coefficient RQ + SA + TTS + Ap + NP
Number (Con) 1 (F) 2 (F) 3 (F) 4 (F) 5 (F)
Start Value .0000 .0000 .0000 .0000 .0000
Data Item *Data0010 *Data0011 *Data0012 *Data0013 *Data0014
% Non-Zero 100.0 100.0 100.0 100.0 100.0
Mean (N-Z) 4.14 4.29 3.90 2.33 2.95
C. of V. % 23.9 19.2 27.3 62.5 47.3
Coefficient CD + PP
Number (Con) 6 (F) 7 (F)
Start Value .0000 .0000
Data Item *Data0015 *Data0016
% Non-Zero 100.0 100.0
Mean (N-Z) 1.86 2.43
C. of V. % 44.9 53.3
RANGES OF INDEPENDENT VARIABLES
Variable RQ SA TTS Ap NP CD
ÄÄÄÄÄÄÄÄÄÄ ÄÄÄÄÄÄÄÄÄÄ ÄÄÄÄÄÄÄÄÄÄ ÄÄÄÄÄÄÄÄÄÄ ÄÄÄÄÄÄÄÄÄÄ ÄÄÄÄÄÄÄÄÄÄ
Chsn Min 1.10 1.20 1.10 1.10 2.00 1.30
Max 4.70 4.80 4.70 4.80 4.60 4.80
Diff Min -3.60 -1.80 -2.70 -3.60 -3.60 -3.60
Max 3.60 3.60 3.60 1.80 1.80 2.70
RANGES OF INDEPENDENT VARIABLES
(continued)
Variable PP
ÄÄÄÄÄÄÄÄÄÄ
Chsn Min 1.10
Max 4.90
Diff Min -3.60
Max 2.70
Data preparation completed
Linear ("Quick") algorithm being used
Convergence achieved after 5 iterations
Analysis is based on 42 observations
Likelihood with Zero Coefficients = -29.1122
Likelihood with Constants only = -23.7273
Initial Likelihood = -29.1122
Final value of Likelihood = -15.2133
"Rho-Squared" w.r.t. Zero = .4774
"Rho-Squared" w.r.t. Constants = .3588
ESTIMATES OBTAINED AT ITERATION 5
Likelihood = -15.2133
RQ SA TTS Ap NP CD
Estimate -.4830 -1.693 .9960 .6018 .3785 -.2490
Std. Error .436 .621 .585 .359 .383 .404
"T" Ratio -1.1 -2.7 1.7 1.7 1.0 -.6
PP
Estimate -.9766
Std. Error .383
"T" Ratio -2.6
Correlation of Estimates (multiplied by 1000)
1 2 3 4 5 6
SA 2 179
TTS 3 -457 -708
Ap 4 192 -66 -47
NP 5 -101 -249 71 -253
CD 6 455 160 185 -82 -65
PP 7 244 630 -456 -372 -380 91
Convergence (option 3) value is .5478E-03

Table 6.4: Control Lines

*PU	PE	RQU	safetyU	TTSU	APU	NPU	cdU	PPU	RQE	safetyE	TTSE	APE	NPE	cdE	PPE
0.9	0.1	2	3	1	3	2	4	3	4	4	3	2	2	1	4
0.9	0.1	2	2	1	2	2	4	3	5	5	4	4	3	2	4
0.9	0.1	2	1	2	4	2	4	4	4	5	5	1	2	2	1
0.1	0.9	2	3	2	3	3	4	4	5	5	4	4	3	1	1
0.9	0.1	1	2	1	3	3	5	5	3	5	3	1	5	2	4
0.9	0.1	1	2	2	3	3	5	2	4	4	5	4	5	2	4
0.9	0.1	1	2	1	3	4	4	3	2	4	4	5	5	3	5
0.1	0.9	2	2	1	2	3	5	3	3	3	3	1	4	3	2
0.9	0.1	1	3	1	3	2	5	3	5	3	2	1	2	3	3
0.9	0.1	2	2	2	3	3	3	3	5	5	5	1	1	1	1
0.1	0.9	1	3	1	3	2	4	5	5	4	3	5	3	2	3
0.9	0.1	1	1	1	3	3	5	5	4	5	5	1	1	1	1
0.9	0.1	2	3	2	5	5	5	5	5	4	2	1	1	1	1
0.9	0.1	2	4	2	4	3	2	4	5	5	4	1	2	2	2
0.1	0.9	2	3	2	3	2	4	1	4	3	5	3	3	1	3
0.9	0.1	1	2	2	3	3	4	1	2	3	2	3	4	1	2
0.9	0.1	2	2	2	4	4	4	4	5	5	5	2	2	2	2
0.9	0.1	2	2	2	4	4	4	4	5	5	5	1	1	1	1
0.9	0.1	1	2	3	5	2	4	4	3	5	5	3	4	2	1
0.9	0.1	1	1	3	3	3	3	4	5	3	4	1	4	2	2
0.9	0.1	2	2	2	3	3	3	2	4	5	4	4	5	4	4
0.9	0.1	2	3	1	3	2	4	3	4	4	3	2	2	1	4
0.9	0.1	2	2	1	2	2	4	3	5	5	4	4	3	2	4
0.9	0.1	2	1	2	4	2	4	4	4	5	5	1	2	2	1
0.1	0.9	2	3	2	3	3	4	4	5	5	4	4	3	1	1
0.9	0.1	1	2	1	3	3	5	5	3	5	3	1	5	2	4
0.9	0.1	1	2	2	3	3	5	2	4	4	5	4	5	2	4
0.9	0.1	1	2	1	3	4	4	3	2	4	4	5	5	3	5
0.1	0.9	2	2	1	2	3	5	3	3	3	3	1	4	3	2
0.9	0.1	1	3	1	3	2	5	3	5	3	2	1	2	3	3
0.9	0.1	2	2	2	3	3	3	3	5	5	5	1	1	1	1
0.1	0.9	1	3	1	3	2	4	5	5	4	3	5	3	2	3
0.9	0.1	1	1	1	3	3	5	5	4	5	5	1	1	1	1
0.9	0.1	2	3	2	5	5	5	5	5	4	2	1	1	1	1
0.9	0.1	2	4	2	4	3	2	4	5	5	4	1	2	2	2
0.1	0.9	2	3	2	3	2	4	1	4	3	5	3	3	1	3
0.9	0.1	1	2	2	3	3	4	1	2	3	2	3	4	1	2
0.9	0.1	2	2	2	4	4	4	4	5	5	5	2	2	2	2
0.9	0.1	2	2	2	4	4	4	4	5	5	5	1	1	1	1
0.9	0.1	1	2	3	5	2	4	4	3	5	5	3	4	2	1
0.9	0.1	1	1	3	3	3	3	4	5	3	4	1	4	2	2
0.9	0.1	2	2	2	3	3	3	2	4	5	4	4	5	4	4

Control Lines

PU	Probability for choosing underground metro	PE	Probability for Choosing Elevated Metro
RQU	Riding quality for Underground Metro	Safety U	Safety for Underground Metro
TTSU	TT savings for Underground Metro	APU	Air Pollution for Underground Metro
NPU	Noise Pollution for Underground Metro	CdU	Congestion and delay for Underground Metro
PPU	Parking Problem for Underground Metro	RWE	Riding quality for Elevated Metro
SafetyE	Safety for Elevated Metro	TTSE	TT Savings for Elevated Metro
APE	Air Pollution for Elevated Metro	NPE	Noise Pollution for Elevated Metro
CdE	Congestion and delay for Elevated Metro	PPE	Parking Problem for Elevated Metro

Specification of Coefficients

Generic variables

01	RQ	02	SA
03	TTS	04	Ap
05	NP	06	CD
07	PP		

-Utility Functions

-Utility for underground u1=p01*d03+p02*d04+p03*d05+p04*d06+p05*d07+p06*d08+p07*d09

-Utility for Metro

u2=p01*d10+p02*d11+p03*d12+p04*d13+p05*d14+p06*d15+p07*d16

6.5 Statistics and coefficient estimates of SP model

The software ALOGIT is used to estimate the models parameters. The statistics and coefficient estimates for the SP model are presented in Table shown below. The Rho-Squared value for this model found to be 0.48. As a starting point the model has developed using all attributes, finally after many trails significant variables are identified and model was developed by using those attributes. It was observed that on reaching the most optimal model specification, the absence of insignificant variables did not alter the value of coefficient estimates of remaining variables.

The respondents care more for their safety, parking problems, air pollution, & health, as well time savings. Congestion & delays gets the least preference but these are already very well represented in travel time savings. Over the entire model clarifies the perception of the people and their choices in terms of the variables indicative of the quality of life.

Table 6.5: Statistics and coefficient estimates of SP model (Annexure: III)

Variable	Coefficient	Standard Error	t-stat
Riding quality	-0.48	0.44	-1.1
Safety	-1.69	0.62	-2.7
Travel time savings	1.00	0.59	1.7
Air pollution	0.60	0.36	1.7
Noise pollution	0.38	0.38	1.0
Congestion and delays	-0.25	0.40	-0.6
Parking problems	-0.98	0.38	-2.6

6.6 Riding Quality Coefficients

Negative sign indicates if Roughness Quality increases , the ridership decreases.

6.7 Safety Coefficients

Negative sign indicates that if safety is worsened, people will not choose that mode, means ridership decreases. The coefficient of safety is higher than other coefficients means people in study area are more sensitive about safety.

6.8 Coefficient of travel time

Savings: Positive sign indicates that Travel time savings increases, people will choose that particular mode.

6.9 Coefficient of Air Pollution

Savings: Positive sign indicates that air pollution savings is more, the ridership will be more that means people from study area are more sensitive about Air pollution & they will choose the mode having less air pollution.

6.10 Coefficient of Noise pollution

Savings: Positive sign indicates that Noise pollution savings is more, the ridership will be more that means people from study area are more sensitive about noise pollution & they will choose the mode having less noise pollution.

6.11 Coefficients of Congestion & Delays

Negative sign indicates if congestion and delays is more, the ridership will be less.

6.12 Coefficient of Parking Problems

Negative Sign indicates if parking cost is more then people will choose public Transport Mode or Private Vehicles.

CHAPTER 7

MODEL BUILDING AND ANALYSIS

The model so developed should be able to provide inputs to the economic evaluation of the identified projects. It should allow the economic feasibility to be expressed in terms of expected **Net Present Value (NPV) and Economic Internal Rate of Return (EIRR).** It should be able to:

- Identify major items of likely economic benefits and dis-benefits.
- Establish appropriate value of travel time by trip purpose and vehicle operating costs.
- Conduct a standard **cost-benefit analysis for a program life of 35 years**
- Conduct sensitivity analysis for investment program
- Assess project benefit distribution across the region

7.1 TRANSPORT STRATEGY:

This activity entails many tasks which are directly or indirectly related to the transportation as a sector. In fact, there will be many tasks here that will be non transportation oriented but have direct bearing on the transportation as a sector.

Following is the list of tasks under this activity :

- Review of the Existing Transport Strategy
- Review of Institutional Arrangement of Transport
- Review of Transport Financing
- Define Alternative Long-Term Transport Strategies
- Prepare a Draft Transport Strategy Document

7.2 STUDY REPORT CONVERGES :

The strategy document will cover the following aspects:

- Current Situation
- Traffic Growth
- Current Constraints
- Long Term Trends and Prospects
- Transport Investment Options
- Demand Management
- Environmental Measures
- Land Use Strategy
- Institutional Arrangement
- Conclusions and Recommendations on Transport Strategy

Each of the components of identified investment program will need to have costing, and techno-economic evaluation. Further, an overall prioritization will also need to be done.

7.3 PUBLIC CONSULTATION :

It is envisaged that the citizens of MMR would be informed and **their views/ suggestions of the Public** about the proposed transport strategy.

7.4 Pilot Study Preliminary results

- Excess cost of Underground Metro is up to double the cost of Elevated Metro

- **Economic cost savings**, in the form of Vehicle Operating Costs and Travel Time savings, from underground Metro compared to Elevated metro, **in construction period itself** , is to the tune of ***9500 crore.***

- On developing the Utility equation from the survey**, we found that 100%** of the people want the **Metro to be underground**.

- We have taken only Vehicle Operating Costs and Travel Time savings, other benefits includes Land Acquisition Cost, Rehabilitation and Resettlement cost, Environmental Cost Social Cost, etc.

CHAPTER 8

IDENTIFICATION OF ECONOMIC BENEFITS AND COST OF UNDERGROUND METRO

Description of economic benefits and costs of the Underground Metro requires the identification of the changes brought out by it in the transport sector of the economy. Most importantly, the diversion of current passenger traffic from road to Metro is not much. As a result, there will be a less reduction in the number of buses, passenger cars and other vehicles carrying passengers on roads with the introduction of the Metro. In Elevated Metro there will be reduction in capacity of roads from 3 lanes to 2 lanes, Capacity will remain same in case of Underground Metro. As per result congestion and pollution on road side will be less in Underground metro.

Investment in the Underground Metro could result in the reduction on road user cost. There will be reductions in motor vehicles' operation and maintenance charges to both the government and the private sector.

The citizen's of Mumbai suburbs will gain substantially with the introduction of the Underground Metro service. It saves travel time due to a reduction of congestion on the roads and lower travel time of the Metro. There will be health and other environmental benefits to the public due to reduced pollution from the transport sector of Metro.

8.1 DESCRIPTION OF THE BENEFIT AND COST FOR UNDERGROUND METRO

8.1.1 Investment

Investment of Metro
Investment Cost of Road Infrastructure

8.1.2 Operation and Maintenance (O&M) Charges

- O & M charges of Metro
- O & M charges reduced due to Underground Metro due to decongestion
- Private buses
- Public buses
- Personal vehicles (cars and two-wheelers)

For all the above three categories underground metro pays an pivotal role in decreasing the operation and maintenance charges as the roads are decongested thus leading to decrease in vehicle operation cost.

8.1.3 Revenue

- Revenue of Metro
- Tax Revenue to Government
- Revenue loss due to Metro
- Private buses, Public buses

8.1.4 Benefits

- R&R
- Acquisition of Land
- Pulling Down the Structure
- Shifting of Utilities Services
- Reduction in Pollution and Health Expenditures
- Due to reduction in congestion on roads
- Savings in travel time
- Due to reduction in travel time for Metro passengers
- Reduction in accidents
- Savings in fuel cost

8.2 MEASUREMENT OF ECONOMIC COSTS AND BENEFITS OF UNDERGROUND METRO VERSUS ELEVATED METRO (ANNEXURE II)

The economic costs of the Metro are calculated after excluding the tax component from the financial costs. The economic benefits due to the Underground Metro could be identified as the following:

- Savings in Foreign Exchange due to reduced Fuel Consumption

- Reduction in Pollution

- The savings at current prices on account of :
  1. Due to less number of Vehicles on road with MRTS Implemented
  2. Due to decongestion Effect
  3. Savings in Time for all passengers using Metro and Roads
  4. Savings in Accidents
  5. Savings in Vehicle Operating Cost (VOC) due to decongestion for residual traffic
  6. Savings in the cost of Road Infrastructure
  7. Saving in Land Acquisition Cost
  8. Savings in Pulling Down the Structures
  9. Savings in Shifting of Utilities Services

With following Assumptions the calculated EIRR for Underground and Elevated Metro is given in Table 8.1

1. After operations of Metro shifting of buses, Car, Two-wheelers and Auto are 30%, 40%, 50% and 40% respectively.

2. Assumptions of vehicle speed for calculation of Vehicle Operating Cost and Value of time are given in Annexure II; Table 1.

Table 8.2.1: Economic Internal Interest Rate

EIIR for Underground Metro	22.70%
EIIR for Elevated Metro	16.07%
EIIR for Partial Elevated / Underground	20.26%

8.3 COST ESTIMATION STUDY OF VARIOUS SCENARIOS OF METRO

Table 8.3.1 Capital Cost Estimate of Partially Elevated / Underground Metro

CAPITAL COST ESTIMATE
CHARKOP-BANDRA-MANKHURD METRO RAIL
for 31.871 Km. Project
Tunnel Under ground : -11.50 km. UG stations=11 Nos
Via duct Elevated : + 20.50 km. Elevated stations= 16 Nos

Sr. No.	Item	Qty.	Rate	Unit	Amount Without Taxes
1.0	Land				665.00
	Sub Total (1)				665.00
2.0	alignment and formation				
2.1	underground section by T.B.M including NATM Station length	11.5	150.00	Km	1,725.00
2.2	Underground section by cut and cover including station length	0.5	80.00	Km	40.00
2.3	elevated section including viaduct length in station	19.871	30.00	Km	596.13
2.4	Entry to Depot (at grade)	0.75	30.00	Km	22.50
	Sub Total (2)				2,383.63
3.0	Station Building				
3.1	underground station (300m length) incl. EM works, lifts, escalators, VAC etc.				
A	Underground Station- Civil works	11	140.00	Each	1,540.00
B	Underground Station - EM works etc.	11	60.00	Each	660.00
3.2	Elevated station				
A	Type (A) way side- Civil works	9	10.20	Each	91.80
B	Type (A) way side- EM works etc	9	1.80	Each	16.20
C	Type (B) Way side with signalling-civil works.	4	11.05	Each	44.20
D	Type (B) Way side with signalling- EM works etc.	4	1.95	Each	7.80
E	Terminal station -civil works	3	17.00	Each	51.00
F	Terminal station- EM works	3	3.00	Each	9.00
G	Signature station (Terminal with extra facilities)- civil works		21.25	Each	
H	Signature station (Terminal with extra facilities)- EM works		3.75	Each	

3.3	Metro Bhavan & OCC buliding				
A	Metro Bhavan & OCC buliding- civil works	LS			67.00
B	Metro Bhavan & OCC buliding- EM works	LS			33.00
	Sub Total (3)				2,520.00
4.0	Depot / Stabling				
A	Civil works	LS			190.00
B	EM works etc	LS			60.00
	Sub Total (4)				250.00
5.0	P-Way				
5.1	Ballastless track for elevated & underground Section	31.871	5.50	Km	175.29
5.2	Ballasred track for sidings etc. in Depot	16	1.60	Km	25.60
	Sub Total (5)				200.89
6.0	Traction and power supply including OHE, ASS etc. Excluding Lifts and Escalators				
6.1	UG section	12	10.50	Km	126.00
6.2	Elevated section	19.871	5.00	Km	99.36
6.3	Lift for elevated section	48	0.20	Each	9.60
6.4	Escalators for elevated sections	65	0.80	Each	52.00
	Sub Total (6)				286.96
7.0	Signalling and Telecommunication				
7.1	Signalling and Telecommunication	31.871	12.00	Km	382.45
7.2	Automatic fare collection				
	a) Undergroun section	11	3.25	Each	35.75
	b) Elevated section	16	2.50	Each	40.00
	Sub Total (7)				458.20
8.0	R & R including Hutments etc.				70.00
	Sub Total (8)				70.00
9.0	Misc, Utilities, Roadworks, other civil works such as median station, signages, Environmental protection				
A	Civil works + EM works	20.371	4.00	Km	81.48
B	Additional cost towards utilities				64.00
C	Cost towards dismeantling & reconstruction of FOB at Kurla Sub-Urban railway station				1.50
	Sub Total (9)				146.98

10.0	Rolling stock	156	6.60	Each	1,029.60
	Sub Total (10)				1,029.60
11.0	Capital expenditure on security				
A	Civil works				0
B	EM works				0
	Sub Total (11)				0
12.0	Total of all items except Land				7,346.26
13.0	General Charges including Design charges @ 5% on all items except land				367.31
14.0	Total of all items including G. Charges				7,713.57
15.0	Contigencies @ 3%				231.41
16.0	Gross Total				7,944.98
	Cost without land				7,944.98
	Cost with land including 3% contingency				8,609.98
17	Insurance 0.6% of Capital cost	7346.26			44.08
		Total cost including insurance			8,654.06
		Say			8,655.00
		Taxes			1,053.00
		Total			9,708.00

- The table-8.3.1 shows the cost estimate of Partially Elevated / Underground Metro based on the March 2007 Price Level.

- The partially Elevated / Underground Metro scenario consists of total 27 stations comprises length of 31.871 Kms. of which Underground Metro consists of 11 stations and 11.5 Kms length, and Elevated Metro consists of 16 stations and 20.371 Kms length. (as per study – Jogeshwari / Bandra Stretch)

- Total cost comes out to be Rs. 9708.00 crores (including Rs. 1,053 crores towards taxes).

- Completion cost of Metro based on 5 % escalation prices for various sources are shown in the following Table

Table 8.3.2 Completion Cost of Fully Elevated Metro at 5 % Escalation Price

Year wise Investment for elevated metro						
Without Taxes and Duties					1111	With Taxes and Duties Completion Cost
Year	Land Cost	Construction cost at March 2007 Prices	Present Costruction cost With 5% Escalation	Completion cost	Present Taxes	
2010	333	427	880	880	111	991
2011	332	1,280	1,866	1,959	350	2,309
2012		1,280	1,482	1,634	367	2,001
2013		854	989	1,145	257	1,402
2014		427	494	600	135	735
	665	4,268	5,711	6,218	1,220	7,438

Table 8.3.3 Completion Cost of Partial Elevated / Underground Metro @ 5 % Escalation Price

Year wise Investment for partly underground metro and partly elevated						
Without Taxes and Duties					1053	With Taxes and Duties Completion Cost
Year	Land Cost	Construction cost at March 2007 Prices	Present Costruction cost With 5% Escalation	Completion cost	Present Taxes	
2010	333	799	1,310	1,310	105	1,415
2011	332	2,397	3,159	3,317	332	3,649
2012		2,397	2,775	3,059	348	3,407
2013		1,598	1,850	2,142	244	2,386
2014		799	925	1,124	128	1,252
	665	7,990	10,019	10,952	1,157	12,109

Table 8.3.4 Completion Cost of Fully Underground Metro at 5 % Escalation Price

Year wise Investment for underground metro						
Without Taxes and Duties					1490	With Taxes and Duties Completion Cost
Year	Land Cost	Construction cost at March 2007 Prices	Present Costruction cost With 5% Escalation	Completion cost	Present Taxes	
2010	200	1,385	1,835	1,835	149	1,984
2011	125	4,156	4,956	5,204	469	5,673
2012		4,156	4,811	5,304	493	5,797
2013		2,771	3,208	3,714	345	4,059
2014		1,385	1,603	1,948	181	2,129
	325	13,853	16,413	18,005	1,637	19,642

8.3.5 EIRR = 20.26%

Partially Under ground Base Scenario											
Sr. No.	Year	Capital Cost	O&M Expenses	Total Out flow	Voc Saving for all vehicles	Passenger time saving	Less pollution	Acci-dent cost	Total Saving	Net cash Flow	Cash Flow
0	2010	1203		1203	443.61	553.98	50.14		1047.73	-155.27	-155.27
1	2011	3102		3102	451.59	563.95	51.04		1066.58	-2035.42	-1692.59
2	2012	2896		2896	459.72	574.1	51.96		1085.78	-1810.22	-1251.77
3	2013	2028		2028	467.99	584.43	52.9		1105.32	-922.68	-530.57
4	2014	1064		1064	476.41	594.95	53.85		1125.21	61.21	29.27
5	2015		189.8	189.8	812.1	612.8	195.78	2.65	1623.33	1433.53	570.02
6	2016		201.19	201.19	826.72	623.83	199.3	2.7	1652.55	1451.36	479.91
7	2017		213.26	213.26	841.6	635.06	202.89	2.75	1682.3	1469.04	403.93
8	2018		226.06	226.06	856.75	646.49	206.54	2.8	1712.58	1486.52	339.89
9	2019		239.62	239.62	872.17	658.13	210.26	2.85	1743.41	1503.79	285.93
10	2020		254	254	887.87	669.98	214.04	2.9	1774.79	1520.79	240.46
11	2021		269.24	269.24	903.85	682.04	217.89	2.95	1806.73	1537.49	202.15
12	2022		285.39	285.39	936.39	706.59	225.73	3.06	1871.77	1586.38	173.45
13	2023		302.51	302.51	970.1	732.03	233.86	3.17	1939.16	1636.65	148.8
14	2024		320.66	320.66	1005.02	758.38	242.28	3.28	2008.96	1688.3	127.64
15	2025		339.9	339.9	1041.2	785.68	251	3.4	2081.28	1741.38	109.48
16	2026	1509	360.29	1869.29	1078.68	813.96	260.04	3.52	2156.2	286.91	15
17	2027		381.91	381.91	1117.51	843.26	269.4	3.65	2233.82	1851.91	80.51
18	2028		404.82	404.82	1157.74	873.62	279.1	3.78	2314.24	1909.42	69.03
19	2029		429.11	429.11	1199.42	905.07	289.15	3.92	2397.56	1968.45	59.18
20	2030		454.86	454.86	1242.6	937.65	299.56	4.06	2483.87	2029.01	50.72
21	2031		482.15	482.15	1287.33	971.41	310.34	4.21	2573.29	2091.14	43.47
22	2032		511.08	511.08	1333.67	1006.38	321.51	4.36	2665.92	2154.84	37.25
23	2033		541.74	541.74	1381.68	1042.61	333.08	4.52	2761.89	2220.15	31.92
24	2034	762	574.24	1336.24	1431.42	1080.14	345.07	4.68	2861.31	1525.07	18.23
25	2035	1934	608.69	2542.69	1482.95	1119.03	357.49	4.85	2964.32	421.63	4.19
26	2036		645.21	645.21	1536.34	1159.32	370.36	5.02	3071.04	2425.83	20.05
27	2037		683.92	683.92	1591.65	1201.06	383.69	5.2	3181.6	2497.68	17.17
28	2038		724.96	724.96	1648.95	1244.3	397.5	5.39	3296.14	2571.18	14.7
29	2039		768.46	768.46	1708.31	1289.09	411.81	5.58	3414.79	2646.33	12.58
30	2040		814.57	814.57	1769.81	1335.5	426.64	5.78	3537.73	2723.16	10.76
31	2041		863.44	863.44	1833.52	1383.58	442	5.99	3665.09	2801.65	9.21
32	2042		915.25	915.25	1899.53	1433.39	457.91	6.21	3797.04	2881.79	7.88
33	2043		970.17	970.17	1967.91	1484.99	474.39	6.43	3933.72	2963.55	6.74
34	2044		1028.38	1028.38	2038.75	1538.45	491.47	6.66	4075.33	3046.95	5.76
35	2045		1090.08	1090.08	2112.15	1593.83	509.16	6.9	4222.04	3131.96	4.92
											-5.7E-13

On the same lines EIRR for Elevated and Underground Metros have been calculated.

8.3.6 FIRR = 7.07%

Partly Underground and Partly Elevated as per study Base Scenario									
Sr. No	Year	Capital Cost	O&M Expenses	Total Out flow	Fare Box Revenue	PD and ADVT	Total Revenue	Net cash Flow	Cash Flow
0	2010	1415		1415				-1415	-1415
1	2011	3649		3649				-3649	-3408.17
2	2012	3407		3407				-3407	-2972.12
3	2013	2386		2386				-2386	-1944.07
4	2014	1252		1252				-1252	-952.78
5	2015		237.25	237.25	558.1	55.81	613.91	376.66	267.72
6	2016		251.49	251.49	636.23	63.62	699.85	448.36	297.65
7	2017		266.58	266.58	725.3	72.53	797.83	531.25	329.41
8	2018		282.57	282.57	826.84	82.68	909.52	626.95	363.09
9	2019		299.52	299.52	942.6	94.26	1036.86	737.34	398.84
10	2020		317.49	317.49	1074.56	107.46	1182.02	864.53	436.77
11	2021		336.54	336.54	1225	122.5	1347.5	1010.96	477.04
12	2022		356.73	356.73	1286.25	128.63	1414.88	1058.15	466.35
13	2023		378.13	378.13	1350.56	135.06	1485.62	1107.49	455.88
14	2024		400.82	400.82	1418.09	141.81	1559.9	1159.08	445.63
15	2025		424.87	424.87	1488.99	148.9	1637.89	1213.02	435.59
16	2026	1775	450.36	2225.36	1563.44	156.35	1719.79	-505.57	-169.57
17	2027		477.38	477.38	1641.61	164.17	1805.78	1328.4	416.13
18	2028		506.02	506.02	1723.69	172.38	1896.07	1390.05	406.71
19	2029		536.38	536.38	1809.87	181	1990.87	1454.49	397.48
20	2030		568.56	568.56	1900.36	190.05	2090.41	1521.85	388.43
21	2031		602.67	602.67	1995.38	199.55	2194.93	1592.26	379.58
22	2032		638.83	638.83	2294.69	229.48	2524.17	1885.34	419.79
23	2033		677.16	677.16	2409.42	240.95	2650.37	1973.21	410.36
24	2034	896	717.79	1613.79	2529.89	253	2782.89	1169.1	227.08
25	2035	2275	760.86	3035.86	2656.38	265.65	2922.03	-113.83	-20.65
26	2036		806.51	806.51	2789.2	278.93	3068.13	2261.62	383.22
27	2037		854.9	854.9	2928.66	292.88	3221.54	2366.64	374.55
28	2038		906.19	906.19	3075.09	307.52	3382.61	2476.42	366.06
29	2039		960.56	960.56	3228.84	322.9	3551.74	2591.18	357.74
30	2040		1018.19	1018.19	3390.28	339.05	3729.33	2711.14	349.6
31	2041		1079.28	1079.28	3559.79	356	3915.79	2836.51	341.63
32	2042		1144.04	1144.04	3737.78	373.8	4111.58	2967.54	333.82
33	2043		1212.68	1212.68	3924.67	392.49	4317.16	3104.48	326.17
34	2044		1285.44	1285.44	4120.9	412.11	4533.01	3247.57	318.69
35	2045		1362.57	1362.57	4326.95	432.72	4759.67	3397.1	311.36
									0.01

On the sane line FIRR for Elevated and Underground Metro have been calculated.

Sensitivity Analysis :

Sensitivity Analysis is the study of how the variation (uncertainty) in the output of a mathematical model can be apportioned, qualitatively or quantitatively, to different sources of variation in the input of a mode. Sensitivity analysis tries to identify what source of uncertainty weights more on the study's conclusions.

Table 8.3.7 Sensitivity Analysis for FIRR

Sr.No.	Particulars	Elevated	Underground	Partial Elevated/ Underground
1.	Base Scenario	10.41%	4.52%	7.25%
2.	10% increase in Capital Cost	9.75%	4.02%	6.68%
3.	20% increase in Capital Cost	9.16%	3.57%	6.17%
4.	10% increase in O & M	10.17%	4.34%	7.05%
5.	10% decrease in O & M	10.64%	4.69%	7.45%
6.	10% decrease in Capital Cost	11.17%	5.09%	7.90%
7.	20% decrease in Capital Cost	12.06%	5.74%	8.66%
8.	10% increase in Revenue	11.38%	5.24%	8.08%
9.	10% decrease in Revenue	9.35%	3.72%	6.34%

Table 8.3.8 Sensitivity Analysis for EIRR

Sr.No.	Particulars	Elevated	Underground	Partial Elevated/ Underground
1.	Base Scenario	16.07%	22.70%	20.26%
2.	10% increase in Capital Cost	14.94%	19.49%	17.74%
3.	20% increase in Capital Cost	13.95%	16.94%	15.80%
4.	10% increase in O & M	15.84%	22.86%	20.01%
5.	10% decrease in O & M	16.30%	23.22%	20.49%
6.	10% decrease in Capital Cost	17.38%	28.45%	23.69%
7.	20% decrease in Capital Cost	18.91%	38.41%	28.76%

From the above 9.2 & table 9.3 of sensitivity analysis it can be seen that how the cost changes with respect to change in benefits and how it affects the EIRR of UG and Elevated Metro.

8.4 BENEFITS GAINED BY LAND ACQUISITION

Rate of Land Acquisition	Rs. 75,000/- per sq. yard
OR	Rs. 90,000/- per sq. metre

	Length (m)	Width (m)	Area (Sqm.)	Cost of Land Acquisition (Rs. in Crores)
Station Area	6,750	35	2,36,250	2,126.25
Route Excluding Station Area	26,000	8	2,08,000	1,872.00
Total			**4,44,250**	**3,998.25**

Assume present status of station area having tenants

Rate of tenants rehabilitation	3,900 Sqm.
Cost of Rehabilitation	Rs. 4.875 Crores/Km.

Table 8.4.1: Summary Table

Sr. No.	Particulars	Elevated Metro	Underground Metro	Partial Elevated / Underground
1.	Construction Cost	7438	19642	12,109
2.	EIRR	16.07%	22.70%	20.26%
3.	FIRR	10.41%	4.52%	7.07%

The above table shows that Economic Benefits of Underground Metro is much higher than the elevated metro, but at the same time (FIRR) of Underground Metro is less than the elevated Metro. Considering both benefits for this particular situation, partially Elevated / Underground Metro is the best option.

8.5 AVERAGE SPEED

Average Speed for different Modes						
	Construction Phase			Operation Phase		
Mode	Without Metro	With Elevated Metreo	With Underground Metro	Without Metro	With Elevated Metro	With Underground Metro
Buses	10	8	10	8	20	25
Cars	15	10	15	10	30	35
TW	15	10	15	10	30	35
Auto	15	10	15	10	30	35

	in 2003				in 2009			
Speed	Buses	Cars	Two Wheelers	Auto	Buses	Cars	Two Wheelers	Auto
8	29.27				41.52			
10	26.11	6.63	1.98	5.39	37.04	9.40	2.81	7.65
15	21.3	4.94	1.68	3.84	30.21	7.01	2.38	5.45
20	18.25	4.07	1.53	3.07	25.89	5.77	2.17	4.35
25	16	3.55	1.44	2.62	22.70	5.04	2.04	3.72
30	14.61	3.15	1.41	2.6	20.72	4.47	2.00	3.69
35	13.32	2.92	1.36	2.59	18.89	4.14	1.93	3.67
40	12.18	2.74	1.33	2.36	17.28	3.89	1.89	3.35
45	11.75	2.74	1.3	2.18	16.67	3.89	1.84	3.09
50	11.41	2.74	1.28	2.04	16.19	3.89	1.82	2.89

Number of Vehicle						
YEAR / MODE	2010	2011	2012	2013	2014	2015
BUS	7,796	7,936	8,079	8,224	8,372	8,523
CAR	5,26,239	5,35,711	5,45,354	5,55,170	5,65,163	5,753,36
2 W	7,02,282	7,14,923	7,27,792	7,40,892	7,54,228	7,67,804
3 W	1,22,061	1,24,258	1,26,495	1,28,772	1,31,090	13,3450

Mode	DAILY VEHICLE UTILIZATION IN KM	VEHICLE INFLUENCE	OCCUPANCY / VEHICLE
BUS	211	30%	34
CAR	30	30%	2.0
2 W	30	30%	1.2
3 W	100	30%	1.8

8.6 VOC

VOC with Elevated Metro Operation Phase					
YEAR / MODE	2015	2016	2017	2018	2018
BUS	509.79	518.96	528.30	537.81	547.49
CAR	844.51	859.71	875.18	890.93	906.97
2 W	504.48	513.56	522.80	532.21	541.79
3 W	538.94	548.64	558.52	568.57	578.81
Total	2,397.71	2,440.87	2,484.80	2,529.53	2,575.06
	758.63	772.29	786.19	800.34	814.74

VOC with Underground Metro Operation Phase					
YEAR / MODE	2015	2016	2017	2018	2018
BUS	446.93	454.98	463.17	471.51	479.99
CAR	782.84	796.93	811.28	825.88	840.75
2 W	486.59	495.34	504.26	513.34	522.58
3 W	536.87	546.53	556.37	566.38	576.58
Total	2,253.23	2,293.79	2,335.08	2,377.11	2,419.90
	903.10	919.36	935.91	952.76	969.90
	144.47	147.08	149.72	152.42	155.16

8.7 VOT

VOT for Elevated @ Operation Phase					
YEAR/ MODE	2015	2016	2017	2018	2019
BUS	551.40	567.95	584.99	602.53	620.61
CAR	529.31	545.19	561.55	578.40	595.75
2 W	261.48	269.32	277.40	285.72	294.29
3 W	217.91	224.44	231.17	238.11	245.25
Total	1,560.10	1,606.90	1,655.10	1,704.76	1,755.90
	565.74	582.72	600.21	618.22	636.76

VOT for Underground @ Operation Phase					
YEAR/ MODE	2015	2016	2017	2018	2019
BUS	441.12	454.36	467.99	482.03	496.49
CAR	453.70	467.31	481.33	495.77	510.64
2 W	224.12	230.85	237.78	244.91	252.26
3 W	186.78	192.38	198.15	204.09	210.21
Total	1,305.72	1,344.90	1,385.25	1,426.80	1,469.60
	692.93	713.72	735.14	757.2	779.91
	127.19	131.00	134.93	138.98	143.15

8.8 Accident Costs

Year / Accidents	2001	2002	2003
Fatal	523	462	377
Serious	1,794	1,409	1,391
Minor Slight	4,799	4,886	4,471

8.9 In the highly congested corridors, the social benefits outweigh for the underground metro compared to the elevated metro. This is obvious on the account of very high direct and indirect cost savings of underground metro compared to elevated metro. There is very large scope for getting space without any constraints and clearances as given here in the Table 8.9.1

Table 8. 9.1: Savings due to Underground Metro (Annexure II)

Sr No.	Particular	Elevated Metro (Cost in Crores)	Under ground Metro (Cost in Crores)	Partially Under Ground (Cost in Crores)
1	Estimated Cost	**7438**	**19642**	**12109**
2	Over all Saving			
	A) Saving During Construction Phase On account of VOC, VOT, Pollution etc.		10135	5431
	B) Saving During Operation Phase On account of VOC, VOT, Pollution etc.		7525	5052
3	**Total Savings**		**17,660.00**	**10,483.00**

CHAPTER 9

SUMMARY
WHY UNDERGROUND METRORAIL FOR SUBURBS?

Although this Evaluation Report indicates necessity for Underground Metro between Jogeshwari and Bandra stretch for the sake of detailed study. However, the Government must invest in implementing Underground Metro throughout the county to other cities like Mumbai.

9.1 Existing Urban Fabric not disturbed.

9.2 It will not Choke the only three Arterial Roads – S.V. Road, Linking Road and Link Road in the Western Suburbs and Sion-Panvel Road in the Eastern Suburbs, many suburbs on these roads are having less width (20 mtrs.) than the proposed Metro Station width (25 mtrs.).

9.3 Marginally Civil cost increase which is LESS than :
- 9.3.1 Vast Commercial spaces available at Underground Stations
- 9.3.2 Land Acquisition Costs.
- 9.3.3 Opportunity Costs
- 9.3.4 Fuel Costs
- 9.3.5 Environmental Costs
- 9.3.6 Mental Trauma Costs

9.4 No necessity for Violation of Basic Civil Laws :
- 9.4.1 Minimum Open Space for Fire Brigade
- 9.4.2 Civil Aviation
- 9.4.3 CRZ Regulations
- 9.4.4 Environmental and Noise Impact

9.5 It will have integrated planning with existing mode of Transportation, such as Bus routes, Railways, Taxis/Autos, Pedestrian zones, etc.

9.6 Underground Metro stations will connect underutilized vital public spaces.

9.7 Citizens are not affected with non-coordination of various Local Authorities.

9.8 No need of Land acquisition, rehabilitation and Compensation.

9.9 All future options of Vibrant City planning Available for several generations.

CONCLUSION

The lack of comprehensive integrated transportation plan for the city and the suburbs is leading to conflicts between individual plans. The MMRDA being a planning agency for the Government of Maharashtra has not yet taken any planning initiative to comprehensively address these complex transportation issues, especially the MMRDA brief to their consultants. A viability study for underground metro was never considered. Decision to pursue with Elevated metro is thus taken arbitrarily without any comparative evaluation.

The Elevated metro plan for Mumbai's suburbs have no future expansion potential. This factor is detrimental to the planning and implementation of any public services particularly, for transportation. Underground metro will at any time have possibility of expansion with additional routes and directions thus having possibility of dealing with future needs and demands.

The people living in the suburbs are being clearly discriminated. MMRDA has proposed underground metro for the city i.e., from Bandra to Colaba. It is a known fact that the densities in the suburbs are equal and even higher than most parts of the city. The volume of construction is higher due to TDR use, SRD projects, growing slums and so on…

The central idea for an Underground Metro is to locate stations in and around open spaces alongwith a host of amenities and parking. Thus we have an opportunity to create new urban landmarks by way of designed public squares, gardens and landscapes.

Vehicular and Pedestrian accesses could be well dispersed around the open spaces. These open spaces would then act as effective interface between the metro and existing realities.
A political will in transforming Mumbai into a 'better city to live-in' then an Underground Metro system would in fact be the only option to implement. In the highly congested corridors, the social benefits outweigh for the Underground Metro. compared to the Elevated Metro. This is obvious on the account of very high direct and indirect cost savings of Underground Metro.

As concluding comments it is justified - technically, socially, economically, environmentally and from all angles, to plan for an Underground Metro to get relieved from the innumerable perennial sufferings which are beyond any cost the citizen can foresee due to Elevated Metro. Government should take care for the public and to solve the future problems for mass transport. Therefore it is suggested to go for Underground Metro for the whole length. Economic viability and bankablility of Underground Metro is far more superior than Elevated Metro.

The underground metro will contribute positively to the quality of life in the city for several generations.

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