Chapter 6

Estimation of Transportation Costs and Benefits
6.1 INTRODUCTION

The entire life cycle of any transportation facility (including design, construction, operation, maintenance, and salvage) is associated with various types of costs and benefits incurred to agency, facility user and facility non-users. Part 1 of this chapter examines how streams of benefits and costs are used for economic analyses of alternative investment options. The present chapter focuses on how to calculate such costs and benefits that are needed for the economic analysis. As shown in Figure 6-2, transportation costs consist primarily of agency costs, user costs and non-user costs. Agency costs are comprised of capital costs, operating costs, maintenance costs. User costs, which are costs incurred by the user of the transportation facility largely consist of vehicle operating costs, travel time costs, delay costs, and safety costs.

6.2 AGENCY COSTS

Agency costs refer to the costs that are borne by the owner or operator of the transportation facility. Agency costs are typically placed into five major categories: advance planning, preliminary engineering, final design, right-of-way acquisition and preparation, construction, maintenance, and operations. In some cases, disposal of physical components of the transportation facility at the end of its service life involves some costs that are referred to as “salvage costs”.

![Figure 6-1: Costs at Various Stages of Transportation Project Development](image)

*Advance Planning Costs*: These include the cost of route and location studies, traffic surveys, and environmental impact assessments, and public hearings. Advance planning costs are typically estimated as a lump sum based on the price of man-hours within the transportation agency or from a selected consultant. In evaluating alternatives, costs should exclude any costs of advance planning work done prior to arriving at the alternatives.

*Preliminary Engineering Costs*: These are the costs of carrying out an engineering study of the project, mainly geodetic and geotechnical investigations. Geodetic investigations involve land and aerial surveys, while geotechnical investigations involve drilling, boring, sampling and filed and laboratory testing to determine soil profiles and other subsurface conditions. If some preliminary engineering has been carried out (especially regarding technical feasibility of competing alternatives), such costs may be excluded from project costs. Estimates of any remaining preliminary engineering work may then be determined as a historical percentage of
total engineering design cost for the respective alternative less any sunk costs, and should be included in project costs (AASHTO Red Book).

*Final Design Costs:* These are the costs associated with preparation of engineering plans and working drawings, technical specifications, and other bid documents for the selected alternative design. Estimates of final design costs may be obtained from past records as a fraction of construction costs or total costs. Final design costs typically account for 10-20% of construction costs (AASHTO Red Book).

*Right-of-Way Acquisition and Preparation Costs:* Acquisition of ROW land typically includes the purchase price, legal costs, costs of obtaining the title, and administrative costs associated with negotiation, condemnation, and settlement. The use of tax assessor valuations or “going” rates for estimating real estates costs is not recommended (AASHTO Red Book). Severance damages are typically significant, and determining the value of remnant acquisitions is often a complex task. In absence of other information, fees and charges associated with ROW acquisition may be assumed as 2% of the purchase price.

In preparing the right-of-way, costs incurred include relocation or demolishing of structures, relocating utilities. A rough estimate of the ROW acquisition costs can be made by a “windshield” survey and a count (including rough dimensions) of structures along the proposed new or expanded right of way (AASHTO Red Book). Given the volume of structures slated for demolition, the agency’s rates for demolition can be applied to obtain an estimate of the total demolition costs. Where buildings need to be relocated it is necessary to consider the costs of acquiring new land and reconstruction of the building. The basis for residential relocation payments, including costs of temporary rentals may be established by existing policy of the transportation agency or the government. The relocation of existing utility facilities has been a headache for many transportation agencies, especially where the exact existing location of the facilities were not properly documented at the time of their installation and are therefore not known at the time of construction. Such utilities include water, gas, telephone, electricity. It is important that all efforts be made to contact the utility companies concerned, an inventory of their affected facilities taken, and the costs of relocation should be provided by these companies. If this is not done, unexpected utility facilities will be encountered during construction, resulting in disruption of such services to the consumers. This results in poor public relations for the transportation agency and extensive delay to the construction progress.

*Construction:* Costs that are typically encountered during construction are associated with surveying, earthworks (including haulage), drainage, supervision and inspection work-zone management. For each item, there is a cost estimate derived from any one or more of the basic inputs of labor, material, manpower, and duly adjusted for overheads and profit. The engineers estimate for such costs, or a historical record of past successful bids may be used. In some cases, construction costs may be estimated as overall category items (such as cost per lane-mile of an asphaltic concrete pavement) rather than line items. In such cases, it may be useful to employ statistical regression may be used to develop such costs as a function of work attributes, location, etc.
**Operating Costs**: These are costs that are associated with a transportation agency’s efforts to sustain a satisfactory level of service, in terms of congestion alleviation, safety enhancement, convenience, and comfort. These costs include charges for utility use (such as electricity for street lighting and traffic signal systems) safety patrols, traffic surveillance, etc. Unlike maintenance costs, operating costs have little no direct bearing on the physical condition of the transportation infrastructure. Operating costs include roadway patrol costs (traffic control centers, equipped vans, communication equipment, manpower, etc.). Operating costs also include cost of research that is aimed at ensuring enhanced safety and congestion mitigation, costs of implementing ITS initiatives, and both fixed and variable costs associated with toll collection. Expected operating costs may be estimated from an agency’s cost records section, in the form of average values duly adjusted to reflect the time value of money. Given adequate historical data, it may be possible to develop annual operating costs models from which such costs can be estimated. Such models are typically a function of facility type and size, age of facility, level of usage, etc.

<table>
<thead>
<tr>
<th>Non-user Costs</th>
<th>User Costs</th>
<th>Agency Costs</th>
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<tbody>
<tr>
<td>Air Pollution Costs</td>
<td>Travel Time Costs</td>
<td>Operating Costs</td>
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<tr>
<td>Safety Costs</td>
<td>Delay Costs</td>
<td>Maintenance Costs</td>
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<tr>
<td>Noise Pollution Costs</td>
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<th>Transportation Costs</th>
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**Figure 6-2**: Various Costs Associated with the Life Cycle of a Typical Transportation Facility.
**Maintenance Costs:** These refer to the costs incurred by an agency in ensuring the physical transportation facility is kept in an acceptable condition. For a highway agency, for instance, maintenance costs include pavement maintenance, bridge maintenance, vegetation control, and snow/ice control. Maintenance costs may be classified according to the source of work (i.e., in-house vs. contact), cycle of work (periodic vs. routine), purpose of work (preventive vs. corrective). In-house work refers to work carried out by the agency district or sub-district personnel on a force account basis. Routine maintenance is that carried out every year such as patching, drainage maintenance, while periodic maintenance such as seal coating occurs every few years. Most transportation agencies have implemented management systems that monitor maintenance work on their facilities and also help in decision support for appropriate and timely maintenance actions. Expected maintenance costs may be estimated from cost records of an agency’s maintenance section. These may be in the form of average values duly adjusted to reflect the time value of money. In some case, it is possible to estimate maintenance costs using annual maintenance expenditure models that take due consideration of factors such as location, facility type, age of facility, level of usage, etc.

### 6.3 USER COSTS

User costs are those costs that are borne by the users of the transportation facility. These include vehicle operation costs, travel time costs, delay costs and safety costs. Vehicle operating costs refer to the expenses involved in running the vehicle associated with that transportation facility. User costs are often directly related to the physical condition as well as performance of the facility. For example, relatively high user costs are expected for a highway that is highly congested and is in a poor physical state, compared to an uncongested highway in a good condition, all else being equal. For highway transportation, vehicle operating costs may be categorized into three components: fluids (fuel, engine oil, brake fluid, power-steering fluid, etc.), light consumable parts (tires, brake pads, wiper blades, etc.), heavy consumable parts (alternators, battery, radiator, etc.). The level of each category of VOC is influenced by driver characteristics, vehicle factors, and facility factors. Driver factors include age, experience, gender, and temperament. Vehicle factors include size and type of vehicle, vehicle technology, age, and mileage. Facility factors include operating speeds, condition of the infrastructure, and vertical and horizontal alignment.

#### 6.3.1 Vehicle Operating Costs

This consists of costs of consumable fluids (such as fuel, engine oil, brake fluid, power steering fluid, etc.) and wearable parts and components (such as tires, alternator, battery, brake pads, wiper blades, etc.).

The computation of each VOC component is discussed below:

*1. Fuel Consumption Costs:* These constitute a major portion of vehicle operating costs. For a given vehicle type, the most significant factor that affects the level of fuel costs is the speed of the vehicle. The relationship between operating speed and fuel consumption depends on the level of speed:
(i) For speeds less than 35 miles per hour,

\[ \Phi = \frac{1}{E} = K_1 + \frac{K_2}{V} \]

where

- \( \Phi \) = fuel consumption in gallons per mile
- \( E \) = fuel economy in miles per gallon
- \( K_1 \) = vehicle dependent parameter associated with fuel consumed to overcome the rolling resistance, and is approximately proportional to the vehicle weight
- \( K_2 \) = vehicle dependent parameter approximately proportional to the idle fuel flow rate
- \( V \) = average speed in miles per hour as over a distance (not uniform speed)

Past research has indicated the following values of \( K_2 \) and \( K_3 \):

Passenger cars: \( \Phi = 0.0362 + \frac{0.0746}{V} \)

Tractor Trailers: \( \Phi = 0.17 + \frac{2.43}{V} \)

(ii) For speeds more than 35 miles per hour,

\[ \Phi = K_1 + K_2 \cdot V + K_3 \cdot V^2 \]

where

- \( \Phi \) = fuel consumption in gallons per mile
- \( K_1 \) = calibration parameter
- \( K_2 \) = vehicle dependent parameter approximately proportional to the idle fuel flow rate
- \( K_3 \) = parameter related to vehicle and kinetic energy changes
- \( V \) = average speed in miles per hour as over a distance (not uniform speed)

2. Tire Costs:

This is computed as follows:

\[ \text{Tire Cost} = \frac{\text{ATRP}}{N} \]

where

- \( \text{ATRP} \) = average retail price of a set of tires used by vehicle
- \( N \) = average life of a set of tires in miles
3. Vehicle Depreciation Costs:
This is computed using the average retail price of a new vehicle as follows:

\[ \text{Depreciation Cost} = \frac{AVRP}{N} \]

where

\[ AVRP = \text{average retail price of a set of tires used by vehicle} \]
\[ N = \text{average vehicle life in miles} \]

4. Vehicle Maintenance Costs:
This is computed as follows:

\[ \text{MAINT Cost} = \frac{ACL + ACP}{N} \]

where

\[ ACL = \text{average cost of labor for vehicle maintenance} \]
\[ ACP = \text{average cost of parts for vehicle maintenance} \]
\[ N = \text{average vehicle life in miles} \]

Instead of calculating individual components of VOC, an aggregate VOC function could be used as follows:
For V less than 35 pmh
\[ VOC = a + b \cdot V \]

For V exceeding 35 mph
\[ VOC = c + d \cdot V + e \cdot V^2 \]

where

\[ VOC = \text{total vehicle operating costs in cents per vehicle-miles of travel} \]
\[ a, b, c, d, \text{and } e \text{ are constants estimated from data.} \]

Factors Affecting Vehicle Operating Costs
For any of the road user cost types discussed above, there are three major factors that influence the magnitude of user costs:

- Human factors (driver’s age, gender, experience, temperament, etc.)
- Vehicle factors (vehicle size, make, age, level of accumulated usage, condition, etc.)
- Facility factors (road surface condition, nature of terrain, geometric design features, etc.)
6.3.2 *Travel Time Costs*

Travel time costs refer to the cost of the time spent by users for the duration of time they spend in the use of the transportation facility. The reduction in travel time is a major driving force behind many transportation system improvements. The changing face of the transportation environment, such as increased user perspectives, gives impetus for the need to address the increasing problem of increasing times for commutes and travel, particularly in urban areas. Traffic signal system optimization, freeway incident management, and ITS are only but a few of the several initiatives that are being taken to decrease travel times by reducing congestion. There are two components of travel time: in-vehicle travel time (IVYTT), and out-of-vehicle travel time (OVTT).

Travel time is typically computed as follows:

For an individual,

\[ TT = ATT \times VTT \]

where

- \( TTC \) = cost of travel time in $/hr
- \( ATT \) = amount of travel time incurred by the individual in hours (OVTT + IVTT)
- \( VTT \) = value of the individual’s travel time in $

For a vehicle,

\[ TTC = OCC \times ATT \times VTT \]

where

- \( TTC \) = cost of travel time in $/hr
- \( OCC \) = vehicle occupancy
- \( ATT \) = amount of travel time incurred by the vehicle in hours (OVTT + IVTT)
- \( VTT \) = value of travel time associated with vehicle type, in $

Factors that affect the amount and value of travel time are shown in Table 6-1 below:

<table>
<thead>
<tr>
<th>Factors affecting <strong>Amount</strong> of Travel Time</th>
<th>Factors affecting <strong>Value</strong> of Travel Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trip length</td>
<td>Trip Purpose</td>
</tr>
<tr>
<td>Vehicle Speed</td>
<td>Time of day</td>
</tr>
<tr>
<td>Vehicle Occupancy</td>
<td>Driver’s socio-economic background</td>
</tr>
</tbody>
</table>
6.3.2.1 The Value of Travel Time

Time is money. So goes the age-old adage. The truism in this statement is recognized and appreciated in the evaluation of transportation system benefits and costs. Travel time is defined as the duration of time spent by the user of a transportation facility in traveling from one geographical location to another. Improvements in transportation systems are justified not only by greater levels of safety, comfort and convenience, and vehicle operation costs, but also reduction of travel time. The savings associated with reduced travel time typically constitutes a significant benefit afforded by an improved transportation system. There are countless vital public and private transportation projects for which a major percentage of the overall economic benefits were attributable to travel time savings. It is obvious that such projects may not have been justified if travel time savings had not been included.

The fundamental nature of time is important to an understanding of the concept of travel time. As has already been stated in this paper, time *per se* has no value. Time is simply the rotation of the Earth and its revolution around the sun, and time is measured by man-made devices. Time is fixed in supply, irreclaimable, irretrievable, unchangeable, and unstorable. These attributes of time make it unexchangeable and therefore cannot be purchased, sold or bartered. It is rather the goods or services that are produced within a certain span of time, not the time itself that can be bought or sold. So can time really be saved? Can time be wasted? Can time have a value? Time cannot be created or destroyed. Every person uses the same amount of time every day and every year. Time is continuously being used. Time is never wasted, it is opportunities that often are. Admittedly, time may be used on an activity considered of low (or even negative) value, but even such time is not wasted in the real sense of the word. Does time have a value? No. The term 'value of time' really means 'value of goods and services that are producable within a time interval.' Travel time is the time used to travel from a point of origin to a point of destination. When the trip is made in less time than before, the reduction in time is considered as 'saved' time even though the difference in time was not really saved but used to perform another activity. This is the basis upon which economic evaluators of transportation systems find the value of travel time and hence determine the benefits derived from reduction in travel times.

The value of travel time is usually not given as a single blanket figure. Most transportation agencies assign different values of travel time for different modes of travel, and even within each mode, for different subgroups (see table 6-1). The fact that travel time values can be obtained even for small subgroups in a small geographical area is remarkable, when viewed against the background of (i) the multiplicity and complexity of factors that influence travel time values and (ii) the strong dependence of the weight of each contributory factor on circumstances of the trip such as trip purpose, traveler's characteristics, time and season of trip etc. To establish any general values of travel time, thus, needs a great deal of circumspection, sound reasoning and good judgment.

As stated in a preceding paragraph, time itself is not valuable *per se*. Rather, it is the value of goods and services produced within the time interval that imparts a sense of value to time. Humans, by our very innate nature, constantly seek to reduce the amount of time required to accomplish any task such as travel, so that more time would be available for other activities. Hence, in the strict sense of the word, savings in travel time is a
misnomer: it is rather that the 'saved' time is used in another productive activity. Valuation of travel time is often considered on the basis of comparing travel between two alternative routes or modes, or comparing travel to another economic activity which could have taken place during the travel period. This chapter discusses various methodologies to define the value of travel time and to compute travel time values.

6.3.2.2 Typical Questions that are Addressed by Travel Time Valuation

• A certain haulage company works on a certain level of daily expenditure that includes drivers' wages and benefits, vehicle operation, maintenance and servicing, and administrative costs. What is the value attached to the time of travel of a truck belonging to this company?

• A vehicle observed on a highway at a certain time during non-work hours is occupied by a certain number of individuals whose incomes are known. What is the value of the time they use for the trip?

• A road user chooses to travel on a short-length toll route over the alternative free route of greater distance. If other service attributes of both alternatives are known, find the value attached to time of travel by the road-user.

• A certain proportion of users prefer to use a particular mode or route of travel, to another alternative. If the time, cost and other service attributes of both alternatives are known, what is the value of time of travel?

• From interviews, it is found that users of a certain transportation facility have indicated that a certain extra cost introduced for the route or mode they currently use would be just sufficient to make them willingly switch from that route or mode to the other. If travel time, cost and other service attributes are known, what is the value they collectively attach to the time of travel?

• From a poll of several individual users of a transportation facility, a set of data which indicates the extent to which each individual is prepared to forgo one service attribute to gain a certain quantity of another, is obtained. For example, in order to gain an additional amount of minutes or hours, or how much time he is prepared to sacrifice to make a certain savings in cost. What is the value they collectively attach to travel time?

6.3.2.3 Factors Affecting the Value of Travel Time

There are several factors that influence the value of time attached to travel. The relative weight of each factor depends on the trip-maker characteristics, trip characteristics, trip length, environmental and seasonal considerations, and mode of travel. Furthermore, given a particular mode of travel the derived value of travel time depends upon the type of approach or model used for the derivation of travel time value. For instance the federal minimum wage does not influence (at least, not directly) the value of travel time derived using the binary logit model.

For auto factors include:

• Number of persons in auto(vehicle occupancy)
- Ages, wages and occupation of persons in the auto
- Purpose and urgency of trip
- Time of day, day of week, season of year
- Relationship between amount of time used for trip and time used for waiting
- Existing level of legal minimum wage

For commercial vehicles factors may include:
- Purpose of trip
- Wages of crew
- Period of travel

6.3.2.4 Some Previous Studies on Travel Time Valuation

The chronology of travel time valuation is an interesting one, marked by conflicting theories, divergent views and points of controversy. Haikalis and Hyman (1966) based their approach using the prevailing wage rate for an unskilled worker, adjusted for vehicle occupancy, and possible unemployed status of occupants. Haney and Thomas (1967), developed mathematical models for the value of passenger car travel time based on field studies of commuter travel in situations where such travel involved a choice between a toll road and a free road. In a similar approach, Claffey (1959), made an earnest attempt to determine what highway users on toll highways were paying for travel time. Claffey measured travel time, fuel consumption, and speed-changes in driving-sections of toll highways and parallel free highways between the same termini. Origin-destination surveys were made to determine the fraction of road users choosing either route. The Claffey study measured the price of time paid under the unique condition of inter-city toll highway use but did not take cognizance of the extent of willingness of travelers to pay the extra cost associated with time reduction. Neither did it include work on urban travel such as home-work-home commuting. De Donnea (1968) put forward a theoretical basis for valuation of travel time savings. In his model, he considers the utility of a consumer for the joint product of an activity and the time required to undertake that activity. From de Donnea's approach, it is concluded that the value of time spent in any activity (such as travel) indeed exists, and that the value of a travel time saving is not only dependent on the activity that replaces travel, but is also a function of the circumstances (e.g. comfort) under which that time is spent. Hence de Donnea showed that all attributes require consideration when finding the value of travel time. Watson's approach (1969) does not vary much from de Donnea's, except that he neglected the circumstances under which time is spent, and makes use of a rather simple time/cost trade-off model which supported the more traditional approach to travel time valuation.

A fairly recent empirical method to estimate the value of travel time was utilized by Hensher (1970). This method involved direct interview of road users, to determine how much of a change in one service attribute would be just enough to cause them to change their choice of mode. This method takes cognizance of the extent of people's willingness to pay, but has problems of possible errors in measurements. Beesley (1971), in his two dimensional plot of trade-offs of attributes, also bases his method on the extent of people's willingness to pay.
Individuals are plotted on the graph based on the extent to which each of them is prepared to sacrifice one service attribute for another.

6.3.2.5 Valuation of Travel Time during Working

Examples of travel during working periods are:

- Technical personnel on their way from office or workshop to attend to a problem or assignment elsewhere.
- Taxi drivers on their usual duty rounds.
- Roving salesmen, delivery men, and other personnel who advertise, market or deliver their goods and services by moving from one place to another. This includes commercial and industrial haulage.

The valuation of working travel time is much simpler than that for non-working time, for the following reasons:

(i) **Availability of easy substitute**: The value of travel time is obtained by considering that that time could have been used on a substitute activity, which is production of goods and services. Hence in contrast to the case of non-working time, a substitute activity for traveling is readily obtainable, for which the value can be computed and alluded to as the value of travel time.

(ii) **Obviation of peculiar considerations**: Since most of the working time used for travel during working time is paid for by the employer or business owner (who is rarely the traveler), problems of individual idiosyncrasies of choice, perceptual variations in time and cost and other measurement problems do not arise.

For such reasons, valuation of working travel time is a relatively easy task. It is therefore not surprising that most researchers have therefore focused addressing the estimation of non-work travel time.

Generally, the value of travel time during working periods is considered equal to the wage rate and other concomitant costs of operation and running. In the case of commercial vehicles, reduction of travel time will lead to reduction in resource utilization in the following respects:

- Greater return on investment. Reduced travel time means fewer transport vehicles to haul a given quantity of goods in the same time interval, hence less investment per given output.
- Less depreciation. Reduction in travel time implies that a given vehicle will be used more hours per day or operated more miles during its useful life than it would at greater trip times. Hence even though depreciation is faster, the rate of depreciation per output is less.
- Less cost of hiring. Reduction in travel time may not necessarily lead to lower wages of drivers but would surely result in less wage per output.

In the case of individual business men on a travel trip, valuation of travel time is similar to that for commercial vehicles. The same general procedure is used. However there is a limitation on the way savings corresponding to extra business time can be converted into extra output, due to the following reasons:
• A significant proportion of business travel is done in the traveler's own time, so that the saving is not translated into extra working time.
• Some business people work whilst traveling, especially in tranquil modes of travel such as the airplane or train. Hence their travel time cannot be considered as time outside working hours.

Computational method
Wage rate per hour = \( w \)
Adjustment to cater for other benefits = \( a \)
Value of extra goods and services produced in time interval, \( t = v_g \)
Value of travel time = \( w + a + v_g/t \)

It is often assumed that any time saving will be converted into additional output by the business traveler or haulage team. In reality, this conversion may not be 100% complete since resources cannot be automatically switched from one task to another. Furthermore, in the case of haulage operations, a few the maximum use to which travel time savings may be put depends on the crew.

6.3.2.6 Valuation of Non-Work Travel Time
A great deal of attention has been paid to finding the value of travel time used for non-work travel. Over the past fifty years, several theoretical and empirical approaches have been adopted by various transportation agencies.

De Donnea's Theoretical Approach
Besides presenting a means to value travel time, de Donnea's approach incorporates the effects of attributes other than cost and time. In this approach, the utility of a consumer for the joint product of an activity and the time required to undertake that activity, are considered.

Mathematically, de Donnea showed that

\[
\frac{\mu - \delta_{t_i}}{\lambda} = \frac{dX_{ki}}{dt} \left( P_k - \frac{\delta_{t_i}}{\lambda} \right)
\]

\[
\delta_{t_i} = \frac{\partial \mu}{\partial G} \cdot \frac{\partial G}{\partial X_{t_i}}
\]

where
\( \mu \) and \( \lambda \) are Lagrange multipliers
In other words, de Donnea showed that the marginal value of time used as input in given activity $i$, is equal to the rate of technical substitution of an input $k$ of activity $i$ and of time (multiplied by) the difference between the price $p$ of the input $k$ and the marginal value of the effect of input $k$ on the circumstances under which the whole time required to produce activity $i$ must be spent. From de Donnea's analysis, it is seen that:

- There exists a value that can be attached to time spent on an activity other than the main economic activity (such as time spent in travel).
- The value of travel time is dependent on the activity that replaces travel.
- Value of travel time is a function of the circumstances under which time is spent (such as the comfort and other amenities experienced during travel). Hence de Donnea's model incorporates one of the most necessary (yet elusive) criteria of travel time valuation.

**Traditional Empirical Methods of Measurement of Travel Time Value**

(a) The toll route / free route approach

The principle underlying this approach is to find trade-off situations that face travelers and to derive values of travel time from measurements of trade-off. A typical situation is the choice of a toll route to save time and lose money, or a non-toll route to save money and lose time.

In such a model, the value of travel time is given by the following expression:

$$V = \frac{(C \times D)}{T} + F$$

where

- $C$ = operating cost per mile
- $D$ = additional distance required to save time
- $T$ = time saved by using faster alternative
- $F$ = toll difference between faster route and slower route
Typical input data may be tabulated as follows:

<table>
<thead>
<tr>
<th>Table 2: Example of Tabulated Typical Input Data</th>
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</thead>
<tbody>
<tr>
<td>Features</td>
</tr>
<tr>
<td>Time</td>
</tr>
<tr>
<td>Operating Cost</td>
</tr>
<tr>
<td>Toll</td>
</tr>
</tbody>
</table>

Work Example: A road user prefers to pay a toll of $0.25 to use a road which enables him to get home from work 45 minutes earlier than when using the normal route which is 3 km longer. If his operating cost is $0.5, what is the value he attaches to his time of travel during such periods?

Solution:

\[ V = \left( (C \times D) / T + F = 0.5 \times 3 + 0.25 \right) / (45/60) = $1.33 \text{ per hour.} \]

(b) Approach based on Binary Logit choice model

This approach for the valuation of travel time is based on a more sophisticated consideration of the traveler's choice situation. In this approach models are constructed on the choice between alternative routes or modes. The principle behind this approach is that weights (measures of comparative importance) are attached by a traveler to costs and time used for any particular route or mode. The ratio of these weights is the value of travel time. The proportion of travelers choosing anyone of two alternatives must be known before the ratio can be computed.

For two alternatives m and n, the proportion of road users choosing a particular alternative is given as

\[ P = \frac{e^{G(X_m)}}{e^{G(X_m)} + e^{G(X_n)}} = \frac{1}{1 - e^{G(X_m-X_n)}} \]

where

- \( G(X_i) \) = satisfaction or utility derived by choosing a particular alternative i
  - \( G(X_i) = \alpha_0 + \sum \alpha_i X_{ik} \), where i = m, n
- \( X_m \) = characteristics or service attributes of alternative i, e.g. cost, time
- \( \alpha_0, \alpha_1, \alpha_2 \) = coefficients obtained from revealed behavior of users.
- \( G(X_m-X_n) = \alpha_0 + \alpha_1 (t_n-t_m) + \alpha_2 (C_n-C_m) \)

Value of travel time is given by

\[ V = \frac{\alpha_1}{\alpha_2} \]
There are several interesting issues regarding the Binary Logit choice model method of travel time valuation:

- **Dominant alternative versus inferior alternative:** From the analysis it is clear that travelers, when faced with a choice situation will have two extreme choices; a most-preferred (dominant) alternative, and a most abhorred (inferior) alternative, with a variety of attribute-exchangeable choices in between. A preferred alternative is one associated with low cost and little time, whereas an abhorred alternative is one which is more expensive and slow.

- **Possibility of negative value of time:** In the event that the specifications for the binary logit choice process for a particular problem are not fully defined such as to encompass the entire gamut of attributes, results of the binary logit analysis would reveal that some individuals choose the abhorred alternative. For example, a person may choose a longer and costlier route because that route traverses several places of scenic appeal, or because that route avoids crime-ridden areas. For such people, the value of travel time would be shown by the model as being negative.

- **'Value' actually refers to 'average price':** For all the groups of people, the coefficients of travel time and travel cost (and indeed for any other travel attribute) used in the choice model are obtained by effectively averaging the prices of time for all individuals, from those in the dominant-choice regime, through those in the exchangeable-attribute regime, to those in the inferior choice regime.

- **Consideration of circumstances under which travel time is used:** Choice models can take account of the circumstances under which travel takes place, by inclusion of additional attribute variables in the model.

- **Utilization of attribute differences rather than attribute ratios:** A unique average price of time can only be obtained by a choice model that is formulated in terms of attribute differences, and the binary logit model does just this. The attribute difference-approach gives a more reliable estimate of the value of travel time than those approaches which are based on a ratio of the attributes. For the latter, estimates of travel time values are a function of time and cost and are thus less reliable.

- **Method estimates the marginality of time value:** The binary logit choice model is associated with a ratio of coefficients, which indicates a marginal price of time, since the value obtained is got from the differences of time and of cost i.e. the 'excess' costs and the 'excess' times.

- **Possibility of stratification:** The relationship between choices, the price of time, and income can be investigated by stratification by income or by using income as an additive variable.

- **Extent of user's willingness to pay:** The binary logit approach does not take cognizance of the extent to which travelers are willing to pay money to obtain a certain time saving or to sacrifice time for a cost saving. Hence in the strict sense of the word, it is the price, not the value of travel time that is found by this method.
Inclusion of accident costs and speed change in Binary logit model

In this method, travel time, fuel consumption and speed changes are measured for non-toll and toll routes, between the same termini.

Typical input data structure for the analysis is as follows:

<table>
<thead>
<tr>
<th>Table3: Example of Typical Input Data Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
</tr>
<tr>
<td>Utility Coefficients</td>
</tr>
<tr>
<td>Travel Time</td>
</tr>
<tr>
<td>Toll</td>
</tr>
<tr>
<td>Running Cost</td>
</tr>
<tr>
<td>Accident Cost</td>
</tr>
<tr>
<td>Speed Change</td>
</tr>
<tr>
<td>Percentage of Road Users</td>
</tr>
<tr>
<td>Free</td>
</tr>
<tr>
<td>Toll</td>
</tr>
<tr>
<td>( \Delta \alpha_0 )</td>
</tr>
<tr>
<td>( \Delta t )</td>
</tr>
<tr>
<td>( \Delta C )</td>
</tr>
<tr>
<td>( \Delta r )</td>
</tr>
<tr>
<td>( \Delta AC )</td>
</tr>
<tr>
<td>( \Delta S )</td>
</tr>
</tbody>
</table>

\[
P_{toll} = \frac{1}{1 + e^{u_{free} - u_{toll}}}
\]

\[
U_{free} - U_{toll} = \log_e \left( \frac{1 - P_{toll}}{P_{toll}} \right)
\]

but \( U_j = \alpha_0 + \alpha_1 t_j + \alpha_2 C_j + \alpha_3 r_j + \alpha_4 AC_j + \alpha_5 S_j \)

Hence

\[
U_{free} - U_{toll} = (\alpha_0 \text{ free} - \alpha_0 \text{ toll}) + \alpha_1 (t_{\text{free}} - t_{\text{toll}}) + \alpha_2 (C_{\text{free}} - C_{\text{toll}}) + \alpha_3 (r_{\text{free}} - r_{\text{toll}}) + \alpha_4 (AC_{\text{free}} - AC_{\text{toll}}) + \alpha_5 (S_{\text{free}} - S_{\text{toll}})
\]

\[
\log_e \left( \frac{1 - P_{toll}}{P_{toll}} \right) = (\alpha_0 \text{ free} - \alpha_0 \text{ toll}) + \alpha_1 \Delta t + \alpha_2 \Delta C + \alpha_3 \Delta r + \alpha_4 \Delta AC + \alpha_5 \Delta S
\]

Hence the value of travel time can be found in a similar manner as in the previous simple Binary logit model.

One important issue associated with this approach is that the speed change is taken as a measure of impedance and then gives an indication of safety, which also deserves to be considered as a service attribute.

(c) Binary logit model for alternative routes or modes that includes a measure of extent of willingness of individuals to sacrifice one attribute for another.

This method is a further improvement on the previous approach, since it incorporates a measure of the extent to which individuals are prepared to incur cost to save time, or to spend time to save cost. This approach involves interviewing individual users of the facility, (by polling or using questionnaires), asking how much of a change in cost of their present mode or route would be just sufficient to cause them to shift their choice of mode or route, to the other alternative. In this method the marginal value attached to travel time by each individual, is provided.
The model is represented by the following equations:

\[ P_c = \frac{1}{1 - e^{U_A - U_C}} \]

where

\[ U_A - U_C = \beta_0 + \beta_1 (t_A - t_c) + \beta_2 (C_A - C_c + TP_C) \]

\[ TP_c = \text{transfer payment on the chosen mode or route} \]

\[ t_A, C_A = \text{time, cost of alternative mode or route} \]

\[ t_c, C_c = \text{time, cost for the chosen mode or route} \]

The inclusion of the transfer payment \( TP_C \) makes the traveler indifferent to any particular choice. In the probability model, the point of indifference is given by a probability of 1/2 (i.e.50-50 chance of either option), which occurs if \( U_A - U_C = 0 \)

Hence the equation becomes

\[ C_A - C_c + TP_C = \gamma_0 + \gamma_1 (t_A - t_c) \]

\[ \gamma_1 = \frac{(C_A - C_c) + TP_C - \gamma_0}{(t_A - t_c)} \]

Some issues associated with this approach are:

- Value of travel time obtained is marginal,
- It takes into account the extent of the willingness of individuals to pay money to gain a certain amount of time, and vice versa,
- The derived equation can be extended to include other attribute differences, and can thus take account of the circumstances under which travel time is used,
- There may be some difficulty in measuring the transfer payment. Individuals may probably not be able to envisage and tell what their indifference threshold would be unless they actually experienced it. It is assumed that underestimates and overestimates given by individuals cancel out to produce a reasonably accurate average value of travel time.

(d) The two-dimensional attribute graph model

This approach is also based on the extent of willingness of individuals to forgo one attribute to gain another. It examines the revealed choices and requires no other additional information than the perceived attributes of the alternatives that are the subject of the choice process.

This approach is restricted to individuals who are in a position to, and are willing to sacrifice one attribute to save another. Such individuals are referred to as 'traders' or 'exchangers.'
Hence an exchanger is defined as an individual who is in the position of trading-off a disadvantage in one attribute to gain an advantage in another. Being an exchanger is not a personal characteristic, but is dictated by characteristics of the choice situation. According to this model, all individuals can be plotted, using their respective trade-off values, on a two-dimensional graph on which the axes represent differences in attribute values.

- Quadrant I: Individuals faced with the preferred choice situation. They are not exchangers.
- Quadrant II: Individuals faced with a choice and opt to save cost and spend time, hence \(+\Delta C\) and \(-\Delta t\). These individuals, who are exchangers, are cost-savings referrers.
- Quadrant III: Individuals with a perfectly abhorred choice, i.e. the chosen alternative is slower and more expensive, hence \(-\Delta C\) and \(-\Delta t\). These individuals are not exchangers. They are satisfied to make that choice probably due to some unspecified, intangible, or exogenous attributes.
- Quadrant IV: Individuals who are faced with a choice and opt to spend money and save time, hence \(-\Delta C\) and \(+\Delta t\). These individuals are exchangers, and are time-saving referrers. The model considers only those individuals that are faced with a choice situation, i.e. those falling within quadrants II and IV.
Example: In a certain situation, Mr. Jones is prepared to pay $2.00 in order to gain 30 minutes of time. His coordinates and position on an exchange graph is as follows:

\[ (-2, +0.5) \]

\[ \frac{1}{2} \text{ hr.} \]

\[ -\Delta t \]

\[ +\Delta t \]

\[ +\Delta C \]

\[ -\Delta C \]

Using this method, the steps involved in the determination of travel time value are as follows:

Step 1 Carry out an attribute-exchange survey among the users of the transportation facility for which user-travel-time value is being sought. Each individual should be asked how much money he is prepared to pay to gain a certain amount of time, or how much time they are willing to forgo to save a specified amount of money.

Step 2 Plot the trade-off points for various individuals on exchange graph.

Step 3 Draw a line through the origin, passing through the two exchange quadrants such that a minimum number of individuals are misclassified (i.e. so that a minimum number of points lie below the line). The line is referred to as the Joint Minimum Classification Line (JMC line).

Step 4 Find the gradient of the line.

Step 5 Compute the reciprocal of the gradient. This is equal to the value of travel time.

Issues associated with the Exchange Plot approach are as follows:

- The JMC line should necessarily pass through the origin of the time-cost graph. This is because the value of travel time for any observation is determined from the slope of the line that joins the position of that observation to the origin but not to any other point.

- This approach is used only when there are equal numbers of observations in quadrant II as in quadrant IV. If there are unequal numbers of observations in the quadrants, a weighting procedure is used for the points in one of the quadrants so that each gradient has an equal weight in determining the location of the JMC line.

- The location of the JMC line is found using a simple manual counting and positioning procedure.
• In this approach, cognizance can be taken of socio-economic characteristics and other attributes. Using income levels for instance, a given sample population can be stratified by income groups, and separate plots made for each income group. Separate values of time can be determined for each group, and the results can be compared for any significant variations.

6.3.2.7 Concluding Remarks on Travel Time Estimation

Reduction in travel time is indeed an important consideration in the evaluation of transportation projects. As has been seen from this paper, state-of-the-art methods of determining the value of travel time generally involve the comparison of two alternative modes or route of travel. In order to obtain true values of travel time it is imperative that the approach used takes into cognizance the extent of willingness of road-users to carry out any exchange of attributes. Furthermore, the model should cater for as many service or travel attributes as found appropriate, not only cost and time. If these considerations are not catered for, it would be the price, not value of travel time, that would be obtained.

In addition, rather than have a blanket figure for travel time values for an entire country, it is advantageous to have different travel time values; for each trip purpose, for each mode, and within each specified geographical area. In this way more accurate 'average' figures of travel time would be obtained for use in evaluation.

6.3.3 Estimation of Safety Costs

Safety costs are costs incurred by users of the transportation facility due to the likelihood of occurrence of crashes. There are generally two approaches of calculating safety costs: the Pre-emptive approach, and After-the-Fact Approach.

Pre-emptive approach:

This is the cost of ensuring that crashes are minimized. Many transportation agencies are implementing risk management systems in order to minimize the occurrences of crashes and also to reduce the increasing amounts of tort liability associated with the use of transportation facilities. Such measures include identification of crash-prone areas and addressing the physical or geometric defects at such locations. Provision of guardrails, road signs, speed bumps, and radio announcement all add to the cost of ensuring safety.

After-the-Fact Approach:

This refers to the cost incurred due to the lack of safety. Crashes may involve property damage only (PDO), serious road user injury, or fatalities. Such costs are typically computed using prevailing insurance rates. Information needed for computation of safety costs for a given facility, using this approach is as follows:

1. Accident rates by type (per vehicle-miles of travel or per number of vehicles)
2. Cost of each type of accident
3. Highway design and traffic factors involved
Highway design factors that play an important role in the computation of safety costs are as follows:

(a) Horizontal curves and vertical grades. It has been observed that when grades exceed 5%, approximately 20% more accidents, compared to average sections, are observed

(b) Illumination. Improved illumination leads to reduced crashes at nighttime

(c) Intersection design

(d) One-way streets. These reduce accidents by 20-45% and reduce pedestrian crashes by an even greater margin.

(e) Speed. Greater variances in operating speeds have been associated with increased number of injury crashes. Also, it has been hypothesized that increasing speeds lead to increasing crashes, but this finding is controversial.

The reduction in crashes in response to a given improvement is termed the Crash Reduction Factor (CRF) of that factor.

Estimation of Crash Costs

Road crashes result in death, injury or property damage. In 2000, a total of 41,821 people lost their lives in motor vehicle crashes and about 3.2 million people were also injured. From the ethical viewpoint, it may seem inappropriate to place dollar values on human lives; however it is useful to have a means of estimating the costs involved in road crashes in order to make informed decisions about crash prevention, risk minimization and compensation or insurance expenditure. Another useful outcome of crash cost estimation is that it enables the evaluation of various safety enhancement programs that reduce the incidence or severity of road crashes in terms of their cost-effectiveness particularly when scarce funds are to be allocated among competing crash reduction programs.

Most state and government officials recognize the magnitude of costs imposed by road crashes on the state and society, and they appreciate the social benefits of avoiding crashes. The government, in an effort to improve highway safety among others signed the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 which included recommendations for the development of a Safety Management System in all states. The Safety Management System is defined as a systematic process, designed to assist decision makers in selecting cost-effective strategies to improve the efficiency and safety of highway traffic, and to protect the investment in the nation’s transportation infrastructure. It is therefore important that crash costs are reliably estimated to for use in Safety Management Systems.

A road crash can be defined as a collision involving at least one moving vehicle and another vehicle or object. The term vehicles broadly refer to bicycles, ridden animals, non-motorized vehicles, and animal-drawn transport, as well as motorbikes, cars, trucks and buses [Ferguson et al., 2000]. Road crashes are usually caused by factors such as driver error, mechanical failure and poor roadway design. Crashes can occur in any of the following ways:

- collision on the carriageway between a vehicle and another vehicle, pedestrian, object or an animal,
• collision off the carriageway such as vehicle collision with a tree after loss of control on the carriageway,
• non-collision on carriageway such as loss of load or breakdown of vehicle,
• non-collision off carriageway such as a roll-over after loss of control on the carriageway,
• others such as a fall from a vehicle.

**Types of Road Crashes**

Road crashes can be broadly classified into three categories namely:

Fatal Crashes – this refers to crashes that result in one or more fatalities within thirty days of occurrence,

Injury crashes – this refers to a crash that results in one or more injuries that are not fatal,

Property damage only crashes – this refers to loss of all or part of an individual’s vehicle and/or property resulting from a road crash not involving injury to a person.

**Scales for Crash Ratings:**

Road crashes can also be weighted on an injury scale by assigning using indices to the level of severity of the road crash. The two commonly used injury scales are the Abbreviated Injury Scale (AIS) and the KABCO Injury Scale.

**Abbreviated Injury Scale (AIS)**

The Abbreviated Injury Scale (AIS) is an anatomical scoring system which was first introduced in 1969 by the Association for the Advancement of Automotive Medicine. The AIS ranks injuries on a scale of 0 to 6: 0 is No Injury, 5 is Critical Injury and 6 is Non-Survivable Injury (fatal). The injuries represents the 'threat to life' associated with an injury and not a measure of the severity of the injury. When multiple injuries are involved or a crash injures several people, the AIS score of the most life-threatening injury (Maximum AIS, or MAIS) is often used to summarize the type and extent of injury. The AIS is updated periodically to provide a reasonably accurate ranking of the severity of injury.
Table 6-4: Abbreviated Injury Scale (AIS) [Blincoe et al., 2002]

<table>
<thead>
<tr>
<th>Code</th>
<th>Severity</th>
<th>Injury Description</th>
<th>Cost per injury (2000 Dollars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIS 6</td>
<td>Fatal</td>
<td>Decapitation, torso transaction, massively crushed chest</td>
<td>$3,366,388</td>
</tr>
<tr>
<td>AIS 5</td>
<td>Critical</td>
<td>Spinal chord injury, excessive second or third degree burns, cerebral concussion (unconscious more than 24hrs)</td>
<td>$2,402,997</td>
</tr>
<tr>
<td>AIS 4</td>
<td>Severe</td>
<td>Partial spinal cord severance, spleen rupture, leg crush, chest wall perforation, cerebral concussion (unconscious less than 24 hours).</td>
<td>$731,580</td>
</tr>
<tr>
<td>AIS 3</td>
<td>Serious</td>
<td>Major nerve laceration; multiple rib fracture, abdominal organ contusion; hand, foot or arm crush/amputation</td>
<td>$314,204</td>
</tr>
<tr>
<td>AIS 2</td>
<td>Moderate</td>
<td>Major abrasion or laceration of skin, cerebral concussion finger or toe crush/amputation, close pelvic fracture</td>
<td>$157,958</td>
</tr>
<tr>
<td>AIS 1</td>
<td>Minor</td>
<td>Superficial abrasion or laceration of skin, digit sprain, first-degree burn, head trauma with headache or dizziness</td>
<td>$15,017</td>
</tr>
<tr>
<td>AIS 0</td>
<td>Uninjured</td>
<td></td>
<td>$1,962</td>
</tr>
</tbody>
</table>

KABCO Injury Scale

The KABCO injury scale defined by the American National Standards Institute (ANSI) is designed for police coding of crash details at a crash scene. The KABCO coding does not require medical judgment; the police officer on the crash scene assesses the injuries sustained and assigns a code depending on the level of severity as shown in Table 6-5. The KABCO coding has been criticized because it does not consistently classify injuries [Miller et al., 1991]. For example a broken arm and a severed spinal cord are considered to be of equal severity. In order to reduce the variability in police reporting the National Highway Safety and Transportation Administration (NHSTA) uses both the AIS and the KABCO scale to describe the extent of an injury.

Table 6-5: KABCO Scale [NSC, 2001]

<table>
<thead>
<tr>
<th>Code</th>
<th>Severity</th>
<th>Injury Description</th>
<th>Cost per injury (2000 Dollars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>K</td>
<td>Fatal</td>
<td>Any injury that results in death within 30 days of occurrence.</td>
<td>3,214,290</td>
</tr>
<tr>
<td>A</td>
<td>Incapacitating</td>
<td>Any injury other than a fatal injury, which prevents the injured person from walking, driving, or normally continuing the activities the person was capable of performing before the injury occurred. e.g. severe lacerations, broken limbs, skull etc</td>
<td>$159,449</td>
</tr>
<tr>
<td>B</td>
<td>Injury Evident</td>
<td>Any injury, other than a fatal injury or an incapacitating injury which is evident to observers at the scene of the accident in which the injury occurred. e.g. abrasions, bruises, minor cuts etc</td>
<td>$41,027</td>
</tr>
<tr>
<td>C</td>
<td>Injury Possible</td>
<td>Any injury reported which is not a fatal, incapacitating or non-incapacitating evident injury. e.g. pain, nausea, hysteria etc</td>
<td>$19,528</td>
</tr>
<tr>
<td>PDO</td>
<td>Property Damage Only</td>
<td>Property damage to property that reduces the monetary value of that property.</td>
<td>$1,861</td>
</tr>
</tbody>
</table>
Review of Past Literature on Crash Costs

There are two important factors in this area that needs consideration: (1) the unit cost per crash and (2) the expected number of crashes reduced as a result of road improvements. Most researches [Miller et al., 2000; Lindberg et al., 1999] in this area agree that the cost per crash consists of two parts: (1) the market or economic costs which include property damage, insurance administrative and legal costs, medical costs, lost production and delay due to congestion caused and (2) the non-market costs which is the emotional and social costs of casualties resulting from road crashes.

Various methods have been developed for the crash costs estimation, Blincoe et al., [2002] examined the economic cost of motor vehicle crashes to the society using the human capital approach. This approach uses the discounted present value of the victim’s income that is foregone due to his premature death or injury to estimate the cost of a road crash [Lindberg et al., 1999]. The study found the total economic cost of motor vehicle crashes in 2000 to be $230.6 billion of which the major part is contributed by the lost market productivity and property damage. These factors separately accounted for 26 percent each of the total economic costs in 2000. The study also developed unit costs per injury sustained in road crashes based on the Injury cost model [Miller et al., 2000] and estimated the economic value of human life at $977,208, with lesser values for the various categories of injuries. Islam [2000] applied the Willingness To Pay (WTP) approach to estimate the value of pain, grief, suffering and uncompensated lost time resulting from crash related injuries. In this study a survey was conducted using employees of Purdue University residing in Tippecanoe County as respondents to estimate how much they are willing to pay to avoid injuries of different types. The study results found that the value of a statistical life or statistical injury (the ratio of the mean WTP per person to the change in statistical risk) varies between $7,499,360 for fatal injury type and $70,793 for a minor injury type for Tippecanoe County in Indiana.

Lindberg et al., [1999] used the concept of marginal external costs to estimate the cost of road crashes. The marginal external costs of road are the incremental costs of a crash borne by society at large, including family and friends, and can also include costs borne by the victims of the crash. Using the willingness to pay approach the study concluded that the non-market cost component was the dominant component and overshadows all other costs components of road crashes. The study found that the non market costs accounts for 90% for fatalities, 80% for severe injuries and 60% for light injuries crash costs. Forkenbrock et al., [1994] developed a statistical model to estimate the cost of road crashes based on the road characteristics and traffic volume. The study used crash and road inventory data from Iowa State to develop a semi-log regression equation to predict the accident cost per million VMT. The results of the study shows that when the average annual daily traffic (AADT) is doubled the cost of road crashes increased by 203.1%. Also reducing the sharpest curve on the segments by two steps reduced the crash costs per million vehicle miles travel (VMT) by 19.0% while the removal of any passing restrictions on the road segments reduced the crash costs by 30.7%.

In the area of crash prediction, Zegeer et al., [1992] developed motor vehicle crash rates by crash type and roadway class using crash data extracted from HSIS. The study found that the most important variables for estimating the crash rates were the area code (urban or rural), the functional class, the number of lanes and
whether the road was divided or undivided. In another study, Zhou and Sisiopiku [1997] investigated the relationship between crash rates and the volume-to-capacity (v/c) ratios of roadways using data from Interstate I-94 in Detroit, Michigan. The study found that the crash rates were highest when the (v/c) ratio was low. It then decreased rapidly as the v/c ratio increased and then gradually increased as the v/c ratio continued to increase.

Brown et al., [1998] also developed crash prediction models to predict crash rates on multi-lane arterial segments based on geometric and access control characteristics for using crash data extracted from Indiana Crash and road inventory database. In this study, the number of crashes was found to increases as the access density and proportion of signalized access points increase. Also the presence of an outside shoulder, two-way left-turn lane, or median without openings between signals leads to a reduction in the number of crashes.

Crash prediction models have proved to be very accurate tools for predicting the expected total number of crashes for a location or a class of locations, however they have not proved satisfactory in isolating the effects of individual geometric or traffic control features. [Harwood et al., 2000]

Current State Practice in Estimation of Crash Costs

The Federal highway Administration (FWHA) Technical Advisory on motor vehicle crashes issued in 1988 recommended that states should use a combined fatal-plus-injury cost and also property damage only if available [FWHA, 1988]. Based on these guidelines most of the states have developed their own methods for estimation of crash costs. A survey of 50 states by Forkenbrock et al., [1994] found that 45 states used specific dollar values for fatalities, personal injuries and property damage whiles the remaining 5 do not assign specific dollar values assign priorities to hazardous locations in deciding on safety projects. Among the 45 states the value assigned to a fatality varies from $500,000 to $3,000,000 with an average of $1,200,000. The value assigned to personal injuries varies from $10,000 to $20,000 with a mean of $17,989, a few states however use higher values the highest being $310,000. Values assigned to property damage only crashes varies from $1,000 to $6,000 with a mean value of $3,100. The two commonly used sources for the dollar value estimates are the annual publication of the National Safety Council Estimates and the 1988 FHWA memorandum. [Forkenbrock et al., 1994]
Table 6-6: Components of Crash Costs [Blincoe et al., 2002]

<table>
<thead>
<tr>
<th>Categories</th>
<th>Components</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct Costs</td>
<td>Emergency Services</td>
<td>• Police and fire department response costs</td>
</tr>
<tr>
<td>Medical Costs</td>
<td>• Ambulance transport.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Emergency room and inpatient costs,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Follow-up visits, physical therapy</td>
<td></td>
</tr>
<tr>
<td></td>
<td>and rehabilitation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Prescriptions, prosthetic devices</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Home modifications.</td>
<td></td>
</tr>
<tr>
<td>Insurance Administration Costs</td>
<td>• Administrative costs of insurance claims</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Defense attorney costs.</td>
<td></td>
</tr>
<tr>
<td>Legal Costs</td>
<td>• Legal fees and court costs from civil litigation</td>
<td></td>
</tr>
<tr>
<td>Workplace Cost</td>
<td>• Retraining of new employees,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Overtime required to accomplish work</td>
<td></td>
</tr>
<tr>
<td></td>
<td>of the injured</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Administrative costs of personnel</td>
<td></td>
</tr>
<tr>
<td></td>
<td>changes</td>
<td></td>
</tr>
<tr>
<td>Indirect Costs</td>
<td>Market Productivity</td>
<td>• Present discounted value of the lost wages and benefits over the victim’s remaining life span.</td>
</tr>
<tr>
<td></td>
<td>Household Productivity</td>
<td>• Present value of lost productive household activity.</td>
</tr>
<tr>
<td></td>
<td>Travel Delay</td>
<td>• Value of travel time delay due to resulting traffic congestion.</td>
</tr>
<tr>
<td></td>
<td>Property Damage Costs</td>
<td>• Value of vehicles, cargo, roadways and other items damaged.</td>
</tr>
<tr>
<td>Intangible Loss</td>
<td>Quality of Life and Pain and Suffering Costs</td>
<td>• Loss of expected years to live (death)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Loss of future health (non-fatal injuries)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Pain, suffering, grief, etc.</td>
</tr>
</tbody>
</table>

Table 6-7: Summary of Economic Crash Costs for 2000 in millions of 2000 dollars [Blincoe et al., 2002]

<table>
<thead>
<tr>
<th>PDO</th>
<th>MAIS 0</th>
<th>MAIS 1</th>
<th>MAIS 2</th>
<th>MAIS 3</th>
<th>MAIS 4</th>
<th>MAIS 5</th>
<th>Fatal</th>
<th>Total</th>
<th>Total%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medical</td>
<td>$0</td>
<td>$3</td>
<td>$11,088</td>
<td>$6,813</td>
<td>$5,854</td>
<td>$4,794</td>
<td>$3,146</td>
<td>$924</td>
<td>$32,622</td>
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<td>Emergency Services</td>
<td>$733</td>
<td>$56</td>
<td>$452</td>
<td>$92</td>
<td>$46</td>
<td>$30</td>
<td>$8</td>
<td>$35</td>
<td>$1,453</td>
</tr>
<tr>
<td>Market Productivity</td>
<td>$0</td>
<td>$0</td>
<td>$8,151</td>
<td>$10,908</td>
<td>$8,996</td>
<td>$3,886</td>
<td>$4,151</td>
<td>$24,898</td>
<td>$60,991</td>
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<td>Household Productivity</td>
<td>$1,111</td>
<td>$84</td>
<td>$2,664</td>
<td>$3,193</td>
<td>$2,653</td>
<td>$1,023</td>
<td>$1,413</td>
<td>$8,010</td>
<td>$20,151</td>
</tr>
<tr>
<td>Insurance Admin.</td>
<td>$2,741</td>
<td>$204</td>
<td>$3,453</td>
<td>$3,012</td>
<td>$2,379</td>
<td>$1,181</td>
<td>$645</td>
<td>$1,552</td>
<td>$15,167</td>
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<td>Workplace Cost</td>
<td>$1,208</td>
<td>$87</td>
<td>$1,175</td>
<td>$852</td>
<td>$537</td>
<td>$172</td>
<td>$78</td>
<td>$364</td>
<td>$4,472</td>
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<tr>
<td>Legal Costs</td>
<td>$0</td>
<td>$0</td>
<td>$699</td>
<td>$2,172</td>
<td>$1,990</td>
<td>$1,230</td>
<td>$756</td>
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<td>Travel Delay</td>
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<td>$1,970</td>
<td>$3,620</td>
<td>$369</td>
<td>$118</td>
<td>$36</td>
<td>$87</td>
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<td>$25,560</td>
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<td>$2,597</td>
<td>$17,911</td>
<td>$1,724</td>
<td>$856</td>
<td>$359</td>
<td>$89</td>
<td>$430</td>
<td>$59,036</td>
</tr>
<tr>
<td>Total</td>
<td>$59,838</td>
<td>$5,000</td>
<td>$49,214</td>
<td>$29,134</td>
<td>$23,430</td>
<td>$12,710</td>
<td>$10,373</td>
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<td>$230,568</td>
</tr>
<tr>
<td>Total %</td>
<td>25.95%</td>
<td>2.17%</td>
<td>21.34%</td>
<td>12.64%</td>
<td>10.16%</td>
<td>5.51%</td>
<td>4.50%</td>
<td>17.72%</td>
<td>100.00%</td>
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</table>
Monetization of Road Crashes

Various economic costing methods have been developed to assess the economic loss to society as a result of motor vehicle crashes. There is no single assessment method that is universally accepted, however the common methods used for determining the value of a fatal or a non-fatal injury are:

*The Human-Capital Cost Approach*

The human capital approach measures the loss to society due to a fatal crash, based on future productive potential of the victim. The approach measures only market costs (property damage, medical treatment, and lost productivity, Insurance administration and legal costs, travel delay. This approach estimates the value economic value of a human life at $977,208, with lesser values for the various categories of injuries set by the MAIS. [Blincoe et al., 2002]

*The Comprehensive/Willingness to Pay Approach*

This approach measures both market and non-market costs, including pain, grief, and reduced quality of life as a result of an injury. It also reflects people’s willingness-to-pay for increased safety (i.e., reduced risk of crashes and reduced crash damages). Blincoe et al., [2002] estimates the value of a fatality in the range of $2-7 million, and assigns a “working value” of $3,366,388. This method is a more appropriate measure of the true cost to society of crashes, and the appropriate value to use when assessing crash prevention [Forkenbrock et al., 1994]. The willingness to pay (WTP) approach has been used to develop WTP values for selected counties in Indiana [Islam, 2002].
Years Lost Plus Direct Cost Approach

This approach includes the same cost components as the comprehensive approach; however, it replaces non-market costs with a non-monetary measure: lost years. The direct costs in this approach refer to the cost components which are given a monetary value. These include property damage, medical costs, emergency services, travel delay, vocational rehabilitation, workplace costs, and administrative and legal costs.

6.3.4 Estimation of Air Pollution Costs

Please see Chapter 12.

6.3.5 Estimation of Noise Pollution Costs

Please see Chapter 13.

6.3.6 Estimation of Energy Costs

Please see Chapter 14.

6.3.7 Estimation of Ecological Damage Costs

Please see Chapter 10.
REFERENCES

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