CHAPTER 5

Travel-Time Impacts

All my possessions for a moment in time.
—Elizabeth I (1533–1603)

INTRODUCTION

There is an old adage that "time is money." But can time have a value? The attributes of time make it unexchangeable and therefore, strictly speaking, time cannot be purchased, sold, or bartered. As such, time has no intrinsic value and therefore the term *value of time* actually means "value of goods, services, or some utility that can be produced within a time interval." 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 was used to perform another activity. This is the conceptual basis upon which transportation analysts consider reductions in travel time to be a "saving" and proceed to measure its benefits in terms of the amount of time saved and the value of each unit of time saved.

Enhancements to a transportation system are often expected to yield increased travel speed or decreased waiting or transfer times, and consequently, reduced travel time. The savings associated with reduced travel time typically constitute the largest component of transportation user benefits. A conference of European Ministers of Transport in Paris in December 2003 concluded that "the valuation standards of time requirements for transport and time savings as a consequence of transport policies are often decisive for the acceptance or rejection of transport policies and transport infrastructure investment projects" (UNESC, 2004).

In this chapter we present issues associated with travel time as a transportation performance measure and methodologies for the assessment of travel-time amounts and unit monetary values for the purpose of evaluating the travel-time impacts of transportation projects. Given that the values of travel time vary by certain attributes of the trip and the trip-maker, it is important to establish the various ways by which travel-time amounts may be categorized.

5.1 CATEGORIZATION OF TRAVEL TIME

5.1.1 Trip Phase

On the basis of trip phase, components of travel-time amount may be categorized as *in-vehicle travel time* (IVTT) or *out-of-vehicle travel time* (OVTT). IVTT is the time incurred by passengers or freight in the course of their transportation by rail, air, water, or highway vehicles from one point to another. IVTT can be determined as the ratio of the distance traveled to the average operating speed. Operating speed, in turn, is influenced largely by prevailing traffic conditions.

OVTT is the "excess travel time" spent outside a vehicle during the journey. It includes the time spent waiting at terminals or transferring between modes. For auto travel, the excess travel time may include parking search time and walking time to and from parking. For transit travel, the OVTT components are the walking time to and from the transit stop and the waiting time at each end of the trip. For freight transportation, excess travel time includes primarily modal transfer times at ports and terminals. For both passenger and freight transportation, out-of-vehicle travel times can be increased by security concerns or weather problems. For example, in the post-9/11 period, the time spent by passengers at airports increased because of security screening procedures.

The categorization of travel time on the basis of trip phase is important because travelers typically attach different disutilities to different trip phases. Research findings suggest that irrespective of travel mode, people generally attach a higher degree of undesirability (and therefore, higher disutility and greater time value) to the time spent *waiting* for the vehicle compared to that spent *traveling* in it (Mohring et al., 1987). For freight transportation, intermodal transfer times can be critical in the ability to meet the requirement of just-in-time services.

Example 5.1 A work-bound commuter walks from home to a bus stop and takes a bus to reach rail transit station A in 7 minutes. At the station, the person boards the train and undertakes a 13-minute trip to a downtown bus stop, where she boards a bus that takes her to the workplace in 5 minutes. Tabulate the IVTT and OVTT associated with the journey. Assume a waiting time at the transit center and bus stops of 3 minutes and a walk time of 2 minutes.

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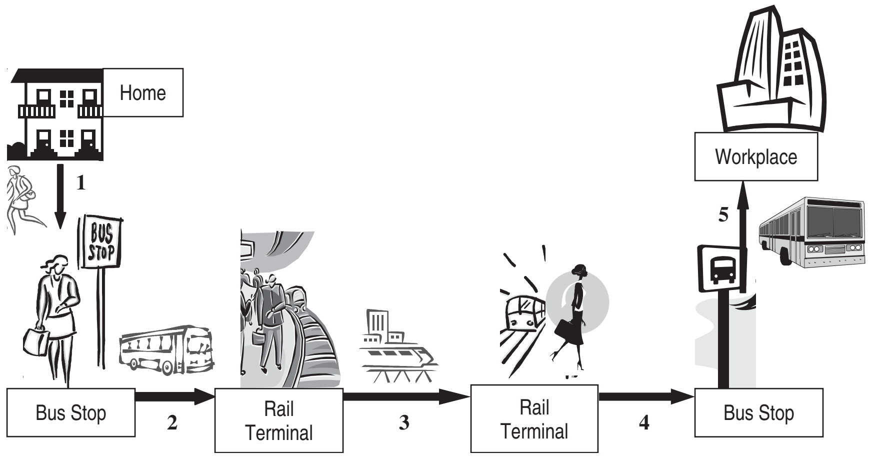

Figure E5.1 Example of trip phases: journey from home to work.

Table E5.1 IVTT and OVTT According to Trip Phase

	Trip Segment	IVTT (min)	OVTT (min)
Journey 1	Walk from home to bus stop	0	2
	Wait at bus stop	0	3
Journey 2	Bus trip from bus stop to rail transit station	7	0
	Wait for rail transit	0	3
Journey 3	Rail transit journey to destination station	13	0
Journey 4	Walk to bus stop	0	2
	Wait at bus stop	0	3
Journey 5	Bus trip from bus stop to workplace	5	0
Total travel time by trip phase		25	13
Total trip travel time		38 min	

SOLUTION The journey from home to work is illustrated in Figure E5.1, and the IVTTs and OVTTs are tabulated in Table E5.1 according to the trip phase.

5.1.2 Other Bases for Travel-Time Categorization

(*a*) *Traveler Aggregation* Travel time may be considered with respect to a person or groups of people classified by socioeconomic characteristics, trip origin and destination or trip purpose, vehicle type, and other factors.

(*b*) *Clocking Status* Travel time is expended by travelers in the course of working (*on-the-clock* travel time) or outside work (*off-the-clock* travel time). Some travel-time estimation procedures treat such travel times separately, as they are likely to have different monetary values.

(*c*) *Flow Entity* For passenger transportation, hourly travel-time values per dollar are typically expressed per person; for freight transportation, travel time is expressed per ton, cubic foot, gallon, barrel, or other unit.

(*d*) *Time of Day* Traffic conditions change constantly, and therefore travel speeds and times vary widely from hour to hour. However, two distinct periods of trip-making behavior in a typical day are the peak and off-peak periods, and travel time is typically estimated separately for these two periods.

5.2 PROCEDURE FOR ASSESSING TRAVEL-TIME IMPACTS

The overall framework for assessing travel-time impacts involves the estimation of travel-time amounts, travel-time values, and overall savings in travel-time costs. This is done for two scenarios: a *base-case scenario* (typically, representing the existing situation without intervention) and an *alternative scenario* (typically representing the improved transportation situation after intervention). Specific steps are shown in Figure 5.1 and discussed below.

Step 0: Establish the Base-Case Year The base case may be for either the current year or a specified future year.

Steps 1 to 3: Estimate the Demand and Capacity Before Intervention Travel speed and time are the

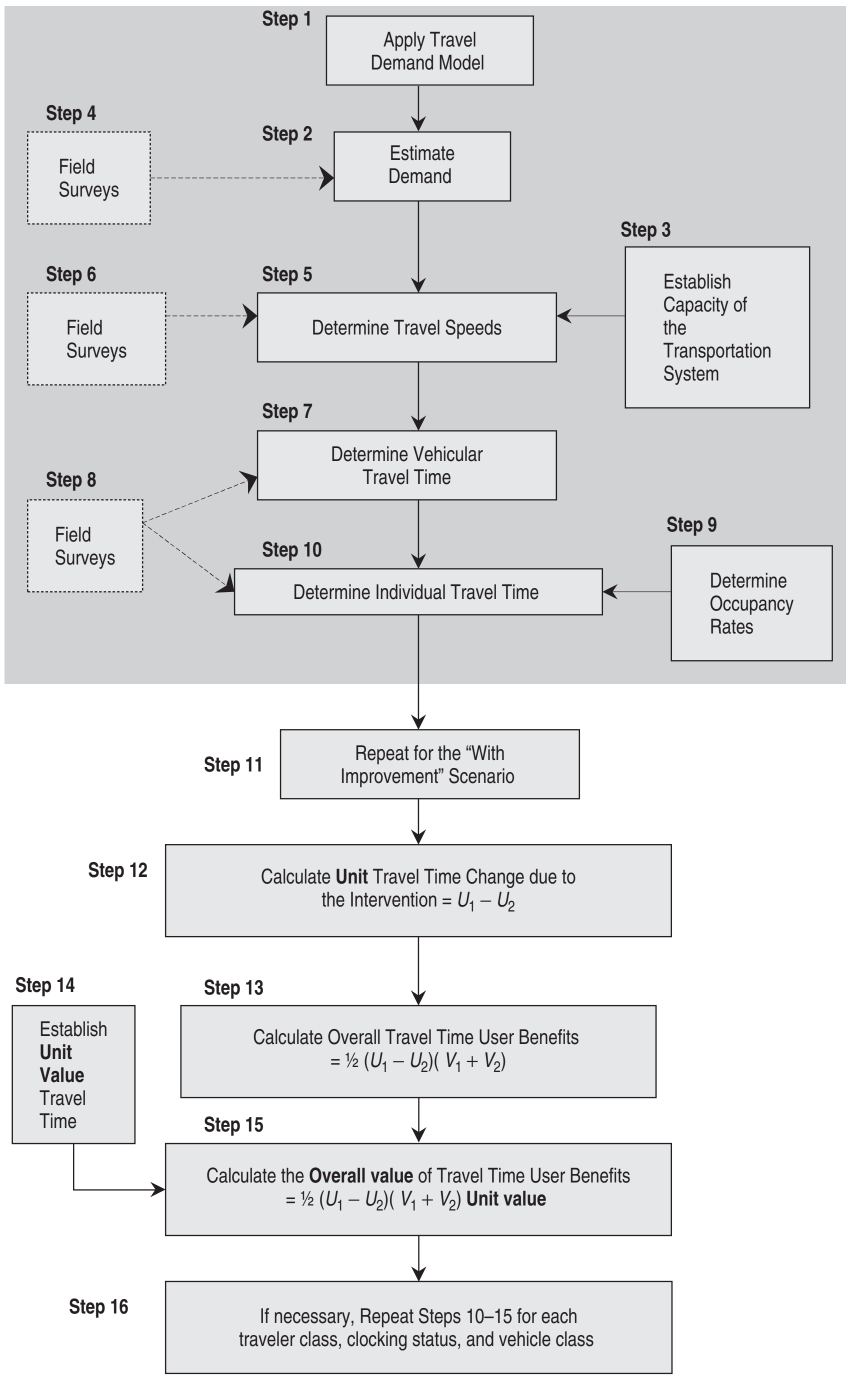

Figure 5.1 Framework for estimating travel time impacts of transportation interventions.

result of both travel demand and capacity of the transportation system. In Steps 1 to 3, therefore, the transportation analyst establishes system demand and capacity so that travel speed and time can be estimated. In base-case scenarios where speed or travel time can be estimated directly from the field, this step can be skipped.

(a) *Demand estimation* In Chapter 3 we present methods, identify relevant software packages, and provide numerical examples for demand estimation.

(b) *Capacity estimation* The capacity of a transportation system is typically a function of system characteristics (such as the number of highway lanes or rail guideways). It can be calculated as a product of the capacity under ideal conditions and requisite capacity adjustment factors. Data on system characteristics can be obtained from databases, such as the Highway Performance Monitoring System (HPMS), that currently exist at state transportation agencies in the United States. Given such data, there are methodologies for estimating system capacity. For example, for highway transportation, a set of equations is available in the *Highway Capacity Manual* (HCM) to estimate capacity as a function of traffic characteristics and roadway geometry (TRB, 2000). A summary of the HCM road capacity estimation procedure is provided as Appendix A5.1.

Step 4: Perform Field Measurements of Travel Demand For the without-improvement case only, as an alternative to (or as a confirmation of results from) steps 1 to 3, it may be necessary to measure the travel demand directly from the field.

Step 5: Determine Travel Speeds before Intervention Travel speeds may be estimated using approaches provided by the HCM method (TRB, 2000), in which the analyst determines speed as a function of highway class, flow rate, density, and free flow speed (FFS); and the COMSIS method (COMSIS Corporation et al., 1995), in which the analyst determines speed as a function of demand and capacity.

(a) *Approach 1: HCM Approach for Speed Estimation* The HCM method (TRB, 2000) provides speed–flow curves for various highway classes. Figure 5.2 presents the speed–flow curve for a basic freeway segment with undersaturated flow conditions. The free-flow speed is the mean speed in the field when volumes are less than 1300 vehicles per hour per lane (vphpl). In the absence of field observations, the *Highway Capacity Manual* recommends the calculation of free-flow speed using a set of adjustment factors for traffic characteristics and roadway geometry. A summary of the HCM procedure for roadway operating speed prediction is provided as Appendix A5.2.

The speed of travel for through movements on urban streets where traffic flow is interrupted due to the presence of signals can be estimated using the speed–flow curves in the *Highway Capacity Manual*, as a function of signal density and intersection volume–capacity (v/c) ratios. Figure 5.3 shows one such speed–flow curve for class II urban streets. The signal timing and street design assumptions used in developing these curves are provided in the footnotes. Similar curves for different sets of assumptions and classes of urban streets available in the

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Figure 5.2 Speed flow curves and level of service for basic freeway segments. (From TRB, 2000.)

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Figure 5.3 Speed flow curves for class II urban streets. Assumptions: 40-mph midblock free-flow speed, 6-mile length, 120-s cycle length, 0.45 g/C. Arrival type 3, isolated intersections, adjusted saturation flow rate of 1700 veh/h, two through lanes, analysis period of 0.25 h, pretimed signal operation. (From TRB, 2000.)

Highway Capacity Manual can be used to determine the average speed at such sections as a function of signal density. For example, using Figure 5.3, the travel speed on a 6-mile urban street with three isolated signalized intersections per mile and peak direction v/c ratio of 0.6 is approximately 20 mph.

Example 5.2 Determine the average passenger car speed on a 6-mile urban freeway section during the off-peak period under undersaturated conditions when the flow rate is 1700 vphpl. The free-flow speed is given as 70 mph.

SOLUTION Using Figure 5.2, corresponding to a free-flow speed of 70 mph and a flow rate of 1700 vphpl, the average passenger car speed is approximately 68 mph under undersaturated conditions.

(b) *Approach II: COMSIS Corporation Method* COMSIS et al. (1995) provided a procedure for speed estimation under the effects of congestion. Applying traffic simulation model runs with FHWA's FRESIM and NETSIM computer programs, a macroscopic simulation model, QSIM, was developed to examine the effects of queuing on speeds. QSIM produced hourly speed outputs for segments with AWDT/capacity ranging from 1 to 16. Average weekday daily traffic (AWDT) was used instead of annual average daily traffic (AADT) to take into account the effect of varying traffic on weekdays and weekends. Speed look-up tables were developed for the estimation of speed at the end of each hour as a function of AWDT/capacity ratio, depending on the functional class of the road. Table 5.1 shows the speed look-up table for estimating hourly speed at freeways.

Since the average daily traffic represents the most common traffic demand information for highway networks, the COMSIS approach is well suited for project planning analysis. This method provides an overall measure of the effect of volume changes and capacity improvements on travel time without requiring detailed profiles of volumes by time of day. To use the speed look-up tables, prior determination of the average weekday traffic (AWDT) and roadway capacity is needed. Average weekday traffic (AWDT) can be determined by applying a conversion factor to the AADT. After AWDT and capacity are determined, the hourly speed, daily speed, peak speed, and off-peak speed can be estimated from speed look-up tables such as Table 5.1.

Example 5.3 In 2004, the annual average daily traffic on a 6-mile stretch of Interstate 65 in Indianapolis was 145,210 vehicles. The capacity of the six-lane freeway is 1900 vehicles per hour per lane. Determine the average speed on the freeway during the morning (7:00 to 10:00 a.m.) and afternoon (4:00 to 5:00 p.m.) peak periods using the speed look-up table developed by COMSIS Corporation for urban and rural freeways. Use a factor of 1.0991 for converting AADT to AWDT.

SOLUTION

Annual average daily traffic (AADT) = 145,210 vehicles

Table 5.1 Freeway Speeds on an Average Weekday[a] (Miles per Hour)

Hour	Ratio of Average Weekday Daily Traffic to Capacity															
Ending	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
12 mn. –1 a.m.	59.94	59.89	59.84	59.78	59.72	59.67	59.61	59.55	59.49	59.43	59.37	59.3	59.22	58.96	58.65	58.27
1–2 a.m.	59.97	59.94	59.9	59.87	59.84	59.8	59.77	59.74	59.7	59.66	59.64	59.6	59.55	59.3	59	58.65
2–3 a.m.	59.97	59.95	59.93	59.9	59.87	59.85	59.82	59.8	59.77	59.75	59.72	59.7	59.67	59.42	59.13	58.78
3–4 a.m.	59.97	59.95	59.93	59.91	59.88	59.86	59.84	59.82	59.8	59.78	59.77	59.76	59.73	59.5	59.21	58.87
4–5 a.m.	59.96	59.93	59.89	59.86	59.82	59.78	59.75	59.71	59.69	59.66	59.64	59.63	59.59	59.35	59.06	58.71
5–6 a.m.	59.89	59.8	59.69	59.58	59.47	59.35	59.23	59.12	59.01	58.91	58.8	58.69	58.57	58.29	57.98	57.66
6–7 a.m.	59.7	59.41	59.08	58.73	58.37	57.98	57.56	57.15	56.73	56.25	55.69	54.99	53.83	52.51	50.16	48.57
7–8 a.m.	59.54	59.09	58.56	57.99	57.37	56.73	55.93	54.28	50.56	45.38	40.77	36.86	33.74	30.01	27.34	25.3
8–9 a.m.	59.65	59.33	58.94	58.54	58.11	57.66	57.09	55.52	50.75	43.57	37.21	31.99	27.87	24.56	22.23	20.58
9–10 a.m.	59.74	59.49	59.21	58.92	58.6	58.28	57.94	57.53	56.1	51.18	42.26	33.4	27.54	24.01	21.74	19.98
10–11 a.m.	59.74	59.5	59.22	58.93	58.62	58.3	57.97	57.61	57.2	56.43	53.15	44.21	33.55	27.24	23.88	21.31
11–12 md.	59.72	59.46	59.16	58.84	58.51	58.16	57.79	57.4	56.97	56.51	55.73	52.24	42.13	32.77	26.97	23.04
12–13 p.m.	59.71	59.43	59.12	58.78	58.43	58.06	57.67	57.26	56.82	56.35	55.83	54.14	47.63	38.06	29.75	24.01
13–14 p.m.	59.7	59.42	59.1	58.76	58.39	58.01	57.62	57.19	56.73	56.24	55.69	54.42	50.14	41.55	31.6	24.47
14–15 p.m.	59.67	59.35	58.99	58.6	58.2	57.76	57.31	56.83	56.34	55.79	55.02	53.21	48.32	40.17	30.24	23.18
15–16 p.m.	59.59	59.2	58.74	58.26	57.73	57.17	56.59	56.00	55.32	54.17	51.64	46.85	40.12	32.39	24.88	19.91
16–17 p.m.	59.52	59.06	58.52	57.92	57.29	56.62	55.8	54.49	52.00	47.41	40.97	34.47	28.87	23.98	19.7	17.11
17–18 p.m.	59.52	59.06	58.51	57.91	57.27	56.59	55.54	53.38	48.91	42.11	34.96	28.97	24.31	20.74	17.79	16.12
18–19 p.m.	59.67	59.35	59	58.62	58.2	57.78	57.14	55.59	51.35	43.65	35.04	28.17	23.3	20.01	17.40	15.91
19–20 p.m.	59.77	59.55	59.31	59.05	58.78	58.49	58.2	57.85	56.99	53.65	45.43	34.53	26.26	21.79	18.37	16.34
20–21 p.m.	59.82	59.65	59.46	59.26	59.05	58.84	58.62	58.39	58.15	57.77	55.98	49.27	37.48	28.67	22.29	18.19
21–22 p.m.	59.83	59.68	59.51	59.33	59.14	58.95	58.75	58.54	58.29	58.02	57.71	56.74	52.66	43.71	32.53	23.25
22–23 p.m.	59.86	59.74	59.6	59.46	59.31	59.16	59	58.82	58.61	58.39	58.18	57.92	57.33	54.59	46.24	32.38
23–12 mn.	59.9	59.81	59.71	59.6	59.49	59.38	59.27	59.14	58.99	58.83	58.68	58.52	58.33	57.79	55.68	45.68
Peak[b]	59.59	59.2	58.74	58.24	57.71	57.14	56.39	54.88	51.27	45.16	38.26	32.07	27.27	23.52	20.57	18.69
Off-peak[b]	59.74	59.5	59.21	58.92	58.6	58.27	57.92	57.56	57.12	56.38	54.57	50.31	43.23	36.4	30.20	25.44
Daily	59.68	59.37	59.02	58.64	58.23	57.8	57.28	56.43	54.58	51.24	46.62	41.11	35.3	30.31	25.95	22.71

[a]Free-flow speed of 60 mph assumed in simulation.
[b]Peak period (7:00–10:00 a.m.); off-peak period (4:00–7.00 p.m.)

Therefore,

annual weekday daily traffic (AWDT)

= (145,210)(1.0991) = 159,600 vehicles

per lane capacity = 1900 vphpl

two-directional hourly capacity of freeway = (1900)(6)

= 11,400 vehicles/h

Therefore, AWDT/C = 159,600/11,400 = 14. From Table 5.1, the average estimated speed during the morning and afternoon peak periods are 26.19 and 23.98 mph, respectively.

Step 6: Perform Field Measurements of Speed For the base or without-improvement case only, where the travel speed under the existing transportation situation is sought, travel speed can be measured in the field directly as an alternative to (or a way to confirm the results from) step 5. For this there are automated traffic monitoring devices that operate on the basis of laser, radar, infrared, and other technologies. Another way is to drive along with the traffic stream and record the speed of travel.

Step 7: Determine the Vehicular Travel Time before Intervention Given the simple relationship between travel speed, distance, and time of day, travel time can be found from the speeds estimated using the COMSIS Corporation speed look-up tables. An alternative approach to calculation of travel time is to use the Bureau of Public Roads function (BPR):

$$\text{travel time (in hours)} = t_0 \left[1 + \alpha \left(\frac{\text{traffic flow rate on the link (vphpl)}}{\text{capacity of the link (vphpl)}} \right)^n \right] \tag{5.1}$$

where

$$t_0 = \text{free-flow travel time} = \frac{\text{link distance (mi)}}{\text{free-flow speed (mph)}}$$

and α and n are constants.

Example 5.4 Determine the morning and afternoon peak-period travel times on the freeway section in Example 5.3.

SOLUTION The travel speeds during the morning and afternoon peak periods on the freeway were calculated to be 26.19 and 23.98 mph respectively. Therefore, the travel time can be calculated as

$$\text{morning travel time} = \frac{(6)(60)}{26.19} = 13.75\,\text{min}$$

$$\text{afternoon travel time} = \frac{(6)(60)}{23.98} = 15.0\,\text{min}$$

Example 5.5 In field studies the traffic flow rate on a four-lane 6-mile section of arterial was reported as 1300 vphpl during the morning peak period. Using the BPR function, determine the travel time on this link during the morning peak period. The capacity of the arterial is 1400 vphpl. Assume that $\alpha = 0.15$ and $n = 4$. The free-flow speed on the arterial is 40 mph.

SOLUTION Using Equation 5.1,

$$\begin{aligned}\text{travel time} &= \left(\frac{6}{40}\right)\left[1 + (0.15)\left(\frac{1300}{1400}\right)^4\right](60)\\ &= 10\,\text{min}\end{aligned}$$

For the purpose of planning future projects, link or corridor travel times can be obtained from the results of the traffic assignment phase of network-level planning. In cases where network-level assignment data are not available, travel times can be estimated by taking projected traffic volume and capacity as input.

Step 8: Perform Direct Field Measurements of Travel Time For the base case (and for existing transportation conditions in particular), an alternative to the determination of travel time in step 7 (or a way to confirm the results from that step) is to measure travel time directly from the field. For this, the analyst can drive along with the traffic stream and record the time spent on traveling between a specific origin–destination pair. In recent years, the use of license plate recognition, GPS, and other technologies has shown much promise in direct and accurate field measurement of travel time.

Step 9: Determine Occupancy Rates before Intervention This step is needed to convert travel time per vehicle to travel time per vehicle occupant. The vehicle occupancy rates for the base case and the alternative scenarios are generally not expected to differ significantly except in cases where the transportation intervention is related directly to vehicle occupancies, such as HOV or HOT system implementation and car pooling initiatives.

Step 10: Determine the Average Unit Travel Time without Intervention Unit in-vehicle travel time per traveler,

$$U_1 = \text{OCC} \times \text{TT}_\text{V}$$

where TT_V is the average vehicular operating travel time and OCC is the average vehicle occupancy.

In cases where the travel speeds of trucks and other commercial vehicles are significantly different from passenger vehicles, separate travel time estimates should be made for each vehicle class.

Step 11: Repeat Steps 1 to 10 for the Intervention Scenario Proposed All the steps in the shaded portion of the procedure (with the exception of the field measurements, steps 4, 6, and 8) are repeated for the alternative or intervention scenario. Because this scenario is only hypothetical, no field measurements can be undertaken. Analysts who wish to establish "field" measures of travel demand, travel speeds, or travel times for the intervention scenario (to confirm the values of these parameters) may use available transportation simulation models to accomplish that task.

Step 12: Calculate the Change in Travel Time Expected due to Intervention For most transportation interventions, it is the in-vehicle travel time that is reduced. In a few cases, however, such as the upgrading of freight transfer terminals, construction of additional transit terminals or bus stops, or an increase in transit service frequency, out-of-vehicle travel time is reduced. The change in travel time is given by the expression $U_1 - U_2$, where U_1 and U_2 are the unit travel times without and with the intervention, respectively.

Step 13: Calculate the Travel-Time User Benefits The user benefits of the intervention or improvement, in terms of travel time, are calculated as the change in consumer surplus: $0.5(U_1 - U_2)(V_1 + V_2)$, V_1 and V_2 are the number of trips (or demand) without and with intervention, respectively. In some cases, the intervention may lead to induced travel demand in the long term.

Step 14: Establish the Unit Value of Travel Time In this step, the value of travel time (expressed in terms of dollars/hour/person, for example) is established. This is arguably the most challenging and contentious aspect of travel-time impact analyses. Many transportation agencies have already established travel-time values that can be updated for use in travel-time impact evaluation. Such updating can be carried out using consumer price indices for automobile or transit users and the producer price index for commercial vehicles. Average values of travel time in the United States and other countries are given in Section 5.3.2 and Appendix A.5. The value of travel time varies from place to place and over the years (due to inflation). As such, the use of travel-time value should be carried out with due adjustments made for such considerations.

Example 5.6 In 2000, the value of 1 hour of travel time for automobile users was \$16.50. On the basis of CPI trends, determine the value of travel time in 2006.

SOLUTION From the trends in CPI for passenger transportation,

$$\begin{aligned} \text{VTT}_{2006} &= \text{VTT}_{2000} \times \frac{\text{CPI}_{2006}}{\text{CPI}_{2000}} = (\$16.50)\left(\frac{176.13}{151.58}\right) \\ &= \$19.17 \text{ per hour} \end{aligned}$$

In most countries, it is assumed that the value of time is directly proportional to income, and hence the attributed values of time should change over time in direct proportion to the change in income (typically represented by GDP per capita). Where travel-time values do not exist, the analyst may use one of several available methodologies to establish such values as discussed in Section 5.3.3.

Step 15: Calculate the Value of Travel-Time User Benefits This is the product of the unit value of travel time (dollars/hour/person) from step 14, and the number of hours represented by the user benefit (from step 13); that is, $0.5(U_1 - U_2)(V_1 + V_2)$(unit value of travel time).

Step 16: If Necessary, Repeat Steps 10 to 13 for Each Traveler Class, Clocking Status, and Vehicle Class Where the amount and value of travel time is the same for all travelers (or averaged across all travelers), this procedure is carried out only once. However, in cases where travelers and trips are segregated by an attribute such as vehicle class (truck vs. automobile), trip purpose (business vs. personal), type of work-related trip (off-the-clock vs. on-the-clock work), or time of day (peak vs. off-peak), the analysis may be repeated for each attribute and the results are summed up to yield the overall travel-time savings.

5.3 ISSUES RELATING TO TRAVEL-TIME VALUE ESTIMATION

5.3.1 Conceptual Basis of Time Valuation

In allocating time among activities, people implicitly trade off the extra consumption that work earns against the foregone leisure that would be required. There is also the possibility of spending extra money to save travel time and thereby augment the amount of time for working or leisure. This possibility arises in at least three contexts:

1. Choice between a fast and expensive mode or route and a cheaper and slower alternative
2. Choice between costly shortcut routes (often due to tolling) and a free but longer alternative
3. Choice between expensive activity or residences located near a workplace and cheaper activity or residences located far from the workplace

By analyzing the relative sensitivity of such choices to variations in money and time cost, the implicit value of the time of travelers can be estimated. This conceptual framework yields the following important insights into the nature of the value of travel-time savings (Gwilliam, 1997):

- Working time produces goods (which are a direct source of welfare) and therefore has a social value that is independent of the workers' preference values.
- Time vs. money trade-off preferences (and hence the value of travel time) vary from person to person. As such, from a practical viewpoint, some simplifying categorization is vital for travel-time valuation.
- The value of nonwork time could be considered as being equal to the wage rate only in hypothetical situations where persons freely choose how many hours to work and do not consider work to be onerous. As such, nonwork time can only be valued empirically.
- Activity and time are consumed jointly. As such, the value of a time saving is related to the value of its associated activity.
- The value of time savings is a ratio between the marginal utilities of time and money. As such, travel-time value depends on the tightness of the budget constraint (and consequently, income) and the time constraint (and consequently, socioeconomic background and other characteristics of the traveler).

5.3.2 Factors Affecting the Travel-Time Value

Several factors can influence the value of travel time, as shown in Table 5.2. The relative weight of each factor depends on the characteristics of the trip maker and trip, trip length, environmental and seasonal considerations, and mode of travel. Furthermore, given a particular mode of travel, the derived value of travel time depends on the type of approach or model used for the derivation.

Table 5.2 Factors Affecting Value and Amount of Travel Time

Factors Affecting Amount of Travel Time	Factors Affecting Value of Travel Time
How long does it take to travel?	*What is the dollar value of 1 hour of travel?*
Trip length	Mode and vehicle of travel
Vehicle speed	Trip phase (in-vehicle vs. out-of-vehicle)
Vehicle occupancy	Trip purpose and urgency
Other factors	Time of day, day of week, season of year
Weather	Trip location (local vs. intercity)
Security concerns	Traveler's socioeconomic background (age, wage, and occupation)
	Relationship between amount of time used for trip and time used for waiting
	Existing level of legal minimum wage
	Travel-time reduction vs. travel-time extension

(*a*) *Influence of Traveler Income* Travel-time values have often been estimated as proportions of either personal or household incomes. In general, higher-income travelers value their time more, but the increment in time value is proportionately lower than that of income. Values of time vary between regions within a country as a result of differences in wages and incomes. The evaluation of investments on the basis of travel-time values that reflect such income-related differences (particularly where the users do not pay directly for investment) is likely to yield a vicious cycle: high-income areas yield high project returns, which attract investment and increase income further, whereas the contrary is seen for low-income areas. To avoid this situation, national average wage rates for major categories of labor can be used, and national average income can be applied in the valuation of leisure-time savings, particularly where poverty alleviation or regional redistribution of income is a national objective (Gwilliam, 1997).

(*b*) *Other Traveler Characteristics* Travelers with higher amounts of free time, such as very young persons and retired elderly persons, are likely to have lower values of time.

(*c*) *Transportation Mode and Vehicle Type* For a given transportation mode, travel-time factors can play roles that vary from dominant to relatively minor, depending on the class, type, or size of the transportation vehicle. For example, for automobiles and buses, dominant factors include the number of occupants, occupant ages, wages and occupation, trip purpose and urgency, time of day, day of week, season of year, relationship between amount of time used for trip and time used for waiting, and existing legal minimum wage level. For commercial vehicles, dominant factors include trip purpose, crew wages, and period of travel.

(*d*) *Trip Status (On-the-Clock and Off-the-Clock)* On-the-clock travel time is associated with work travel, and has values that are based on costs to the employer such as wages and fringe benefits, costs related to vehicle productivity, inventory-carrying costs, and spoilage costs. Off-the-clock trips include trips for commuting to and from work, personal business, and leisure activity. Heavy trucks are assumed to be used only for work, so the value of time for their occupants is the on-the-clock value. Table 5.3 summarizes the estimates of cost components of the value of travel time by vehicle type based on FHWA's HERS software.

(*e*) *Trip Phase (In-Vehicle vs. Out-of-Vehicle)* The opportunity costs of the time spent inside the vehicle and that spent out of the vehicle may be same but the relative disutility between these two travel-time components may differ from each other. For example, waiting for a bus or train may be more unpleasant than riding in the bus or train, and trip-makers implicitly attach a higher value of travel time for waiting compared to actual traveling. The value of walking and waiting time can be two to three times greater than riding (in-vehicle) (Small, 1992). Recent European studies show that transfer time and waiting time values exceed those of in-vehicle times by a factor of 1.33 to 2, and Chilean studies indicate an even higher ratio. A World Bank publication recommends that where local evidence is unavailable, all "excess" (i.e., out-of-vehicle) travel time should be valued at a premium of 50% above that of in-vehicle travel time (Gwilliam, 1997).

Table 5.3 Distribution of Hourly Travel-Time Values by Vehicle Class (2005 Dollars)

	Vehicle Class						
Category	Small Automobile	Medium-sized Automobile	4-Tire Truck	6-Tire Truck	3- or 4-Axle Truck	4-Axle Combination Truck	5-Axle Combination Truck
Labor/fringe	$32.22	$32.22	$22.10	$26.84	$22.35	$26.92	$26.92
Vehicle productivity	$2.11	$2.48	$2.67	$3.77	$10.78	$9.10	$9.78
Inventory	$0.00	$0.00	$0.00	$0.00	$0.00	$2.02	$2.02
On-the-clock	$34.34	$34.70	$24.77	$30.61	$33.13	$38.04	$38.72
Off-the-clock	$17.54	$17.58	$18.50	$30.61	$33.14	$38.04	$38.73

Source: Updated from Forkenbrock and Weisbrod (2001).

(*f*) *Trip Purpose* *Work trips* have usually been valued on the assumption that the value to an employer of the working time of employees must, at the margin, be equal to the wage rate, bumped up by extra costs that are directly associated with employment of labor, such as health benefits, social security taxes, and costs of uniforms. In the United Kingdom, a "bumping-up factor" of approximately 0.33 is typically applied (Gwilliam, 1997). It may be argued that where high levels of unemployment exist, shadow prices below the wage rate could be used.

(*g*) *Trip Length and Size of Travel-Time Reduction* All other factors remaining the same, differences in trip length may lead to different values of travel time. A recent study (ECONorthwest and Parsons, 2002a) indicated that the value of travel time at peak periods was approximately 45 to 50% of the pretax hourly wage (except for trips of less than 1 mile in length). Time values were determined to range from 8% of the pretax wage rate for trips less than 1 mile, to 49% for trips between 11 and 25 miles, and thereafter dropped to 41%. Off-peak values had the same pattern but were considerably lower than the peak values (generally about two-thirds of the peak values). Also, the unit travel-time value for long trips (travel time exceeding 30 minutes) was 20% higher than that for short trips (travel time less than 20 minutes).

The unit time value for car trips over 50 km in length in Sweden was found to be more than twice that for shorter journeys. For non-car modes travel time value was about 20% higher for long than for short trips. Studies in the UK and the Netherlands showed similar effects, particularly for business travelers. Also, it was determined that the unit value of time was higher when the time savings constituted a larger proportion of the base trip time. The UK and Dutch studies showed very small or zero unit time values for very small time savings (<5 minutes) and indicated greater unit values for time losses compared to time savings (Gwilliam, 1997).

(*h*) *Direction of Travel-Time Change (Increase vs. Reduction)* In cases where there is a change in travel time, the value of travel time can also depend on whether the change is favorable (i.e., decreased travel time due to improved conditions) or whether it is adverse (i.e., increased travel time due to worsened travel conditions). In other words, all other factors remaining the same, the value attached to each hour of reduced travel time may be different from that attached to each hour of increased travel time.

(*i*) *Trip Mode* Some trips (such as park-and-ride trips to work) involve more than one mode. In such cases, the separate effects of changes in aggregate travel times should be identified. Also, empirical evidence suggests that slower modes generally attract low-income travelers who have lower values of time; while faster modes attract travelers with higher incomes and thus higher values of travel time. For example, in-vehicle travel-time values (corrected for income and other factors) were found to be highest for high-speed rail followed by air, car, intercity train, regular train, long-distance bus, and local bus, in that order (VTPI, 2005). Therefore, it has been argued that the time savings for individuals attracted to an improved mode should be valued at the rate appropriate to the mode from which they are transferring.

Travel conditions (which typically are a function of the time of day) significantly influence the value of travel time. Table 5.4 presents the results of a study that investigated travel-time values at Boston and Portland on the basis of transportation mode and time of day. Estimated travel-time costs per passenger mile for peak period and off-peak period travel in areas of high,

Table 5.4 Travel-Time Values in Two Cities (Cents per Passenger-Mile)

City	Urban Density	Expressway		Non-expressway		Commuter Rail		Rail Transit		Bus		Bicycle		Walk	
		Peak	Off-Peak	Peak	Off-Peak	Peak	Off-Peak	Peak	Off-Peak	Peak	Off-Peak	Peak	Off-Peak	Peak	Off-Peak
Boston	High	24.3	9.6	40.4	23.9	28.9	22.7	40.1	28.6	50.5	39.8	60.6	47.8	243	159
	Medium	15.2	8.0	24.3	15.9	19.8	14.0	28.1	25.3	50.5	39.8	60.6	47.8	202	159
	Low	11.0	8.0	20.2	13.6	19.0	13.3	n/a	n/a	50.5	39.8	60.6	47.8	202	159
Portland, ME	High	11.1	7.8	19.9	13.1	n/a	n/a	n/a	n/a	42.6	33.5	49.8	39.2	166	131
	Medium	10.0	7.1	16.6	11.2	n/a	n/a	n/a	n/a	42.6	33.5	49.8	39.2	166	131
	Low	7.7	6.0	12.4	9.8	n/a	n/a	n/a	n/a	30.2	23.8	49.8	39.2	166	131

Source: VTPI (2005).

medium, and low urban densities are presented. It is clear that the value of travel time (cents per passenger-mile) in congested conditions exceeds that of uncongested conditions, irrespective of travel mode.

5.3.3 Methods for Valuation of Travel Time

Valuation of travel time is typically carried out by comparing travel between two alternative routes or modes, or comparing travel to another economic activity that could have taken place during the travel period. The value of travel time can be found by using the wage rate, revealed preference, or stated preference methods. The basic concept underlying each of these methods can best be explained using time-cost exchange plots.

(*a*) *Exchange Plot* This involves solicitation of choice preferences of travelers and can be used to explain the behavioral response to travel options varying in terms of time and cost (Hensher and Button, 2000). In this method, the willingness-to-pay concept is considered to be restricted to those who are in a position, and are willing, to trade-off a disadvantage in one attribute to gain an advantage in another. Such persons are referred to as *traders* or *exchangers*. Using this method, the exchange preferences of each person in a group of travelers faced with a choice between two travel options can be obtained. Their respective trade-off values can be plotted on a two-dimensional graph whose axes represent time and cost attributes. Consider two travel options for each traveler such that:

$$\Delta C = \text{cost of option not chosen} - \text{cost of option chosen.}$$

$$\Delta t = \text{time for option not chosen} - \text{time for option chosen.}$$

$\Delta C > 0$: this indicates that the cost of the chosen option is lower and therefore the traveler is a *cost saver*.

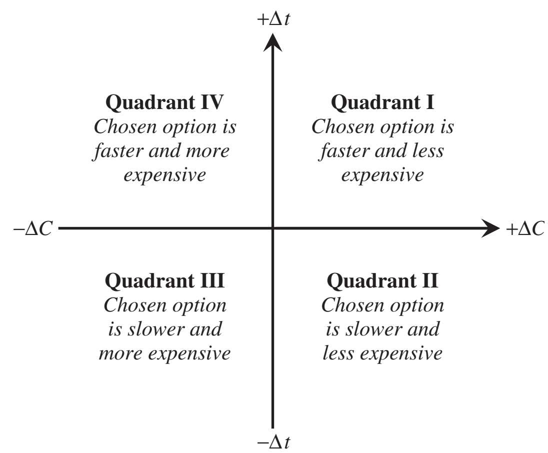

Figure 5.4 Exchange plot for an individual traveler.

$\Delta t > 0$: this indicates that the travel time for the chosen option is less and therefore the traveler is *time saver*. Depending on the sign of ΔC and Δt, an individual traveler can be in one of the four quadrants shown in Figure 5.4.

- *Quadrant I:* these persons are not exchangers.
- *Quadrant II:* persons who opt to save cost and spend time, hence $+\Delta C$ and $-\Delta t$. These people are exchangers and cost-savers.
- *Quadrant III:* these persons are not exchangers.
- *Quadrant IV:* persons who opt to spend money and save time, hence $-\Delta C$ and $+\Delta t$. These people are exchangers and time-savers.

Exchange plots consider only those people who are faced with a choice situation (i.e., those falling within quadrants II and IV), and involve the following steps:

1. Conduct a survey of travelers by asking how much money they are prepared to pay to gain a certain

amount of time, or how much time they are willing to forego to save a specified amount of money.
2. Plot the trade-off points for various people on an exchange graph.
3. Draw a line through the origin, passing through the two exchange quadrants such that a minimum number of people are misclassified. This can be achieved by making sure that a minimum number of points lie below the line. The line is referred to as the *joint minimum classification* (JMC) *line*.
4. Find the gradient of the JMC line.
5. Compute the reciprocal of the gradient. This is equal to the value of travel time.

Issues associated with exchange plots are as follows:

- 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 by manual counting and positioning.
- In this approach, socioeconomic characteristics and other attributes can be considered. Using income levels, for instance, a given sample population can be stratified by income groups, with 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.

Exchange plots offer a direct means to explaining the concept of travel-time valuation without resorting to statistical details. When multiple options are involved, this approach is described as *score maximization* to determine the value of travel time (Manski, 1975). The line with the least number of misclassifications provides the maximum score.

Example 5.7 In 2006, a time–cost trade-off survey was conducted among 10 randomly selected commuters along a transportation corridor. People were asked to choose between two alternatives in terms of travel time and cost. Their responses are presented in Table E5.7. Use the exchange plot method to estimate the value of travel time.

SOLUTION The stated preference data obtained from the survey were used to tabulate Table E5.7. ΔT and ΔC were used to plot the exchange graph shown in Figure E5.7. The JMC line was plotted manually such that the minimum number of people were misclassified and its gradient was calculated as $[15 - (-14)/60]/[2.5 - (-2.5)] = 29/300$. Therefore, the value of travel time = \$10.34/person-hour.

(*b*) *Wage Rate Method* The wage rate method is the simplest and the most commonly used method to estimate the value of travel time (Forkenbrock and Weisbrod, 2001). In this method, two types of travel time need to be considered: on- and off-the-clock travel time.

Valuation of On-the-Clock Travel Time: Generally, the value of travel time during working periods is

Table E5.7 Travel-Time and Cost Trade-offs

	Time (min)		Cost (dollars)			
Commuter	For the Option Not Chosen (I)	For the Chosen Option II	For the Option Not Chosen (I)	For the Chosen Option II	ΔT (I-II)	ΔC (I-II)
1	68	65	0.65	1.10	3	−0.45
2	45	49	1.36	0.78	−4	0.58
3	57	47	0.42	2.14	10	−1.72
4	55	63	1.73	0.43	−8	1.3
5	55	43	0.89	2.8	12	−1.91
6	56	43	0.90	2.87	13	−1.97
7	58	64	1.83	0.55	−6	1.28
8	53	44	0.80	2.50	9	−1.7
9	50	62	2.44	0.53	−12	1.91
10	56	63	2.45	0.76	−7	1.69

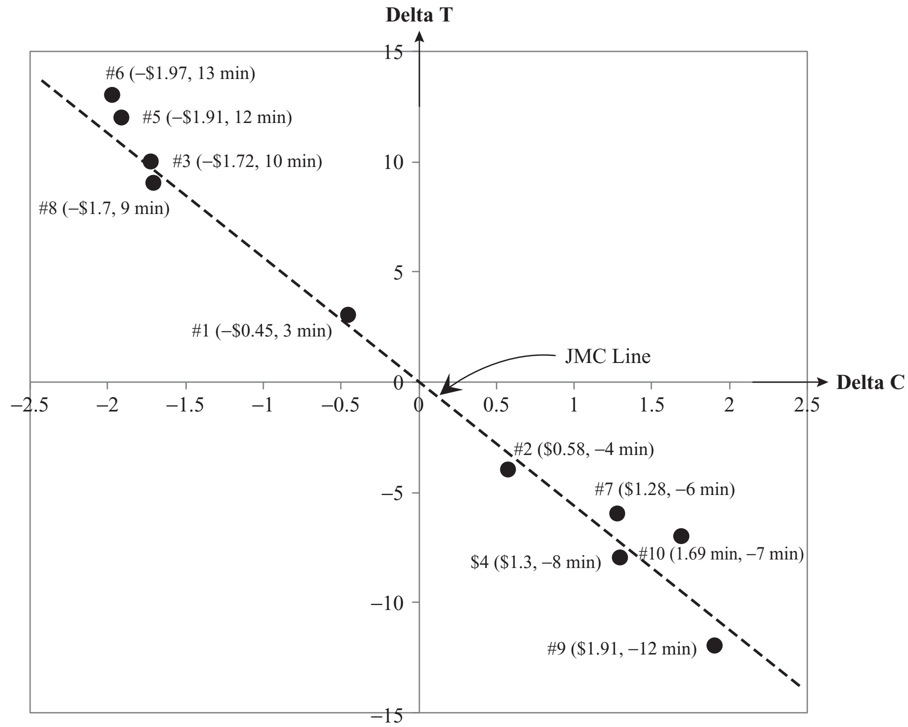

Figure E5.7 Exchange plot graph.

considered equal to the wage rate plus concomitant costs of transportation operations. Particularly, for commercial vehicles, reduced travel time can mean:

- Fewer vehicles are required to haul a given quantity of goods in the same time interval, translating into reduced investment per given output.
- A given vehicle can 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 lower.
- Wages are lower for the output achieved.

Examples of on-the-clock travel include technical personnel on their way from office or workshop to attend to a problem or assignment elsewhere, taxi drivers on their usual duty rounds, and roving sales persons, postal and Fedex/UPS delivery workers, and other personnel who advertise, market, or deliver goods and services by moving from one place to another. This includes commercial and industrial haulage.

Work-based travel time may be calculated on the basis of wage rates as follows: Let the wage rate per hour $= w$ (dollars/h), the adjustment for worker benefits $= a$ (dollars/h), and the value of extra goods and services produced in time interval t (hours) $= v_g$. Then the value of travel time (dollars/h) $= w + a + v_g/t$.

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 automatically be switched from one task to another. Furthermore, in the case of haulage operations, the maximum use to which travel-time savings may be put depends on the type and size of the crew. Table 5.5 presents the unit work travel-time values as a percentage of wage rate, for various modes.

Valuation of Off-the-Clock Travel Time: HERS considers the value of off-the-clock (nonwork) travel time for drivers as approximately 60% of the wage rate exclusive of benefits, and the value of time for passengers as 45% of the wage rate. Table 5.6 shows the recommended in-vehicle nonwork travel time values as a percentage of the wage rate for various modes of travel. The percentages presented for surface modes apply to all combinations of in- and out-of-vehicle times. The walk access, waiting, and transfer times are valued at 100% of the wage rate.

Table 5.5 Unit Work Travel-Time Values as a Percentage of Wage Rate

	Surface Modes[a]	Air Travel[a]	Truck Drivers
Local travel	100 (80–120)	NA	100
Intercity travel	100 (80–120)	100 (80–120)	100

Source: ECONorthwest and Parsons (2002).
[a] Values in parentheses indicate range. NA, not applicable.

Table 5.6 Unit Nonwork Travel-Time Values as a Percentage of Wage Rate

	Surface Modes[a]	Air Travel[a]	Truck Drivers
Local travel	50 (35–60)	NA	NA
Intercity travel	70 (60–90)	70 (60–90)	NA

Source: ECONorthwest and Parsons (2002).
[a] Values in parentheses indicate range. NA, not applicable.

Table 5.7 Values of Travel Time for Personal and Business Travel

Trip Purpose	Trip Phase	Trip Location	Value of Travel Time (dollars/hour per person)
Personal	In-vehicle	Local	50% of wages
		Intercity	70% of wages
	Out-of-vehicle (waiting, walking, or transfer time)	All locations	100% of wages
Business	In-vehicle	All locations	100% of total compensation
	Out-of-vehicle (waiting, walking, or transfer time)	All locations	100% of total compensation

Source: ECONorthwest and Parsons (2002).

Table 5.7 presents in- and out-of-vehicle travel-time values as a percentage of the wage rate for various modes of travel applicable to both on- and off-the-clock times. According to a World Bank study (Gwilliam, 1997), where it is not possible to derive local values, travel-time values can be estimated using prevailing wage rate and average household income, as shown in Table 5.8.

Example 5.8 It is sought to determine the values of on-the-clock travel time on the basis of the following wage information: hourly wages are \$16.25, \$12.16, and \$16.38 for the users of automobiles, light-duty trucks, and heavy-duty trucks, respectively. Also, the value of fringe benefits (per hour) are \$6.44, \$6.76, and \$9.11, respectively, for the users of these vehicle classes. The average automobile occupancies for on- and off-the-clock trips are 1.22 and 1.58, respectively. The corresponding average vehicle occupancies for light-duty trucks are 1.03 and 1.18, respectively. The average vehicle occupancy for heavy-duty trucks is 1.04. Assume that the heavy-duty trucks are operated only during working hours. Assume that 10% of all automobile trips and 70% of all light-duty truck trips are made during working hours. These trips include the trips made by rental vehicles and those of automobile trips that are used entirely for work-related travel. The freight inventory value (the time value of the average payload, i.e., the interest cost per hour of the cargo) for heavy-duty trucks is \$1.88. Assume that the freight inventory values for light-duty trucks and automobiles are negligible. Determine the value of travel time for personal and work travel.

Table 5.8 Values of Travel Time Based on Wage Rate and Income

Trip Purpose	Rule	Value[a]
Work trip	Cost to employer	$1.33W$
Business	Cost to employer	$1.33W$
Commuting and other nonwork	Empirically observed value	$0.3H$ (for adults), $0.15H$ (for children)
Walking or waiting	Empirically observed value	1.5 × value for trip purpose
Freight or public transport	Resource cost approach	Vehicle time cost + driver wage cost + occupants' time

Source: Gwilliam (1997).
[a] W, wage rate per hour; H, household income per hour.

SOLUTION (1) *Computation of the cost of employees per vehicle to employers for 1 hour of travel time* The cost is computed by multiplying the total compensation of each employee by the average vehicle occupancy of the vehicle:

$$\text{total compensation (dollars/hr)} = \text{wage} + \text{fringe benefits}$$

For automobiles:

$$\text{cost} = \$(16.25 + 6.44)(1.22) = \$27.68/\text{h}$$

For light-duty trucks:

$$\text{cost} = \$(12.16 + 6.76)(1.03) = \$19.49/\text{h}$$

For heavy-duty trucks:

$$\text{cost} = \$(16.38 + 9.11)(1.04) = \$26.51/\text{h}$$

(2) *Computation of the total on-the-clock travel-time value* This is computed as the sum of the travel-time cost of employees per vehicle to employers and the freight inventory value for the respective vehicle type. The cost of vehicle productivity for each mode is assumed negligible for this case. Table E5.8.1 shows calculated total on-the-clock travel-time values.

(3) *Computation of the weighted average travel-time value for on-the-clock trips based on miles traveled by each mode during working hours*

$$\text{Weighted travel-time value for automobiles during working hours} = (\$27.68)(0.1) = \$2.77/\text{h}$$

$$\text{Weighted travel-time value for light-duty trucks during working hours} = (\$19.49)(0.7) = \$13.64/\text{h}$$

$$\text{Weighted value of travel time for heavy-duty trucks during working hours} = (\$28.39)(1.0) = \$28.39/\text{h}$$

(4) *Total off-the-clock travel-time value* This is computed as a percentage fraction of wage rates excluding the benefits. It is assumed that heavy-duty trucks do not operate off-the-clock.

For automobiles:

$$\text{Value of driver's travel time} = 60\%\text{of wage rate} = (\$16.25)(0.6)(1) = \$9.75/\text{h(one driver)}$$

$$\text{Value of passenger's travel time} = 45\% \text{ of wage rate} = (\$16.25)(0.45)(0.58)(\text{Occupancy} = 1.58) = \$4.24/\text{h}$$

Table E5.8.1 Computation of Total On-the-Clock Travel-Time Value (2005 Dollars) for Example 5.8

	Automobiles	Light Trucks	Heavy Trucks
Average vehicle occupancy	1.22	1.03	1.04
Cost of employees	\$27.68	\$19.49	\$26.51
Freight inventory value (per hour)	0.00	0.00	1.88
Total on-the-clock travel-time value	27.68	19.49	28.39

Hence, the total travel time value for automobiles = \$9.75 + \$4.24 = \$13.99/h.

For light-duty trucks:

Value of driver's travel time = 60% of wage rate
= (\$12.16)(0.6)(1) = \$7.30/h(one driver)

Value of passenger's travel time = 45% of wage rate
= (\$12.16)(0.45)(0.18)(Occupancy = 1.18)
= \$0.98/h

Hence, the total travel-time value for light-duty trucks = \$7.30 + \$0.98 = \$8.28/h.

(5) *Computation of the weighted off-the-clock travel-time value based on miles traveled by automobiles and light-duty trucks during off-the clock hours.*

Weighted off-the-clock travel-time value for automobiles = (\$13.99)(1 − 0.1) = \$12.59/h

Weighted off-the-clock travel-time value for light-duty trucks = (\$8.28)(1 − 0.7) = \$2.48/h

The total weighted average travel time value for each mode is computed by adding the weighted on-the-clock [from Step (3)] and off-the-clock [from Step (5)] travel time values as shown in Table E5.8.2.

The unit travel-time values computed in this example can vary with several other factors (e.g., trip length, income level, traffic density, peak/off-peak hours), as discussed earlier in this chapter.

(*c*) *Revealed Preference Approach (RPA)* In the RPA approach of travel time valuation, actual decisions of travelers regarding the choice of transportation options that differ by travel time and/or travel cost are modeled. Such options could relate to mode choice (fast but costly mode vs. slow but inexpensive mode) or route choice (fast but costly toll route vs. slow but free route).

The underlying principle is that weights (which reflect relative importance) are assigned by travelers to cost and time used for any particular route or mode; the ratio of these weights is a measure of their travel-time value. The proportion of travelers choosing any one of the two alternatives must be known before the ratio can be computed. For two modes or route alternatives m and n, the proportion of travelers that choose a particular alternative m is given as

$$P_m = \frac{e^{U_m}}{e^{U_n} + e^{U_m}} = \frac{1}{1 + e^{U_n - U_m}} \tag{5.2}$$

where

$$U_k = \text{satisfaction or utility associated with a particular alternative } k$$
$$= \alpha_0 + \sum \alpha_i Z_{ik} \tag{5.3}$$

Z_{ik} is the ith characteristic or service attribute of alternative k (e.g., cost, time, comfort, convenience), and α_0, α_i are coefficients obtained from the revealed behavior of users.

The simplest form of the utility function is when the travel time (t) and travel cost (c) are the only service attributes considered.

$$U_n - U_m = \Delta\alpha_0 + \alpha_1(t_n - t_m) + \alpha_2(C_n - C_m) \tag{5.4}$$

However, equation (5.4) can account for the circumstances in which the time is spent by including other variables, such as the expected number of crashes and number of speed changes.

Example 5.9 In this example, the two alternatives are a toll route and a non-toll route (free route) from which the traveler must choose. Attributes for each alternative are travel time, out-of-pocket costs (toll and fuel consumption), speed changes (SC) and crash costs (CC). The input data structure for the analysis is shown in Table E5.9 Show how the value of travel time can be estimated.

Table E5.8.2 Weighted Travel-Time Values by Vehicle Class (Dollars/Hour) for Example 5.8

	Automobiles	Light-Duty Trucks	Heavy-Duty Trucks
On-the-clock trips	\$2.77	\$13.64	\$28.39
Off-the-clock trips	12.60	2.48	0.00
Total weighted average	15.37	16.12	28.39

Table E5.9 Input Data Structure for Toll Route vs. Free Route Example

	Travel Time	Toll	Fuel Cost	Crash Cost	Number of Speed-Cycle Changes	Total Out of Pocket Costs	Percentage of Road Users
Alternative 1 (toll route)	T_{toll}	F_{toll}	$Fuel_{toll}$	CC_{toll}	SC_{toll}	$C_{toll} = F_{toll} + Fuel_{toll}$	P_{toll}
Alternative 2 (free route)	T_{free}	$F_{free} = 0$	$Fuel_{free}$	CC_{free}	SC_{free}	$C_{free} = Fuel_{free}$	$1 - P_{toll} = P_{free}$
	ΔT	ΔF	ΔFuel	ΔCC	ΔSC	ΔC	

Table E5.10 Values for Dependent and Independent Variables Used in Calibration

Sample	P_{toll}	ΔSC (No. of Speed Cycle Changes) (Free−Toll)	ΔT (min) (Free−Toll)	ΔC (Free−Toll)	$\text{Log}_e \dfrac{1 - P_{toll}}{P_{toll}}$
1	0.26	7	15.23	−0.52	1.05
2	0.32	9	13.59	−0.22	0.75
3	0.29	14	12.55	−0.77	0.90
4	0.30	5	19.83	−0.58	0.85
5	0.26	7	15.85	−0.60	1.05
6	0.34	10	19.24	−0.47	0.66
7	0.24	6	16.21	−0.57	1.15
8	0.27	11	13.67	−1.37	0.99
9	0.28	5	18.01	0	0.94
10	0.26	3	19.19	−1.16	1.05

SOLUTION The differences in utility between the toll and free route can be expressed as follows:

$$\begin{aligned} U_{free} - U_{toll} &= (\alpha_{0\ free} - \alpha_{0\ toll}) + \alpha_1(T_{free} - T_{toll}) \\ &\quad + \alpha_2(C_{free} - C_{toll}) + \alpha_3(CC_{free} - CC_{toll}) \\ &\quad + \alpha_4(SC_{free} - SC_{toll}) \end{aligned}$$

$$P_{toll} = \frac{1}{1 + e^{U_{free} - U_{toll}}}$$

$$U_{free} - U_{toll} = \log_e \frac{1 - P_{toll}}{P_{toll}}$$

$$\begin{aligned} \log_e \frac{1 - P_{toll}}{P_{toll}} &= (\alpha_{0\ free} - \alpha_{0\ toll}) + \alpha_1\ \Delta T + \alpha_2\ \Delta C \\ &\quad + \alpha_3\ \Delta CC + \alpha_4\ \Delta SC \end{aligned} \qquad (E5.9)$$

The value of travel time is given by the ratio of the time and cost coefficients, α_1/α_2. The model can also include terms relating to comfort, scenic appeal, and other factors that affect the driving environment.

Example 5.10 Travel choice behavior was observed along 10 locations over a given period during morning peak hours, where commuters had to choose between a toll road and a free road. The differences between trip costs, travel times, and speed-cycle changes are given in Table E5.10 for all the locations. The fraction of commuters choosing the toll road over the free road is also given. Determine the travel-time value (TTV) per vehicle and per person assuming average vehicle occupancy of 1.15.

SOLUTION The model given in equation (E5.9) can be calibrated using the data.

$$\begin{aligned} \log_e \frac{1 - P_{toll}}{P_{toll}} &= (\alpha_{0\ free} - \alpha_{0\ toll}) \\ &\quad + \alpha_1 \Delta T + \alpha_2 \Delta C + \alpha_3 \Delta SC \end{aligned}$$

It is assumed that the crash cost is the same on both the routes and is not a consideration in the decision-making process.

The calibrated model using linear regression is as follows:

$$\log_e \frac{1 - P_{\text{toll}}}{P_{\text{toll}}} = \underset{(4.650)}{(1.97)} - \underset{(-2.353)}{(0.04656)}\ \Delta T - \underset{(-1.590)}{(0.146)}\ \Delta C - \underset{(-2.986)}{(0.047)}\ \Delta \text{SC}$$

$$R^2 = 0.648$$

The numbers in parentheses (t-statistics) indicate that all the variables are significant. Therefore,

$$\text{TTV(per vehicle)} = \frac{\alpha_1}{\alpha_2} = \left(\frac{-0.04656}{-0.146}\right)(60) = \$19.12/\text{vehicle-h}$$

$$\text{TTV(per person)} = \frac{\$19.12}{1.15} = \$16.63/\text{person-h}$$

(*d*) *Stated Preference Approach* (SPA) SPA involves a willingness-to-pay (WTP) survey of individual travelers (by polling or using questionnaires), presenting a series of hypothetical choices closely related to their current modes of travel through repetitive questioning. The change in cost of their present mode or route that would be just sufficient to cause them to switch to the another mode or route can be determined. Such a cost can be termed *switching threshold*.

At relatively little cost and on the basis of a single experiment, SPA can be used in a wide range of contexts offering alternatives designed to give numerous credible trade-off possibilities.

For any two routes or modal alternatives, A and B, the binary logit model can be represented by

$$P_B = \frac{1}{1 + e^{U_A - U_B}} \tag{5.5}$$

where

$$U_A - U_B = \beta_0 + \beta_1(t_A - t_B) + \beta_2(C_A - C_B + \text{ST}_B) + \beta_3(\text{CC}_A - \text{CC}_B) \tag{5.6}$$

Here ST_B is the switching threshold for alternative B, t_A and C_A are the time and cost associated with alternative A, and t_B and C_B are the time and cost associated with alternative B.

CC_A, CC_B = Crash cost associated with A and B, respectively.

By including the switching threshold ST_B in the utility function, the traveler is made indifferent to any specific route or mode choice. The point of indifference (which represents a 50–50 chance of either option being chosen) occurs when $U_A - U_B = 0$. Hence, equation (5.6) can be rewritten as

$$(C_A - C_B + ST_B) = \lambda_0 + \lambda_1(t_A - t_B) + \lambda_2(\text{CC}_A - \text{CC}_B) \tag{5.7}$$

The value of travel time is given by the coefficient λ_1.

There may be some difficulty in measuring the switching threshold. Some travelers may not be able to envision and properly weigh the options and reliably define what their indifference threshold would be unless they actually experience it. It may be assumed that underestimates and overestimates given by individuals cancel out to produce a reasonably accurate average value of travel time.

Example 5.11 Two travel alternatives are available to commuters traveling between the downtown and suburbs of Metropolis city: rapid rail transit (RRT) and a slower but less expensive surface bus transit (SBT). In a survey, ten SBT users were asked to indicate the amount of money (between zero and five dollars, that would have to be paid to them in order for them to consider RRT as equally attractive as SBT (in other words, the travelers were asked to indicate their switching thresholds). The switching thresholds, and the travel time and cost differentials, are given in Table E5.11. Calculate travel-time value. Assume all other attributes are the same for the two modes.

SOLUTION Using the Logit Model,

$$P_{\text{RRT}} = \frac{1}{1 + e^{U_{\text{SBT}} - U_{\text{RRT}}}}$$

where P_{RRT} is the probability that an individual travels using RRT and U is the utility attached by an individual to his or her travel choice. The expression can be rewritten as

$$\frac{1 - P_{\text{RRT}}}{P_{\text{RRT}}} = e^{U_{\text{SBT}} - U_{\text{RRT}}}$$

$$\log_e\left(\frac{1 - P_{\text{RRT}}}{P_{\text{RRT}}}\right) = U_{\text{SBT}} - U_{\text{RRT}}$$

When a traveler considers both modes to be equally attractive, $P_{\text{SBT}} = P_{\text{RRT}} = 0.5$. Hence,

$$\log_e\left(\frac{1 - 0.5}{0.5}\right) = U_{\text{SBT}} - U_{\text{RRT}}$$

$$0 = \beta_0 + \beta_1(T_{\text{SBT}} - T_{\text{RRT}}) + \beta_2[C_{\text{SBT}} - (C_{\text{RRT}} - \text{ST}_{\text{RRT}})]$$

$$C_{\text{SBT}} - (C_{\text{RRT}} - \text{ST}_{\text{RRT}}) = \lambda_0 + \lambda_1(T_{\text{SBT}} - T_{\text{RRT}})$$

$$\Delta C + ST_{\text{RRT}} = \lambda_0 + \lambda_1 \Delta T \tag{5.8}$$

Table E5.11 Time and Cost Data for Model Calibration and Switching Threshold Values

Individual	ΔT (mins/trip) ($\text{TIME}_{\text{SBT}} - \text{TIME}_{\text{RRT}}$)	ΔC (\$/trip) ($\text{COST}_{\text{SBT}} - \text{COST}_{\text{RRT}}$)	ST_{RRT} (\$/trip)	$\Delta C + \text{ST}_{\text{RRT}}$ (\$/trip)
1	3.00	−$2.00	1.00	−1.00
2	8.00	−$3.50	1.50	−2.00
3	6.50	−$3.50	1.75	−1.75
4	5.50	−$2.50	1.00	−1.50
5	4.00	−$2.50	1.50	−1.00
6	7.00	−$5.00	2.75	−2.25
7	5.00	−$4.00	2.75	−1.25
8	1.50	−$3.00	2.25	−0.75
9	7.00	−$4.00	2.00	−2.00
10	8.50	−$5.50	3.00	−2.50

where T_i and C_i represent the travel time and cost associated with mode i. The variable ΔT indicates the additional time taken by "default" alternative (in this case, the surface bus transit) compared to other alternative (in this case, rapid rail transit) for each trip. For each traveler, the variable ΔC represents the additional travel cost of the default alternative relative to the other alternative, and ST_{RRT} represents the traveler's threshold cost value for switching from the default alternative (surface bus transit) to the other alternative (rapid rail). The data for travel time and cost for the two modes and switching threshold values are provided in Table E5.11.

Using any standard statistical software, the regression model shown in Equation 5.8 can be calibrated as follows:

$$\Delta C + \text{ST}_{\text{RRT}} = \underset{(1.14)}{0.194} - \underset{(-8.93)}{(0.251)(\Delta T)} \qquad R^2 = 0.91$$

The values in parentheses are the t-statistics of the coefficients. The value of the travel time (per person-hr) TTV can be calculated using the coefficient of ΔT:

$$\text{TTV} = (0.251)(60) = \$15.07/\text{person-hour}$$

The use of logit models to estimate the travel-time value can be generalized further by allowing the parameters in the utility model to vary in the population to account for random taste heterogeneity (Hess et al., 2004). The estimated travel-time value using logit models is sensitive to the model specification. Algers et al. (1998) found that the travel-time value obtained from ordinary logit model specification with fixed model parameters as used here was significantly lower than the value estimated from mixed logit model specification when the coefficients were assumed to be normally distributed in the population.

5.4 CONCLUDING REMARKS

With increased globalization, specialization, and transportation seamlessness, it is expected that travel time, as an evaluation criterion, will play an increasingly important role. As noted in a recent publication by the United Nations (UNESC, 2004), the time costs of international trade have become more important than the resource costs of transportation as evidenced by the strong shift to freight air transport even though air transportation costs, at about 25% of the product value, exceed surface transportation costs. A major reason for this development is the shortening of product cycles. These developments concern not only relatively small high-tech sectors but also labor-intensive sectors, such as the clothing industry. As such, proximity to major market areas seems to be an increasingly important determinant for the location of industries relative to the real wage costs at different locations. The increased importance of transportation times for international and interregional trade indicates the challenge for transport policy to react to, anticipate, and support these developments.

SUMMARY

Transportation provides a means for people and goods to move from one point to another, and travel time is a major resource that is spent in achieving this goal. Transportation system interventions are generally expected to result in increased travel speed (and consequently, reduced travel time). When the trip is made in less time than before, the reduction in time, considered as "saved" time, is used to perform another activity. On the basis of travel time and cost trade-offs, the value of travel time can be estimated and the time-reduction benefits of transportation interventions can be determined. There are countless vital public and private transportation projects of various modes where travel-time savings constitute a large fraction of economic benefits.

In estimating overall travel-time costs or benefits, two important elements are the amount of travel time and the unit value of the travel time. Travel time can be categorized on various bases including trip phase, flow entity, and clocking status. The overall framework for assessing travel-time impacts involves consideration of a base-case scenario and the improvement scenario. The steps involve establishment of the base year; estimation of the demand and capacity of the transportation system with and without intervention; determination of travel speeds and times; field measurements to determine (or confirm) travel demand, speeds, and times; determination of vehicle occupancy rates with/without intervention; calculation of savings (or increase) in travel-time amounts due to the intervention; establishing the unit value of travel time; and calculating the overall cost savings (or increase) in travel-time costs for all traveler classes, clocking status, and vehicle classes.

Behavior exhibited by travelers that enable travel-time valuation are typically in the context of choice between fast and expensive modes or routes and cheaper, slower alternatives, and choice between costly activity or residences located near a workplace and cheaper activity or residences located far from the workplace. By analyzing the relative sensitivity of such choices to variations in time and cost, the implicit value of travel time of travelers can be identified. The valuation of travel time is considered a challenging task and may show some inconsistencies due to reasons such as difficulty in isolating the relationship between travel-time value and travel characteristics, costliness of data collection, differences between perceived travel costs and actual travel costs, and lack of a consistent explanation of consumer behavior in situations where consumption activities involve the expenditure of time as well as money.

The use of travel time as a transportation investment performance measure (and consequently, as a criterion for impact evaluation) is widespread. In some countries, lack of local information on the value to time savings has led to the exclusion of travel-time savings in economic evaluation.

EXERCISES

5.1. The AADT on a 4-mile stretch of I-70 in Marion County in 2005 was reported as 160,500. The capacity on the eight-lane freeway is 1750 vehicles per hour per lane. Plot the hourly travel time profile for the freeway using the speed look-up table developed by COMSIS Corporation (Table 5.1). Use a conversion factor of 1.12 for converting the AADT to AWDT. A reconstruction project increases the number of lanes on the freeway to 10 and the capacity to 1900 vehicles per hour per lane. Calculate the travel-time savings in the morning peak period between 8:00 and 9:00 a.m. of the opening year (2010). The value of travel time is $14.50 per person per hour in the current year (2005). The CPI index for 2005 is 160.40 and for 2010 is 190.85. Assume that the average vehicle occupancy is 1.07 and that there are 250 working days in the opening year.

5.2. Prove that the value of travel time is given by the ratio of coefficient of travel time and cost in the route choice utility model. Assume that the utility model includes only these two route-specific

Table EX5.3 Input Data for Wage Rate Based Approach

	Trip Purpose	Vehicle Hours Saved	Percent Miles Traveled	Unit Travel-Time (dollars) Value	Average Vehicle Occupancy
Local auto	On-the-clock	300	10		1.22
	Off-the-clock		90		1.58
Intercity auto	On-the-clock	150	15		1.12
	Off-the-clock		85		1.62
Light trucks	On-the-clock	60	100	19.49	1.03
Heavy trucks	On-the-clock	80	100	30.43	1.00

Table EX5.4 Travel Time and Cost Data for Exchange Plot Approach

$T_{toll} - T_{free}$ (min)	4	−6	12	−10	−5	−8	12	10	−5	11
$C_{toll} - C_{free}$ ($)	−0.5	1.75	−1.75	2	1.5	1	−2.25	−2	1.8	−1.85

Table EX5.5 Data for Binary Logit Model to Estimate Travel-Time Value

Location	Fraction Choosing Route B	Travel Time (min)		Travel Cost (dollars)		No. of Speed Changes	
		A	B	A	B	A	B
1	0.68	13.47	31.51	2.35	1.47	12	22
2	0.72	18.06	32.10	2.36	1.80	10	20
3	0.69	18.34	30.86	2.76	1.69	11	27
4	0.69	16.04	33.76	2.72	1.68	15	23
5	0.74	19.09	31.18	2.81	1.73	14	26
6	0.68	18.09	35.44	2.43	1.66	12	24
7	0.72	16.65	29.87	2.51	1.50	15	23
8	0.73	15.68	27.62	3.15	1.48	10	21
9	0.72	15.34	33.35	2.41	1.79	16	22
10	0.73	16.98	37.74	3.43	1.86	16	21

variables. How does the value of travel time change if socioeconomic variables of the traveler are included in the model?

5.3. An economic evaluation has to be performed for a congestion mitigation project implemented on U.S. Route-52 in Indiana. The vehicle hours of travel time saved, unit travel-time value, and the average vehicle occupancy of each mode are given in Table EX5.3. Compute the travel-time savings using the plausible range of travel-time values recommended by USDOT (Tables 5.4 and E5.7). Assume that the wage rate is $16.25 for the automobile passengers and that the fringe benefits are worth $6.44.

5.4. Determine the value of travel time using the exchange plot method for the travel-time and travel-cost data in Table EX5.4, obtained from a stated preference survey of 10 commuters facing the choice of a toll road or a free road.

5.5. Determine the value of travel time using the binary logit model from the route choice data given in Table EX5.5. Assume an average vehicle occupancy of 1.3.

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APPENDIX A5.1: ESTIMATION OF ROADWAY CAPACITY USING THE HCM METHOD (TRB, 2000)

The primary objective of capacity analysis is to estimate the maximum number of vehicles a facility can accommodate with reasonable safety during a specified time period. The capacity of a roadway segment is highest when all roadway and traffic conditions meet or exceed their base values. These base conditions, which are determined using empirical studies, assume good weather, familiarity of users with transportation facility, good pavement conditions, and uninterrupted traffic flow. In general, the conditions that prevail on most highways are different from the base conditions. As a result, the computations of capacity, service flow rate, and level of service require adjustments.

HCM classifies transportation facilities into two categories of flow: uninterrupted and interrupted. Freeways are an example of an uninterrupted flow facility. The multilane highways and two-lane highways can also have uninterrupted flow in long segments between two points of interruption. This appendix summarizes the HCM capacity analysis methodology for freeways, multilane highways, and two-lane highways.

(*a*) *Basic Freeway Segments* A divided roadway segment having two or more lanes in each direction, full access control, and uninterrupted flow irrespective of traffic merging and diverging from ramps is referred to as a basic freeway segment. The base conditions for basic freeway segments are as follows:

- A minimum lane width of 12 ft
- Minimum right shoulder clearance (between the edge of the travel lane and objects) of 6 ft
- Minimum median lateral clearance of 2 ft
- Traffic stream comprising passenger cars only
- Five or more lanes in each direction of travel (urban areas only)
- Interchange spacing greater than 2 miles
- Driver population comprising of users of high familiarity
- Level terrain (no grades greater than 2%)

As the operating conditions are more restrictive than the base conditions, the base free-flow speed is adjusted according to the extent of deviation from the base conditions, resulting in a reduced free-flow speed. Table A5.1.1 shows the relationship between capacity and free-flow speed for basic freeway segments. It can be noted from Table A5.1.2 that, given a free-flow speed, the capacity of a basic freeway segment is the maximum service flow rate at LOS E. This is because the upper boundary of the LOS E corresponds to a volume/capacity (v/c) ratio of 1.0.

Table A5.1.1 Relationship between Free-Flow Speed and Capacity on Basic Freeway Segments and Multilane Highways

Basic Freeway Segments		Multilane Highways	
Free-flow Speed(mi/h)	Capacity (pc/h/ln)	Free-flow Speed (mi/h)	Capacity (pc/h/ln)
75	2400	60	2200
70	2400	55	2100
65	2350	50	2000
60	2300	45	1900
55	2250		

Table A5.1.2 LOS Criteria for Basic Freeway Segments and Multilane Highways

	Basic Freeway Segments LOS					Multilane Highways LOS				
Criterion	A	B	C	D	E	A	B	C	D	E
	FFS = 75 mi/h					FFS = 60 mi/h				
Maximum Density (pc/mi/ln)	11	18	26	35	45	11	18	26	35	40
Average Speed (mi/h)	75	74.8	70.6	62.2	53.3	60	60	59.4	56.7	55
Maximum v/c	0.34	0.56	0.76	0.9	1	0.3	0.49	0.7	0.9	1
Maximum Service Flow Rate (pc/h/ln)	820	1350	1830	2170	2400	660	1080	1550	1980	2200
	FFS = 70 mi/h					FFS = 55 mi/h				
Maximum Density (pc/mi/ln)	11	18	26	35	45	11	18	26	35	41
Average Speed (mi/h)	70	70	68.2	61.5	53.3	55	55	54.9	52.9	51.2
Maximum v/c	0.32	0.53	0.74	0.9	1	0.29	0.47	0.68	0.88	1
Maximum Service Flow Rate (pc/h/ln)	770	1260	1770	2150	2400	600	990	1430	1850	2100
	FFS = 65 mi/h					FFS = 50 mi/h				
Maximum Density (pc/mi/ln)	11	18	26	35	45	11	18	26	35	43
Average Speed (mi/h)	65	65	64.6	59.7	52.2	50	50	50	48.9	47.5
Maximum v/c	0.3	0.5	0.71	0.89	1	0.28	0.45	0.65	0.86	1
Maximum Service Flow Rate (pc/h/ln)	710	1170	1680	2090	2350	550	900	1300	1710	2000
	FFS = 60 mi/h					FFS = 45 mi/h				
Maximum Density (pc/mi/ln)	11	18	26	35	45	11	18	26	35	45
Average Speed (mi/h)	60	60	60	57.6	51.1	45	45	45	44.4	42.2
Maximum v/c	0.29	0.47	0.68	0.88	1	0.26	0.43	0.62	0.82	1
Maximum Service Flow Rate (pc/h/ln)	660	1080	1560	2020	2300	490	810	1170	1550	1900
	FFS = 55 mi/h									
Maximum Density (pc/mi/ln)	11	18	26	35	45					
Average Speed (mi/h)	55	55	55	54.7	50					
Maximum v/c	0.27	0.44	0.64	0.85	1					
Maximum Service Flow Rate (pc/h/ln)	600	990	1430	1910	2250					

(*b*) *Multilane Highways* The base conditions for multilane highways are as follows:

- A minimum lane width of 12 ft
- Minimum total lateral clearance of 12 ft from roadside objects (right shoulder and median) in the travel direction
- Traffic stream comprising passenger cars only
- Absence of direct access points along the roadway segment
- Divided highway
- Level terrain (grade less than 2%)
- Driver population comprising of highly familiar roadway users
- Free-flow speed higher than 60 mi/h

The operating free-flow speed is calculated through adjustments to the base free-flow speed according to the prevailing conditions. Procedures for making speed adjustments are discussed in Appendix A5.2.

Table A5.1.1 shows the relationship between free-flow speed and capacity for multilane highways. Again, it is important to note that the values of capacity correspond to the maximum service flow rate at LOS E and a v/c ratio of 1.0.

(*c*) *Two-Lane Highways* The base conditions for two-lane highways are as follows:

- A minimum lane width of 12 ft
- Minimum shoulder width of 6 ft
- Highway segment with 0% no passing zones
- Traffic stream comprising of passenger cars only
- No direct access points along the roadway
- Level terrain (grade less than 2%)
- No impediments to through traffic due to traffic control or turning vehicles
- Directional traffic split of 50/50

The capacity for extended lengths of two-lane highway segments under base conditions is 3200 passenger cars per hour combined for both directions. For short lengths of two lane highways, such as bridges or tunnels, the capacity varies from 3200 to 3400 passenger cars per hour for both directions of travel combined.

Example A5.1 Determine the capacity (per lane) on a six-lane divided urban freeway. The free-flow speed was found to be 57.5 mi/h after adjustments for lane width, lateral clearance, number of lanes, and interchange density were made to the base free-flow speed.

SOLUTION From Table A5.1.1, the capacity corresponding to a free flow speed of 55 mi/h is 2250 pc/h and corresponding to 60 mi/h is 2300 pc/h. Interpolating linearly, the capacity corresponding to a free-flow speed of 57.5 mi/h will be 2275 pc/h for each lane on the six-lane divided urban freeway.

Alternatively, Exhibit 23-15 on Page 23-14 in HCM (2000) could be used to determine the capacity of the basic freeway segment on the basis of its interchange spacing (in miles) and number of lanes.

APPENDIX A5.2: ESTIMATION OF ROADWAY OPERATING SPEEDS USING THE HCM METHOD (TRB, 2000)

Given the travel demand and system capacity from step 3, the travel speeds can be estimated for both the base case and the case under investigation. This may be done using network-wide travel demand modeling for an overall network (which yields results for each link in the network) or solely for a single link. Even where only a single route or link is under investigation, network-level analyses are typically preferred, because unlike the project-level speed estimation, they typically give due cognizance to trips diverted to or from other routes from or to the facility under the improvement scenario. The vital overall contribution of travel speeds to an evaluation of transportation effects is evidenced in its due consideration to a wide range of impact types, such as vehicle operating costs, vehicular emissions, noise, and energy use. Besides field monitoring, travel speeds may be estimated using approaches provided in the HCM or using the COMSIS method as discussed in Section 5.2. This appendix discusses the HCM method.

The free-flow speed is the mean speed of passenger cars measured under low-to-moderate flows (under 1300 pcphpl). Speeds on a specific freeway section are expected to be virtually constant in this range of flow rates. The free-flow speed can be estimated indirectly on the basis of the physical characteristics of the freeway section under investigation. These physical characteristics include lane width, right-shoulder lateral clearance, number of lanes, and interchange density. The following equation can be used for the estimation of free-flow speed:

For basic freeway sections:

$$\text{FFS} = \text{FFS}_i - f_{\text{LW}} - f_{\text{LC}} - f_N - f_{\text{ID}}$$

For multilane rural and suburban roads:

$$\text{FFS} = \text{FFS}_i - F_M - F_{\text{LW}} - F_{\text{LC}} - F_A$$

where FFS = estimated free-flow speed (mph)
FFS_i = estimated ideal free-flow speed, 70 or 75 mph

f_{LW} = adjustment for lane width
f_{LC} = adjustment for right-shoulder lateral clearance
f_N = adjustment for number of lanes (not applicable to multilane roads)
f_{ID} = adjustment for interchange density (not applicable to multilane roads)
F_M = adjustment for median type (not applicable to freeways)
F_A = adjustment for access points (not applicable to freeways)

HCM recommends that an ideal free-flow speed of 75 mph can be assumed for rural freeways. For urban and suburban freeways, the recommended ideal free-flow speed is 70 mph.

(*a*) *Adjustment for Median Type* The first adjustment to free-flow speed relates to the median type. This adjustment is not required for free-flow speed on freeways. For rural and suburban multilane roads, the adjustment factors are given in Table A5.2.1.

(*b*) *Adjustment for Lane Width* The ideal lane width is 12 ft. The ideal free-flow speed is reduced when the average width across all lanes within a freeway section is less than 12 ft. Adjustment factors to reflect the effect of narrower average lane widths are provided in Table A5.2.2.

(*c*) *Adjustment for Right Shoulder Lateral Clearance* According to the HCM, the ideal lateral clearance is 6 ft or greater on the right side and 2 ft or greater on the median or left side. The ideal free-flow speed has to be adjusted if these requirements are not met. There are no adjustment factors to reflect the effect of median lateral clearance of less than 2 ft. However, lateral clearance of less than 2 ft on either the right or left sides is often rare. The adjustment factors for right shoulder lateral clearance are shown in the Table A5.2.3.

For rural and suburban multilane roads, adjustment factors are given for the total lateral clearance (Table A5.2.4), which is the sum of the lateral clearances of the median (if greater than 6 ft, use 6 ft) and right shoulder (if greater than 6 ft, use 6 ft).

(*d*) *Adjustment for Number of Lanes* Freeway sections with five or more lanes in one direction are considered ideal with respect to the free-flow speed. When there are fewer than five lanes, the free-flow speed is less than ideal.

Table A5.2.1 Adjustment Factors for Median Type

Median Type	Reduction in Free-Flow Speed (mph)
Undivided highways	1.6
Divided highways	0

Table A5.2.2 Adjustment Factors for Lane Width

Lane Width (ft)	Reduction in Free-Flow Speed	
	Freeways	Multilane Roads
≥12	0.0	0.0
11	1.9	1.9
10	6.6	6.6

Table A5.2.3 Adjustment Factors for Right Shoulder Lateral Clearance

Right Shoulder Lateral Clearance (ft)	Reduction in Free-Flow Speed (mph) Lanes in One Direction		
	2	3	4
≥6	0.0	0.0	0.0
5	0.6	0.4	0.2
4	1.2	0.8	0.4
3	1.8	1.2	0.6
2	2.4	1.6	0.8
1	3.0	2.0	1.0
0	3.6	2.4	1.2

Table A5.2.4 Adjustment Factors for Total Lateral Clearance

Four-Lane Highways		Six-Lane Highways	
Total Lateral Clearance (ft)	Reduction in Free-Flow Speed (mph)	Total Lateral Clearance (ft)	Reduction in Free-Flow Speed (mph)
12	0	12	0
10	0.4	10	0.4
8	0.9	8	0.9
6	1.3	6	1.3
4	1.8	4	1.7
2	3.6	2	2.8
0	5.4	0	3.9

Table A5.2.5 Adjustment Factors for Number of Lanes

Number of Lanes (One Direction)	Reduction in Free-Flow Speed (mph)
≥5	0.0
4	1.5
3	3.0
2	4.5

Adjustment factors to reflect the effect of the number of lanes on ideal free-flow speed are shown in Table A5.2.5. Only mainline lanes (basic and auxiliary) are considered in the determination of number of lanes. For example, HOV lanes are not included. These adjustment factors were computed on the basis of data collected on urban and suburban freeway sections and do not reflect conditions on rural freeways which typically carry two lanes in each direction. Hence, the value of the adjustment factor for rural freeways is taken as zero.

(*e*) *Adjustment for Interchange Density* The ideal interchange density according to the HCM is 2-mile interchange spacing. If the density of interchanges is greater, the ideal free-flow speed is reduced. The HCM-recommended adjustment factors for interchange density are given in Table A5.2.6. An interchange is defined as having at least one on-ramp. Hence, interchanges with only off-ramps are not considered in determining interchange density. Interchanges considered should include typical interchanges with arterials or highways and major freeway to freeway interchanges.

(*f*) *Adjustment for Access Point Density* This adjustment factor is applicable to rural and suburban multilane roads. It is not applicable to freeways. When the data on the number of access points on the highway section is not available, the HCM recommends the use of the values shown in Tables A5.2.7 and A5.2.8, depending on the type of development.

Table A5.2.6 Adjustment Factors for Interchange Density

Interchanges per Mile	Reduction in Free-Flow Speed (mph)
≤0.50	0.0
0.75	1.3
1.00	2.5
1.25	3.7
1.50	5.0
1.75	6.3
2.00	7.5

Table A5.2.7 HCM-Recommended Access Point Density for Different Types of Developments

Type of Development	Access Points per Mile (One Side of Roadway)
Rural	0–10
Low-density suburban	11–20
High-density suburban	21 or more

Table A5.2.8 Adjustment Factors for the Effects of Access Point Density on Free-Flow Speed

Access Points per Mile	Reduction in Free-Flow Speed (mph)
0	0.0
10	2.5
20	5.0
30	7.5
40 or more	10.0

Example A5.2 Determine the ideal free-flow speed on a 6-mile urban freeway section with three lanes in each direction, a lateral clearance of 4 ft on the right and left sides and with a lane width of 11 ft over the entire section. There are six interchanges within the section.

SOLUTION Assuming an ideal free-flow speed of 70 mph on the urban freeway under consideration, the free-flow speed on the freeway section can be calculated using the equation

$$\text{FFS} = \text{FFS}_i - f_{\text{LW}} - f_{\text{LC}} - f_{\text{N}} - f_{\text{ID}}$$

where

Factor due to lane width, f_{LW}	2.0 mph (refer to Table A5.2.2)
Factor due to right shoulder lateral clearance, f_{LC}	0.8 mph (refer to Table A5.2.3)
Factor due to number of lanes, f_N	3.0 mph (refer to Table A5.2.5)
Interchange density, ID	6 interchanges over 6 miles of freeway 1 interchange per mile

Factor due to interchange density, f_{ID} 2.5 mph (refer to Table A5.2.6)

Hence, the free-flow speed on the given freeway section is

$$\text{FFS} = 70 - 2 - 0.8 - 3.0 - 2.5 = 61.7 \text{ mph}$$

APPENDIX A5.3: TRAVEL TIMES USED IN WORLD BANK PROJECTS

Tables A5.3.1 and A5.3.2 list the values of passenger and crew travel times, respectively, that have been used in World Bank projects.

Table A5.3.1 Values of Passenger Travel Time ($/h)

Year	Country	Motor-cycle	Car	Pick-up	Bus	Truck	Rail	Project
1992	Venezuela		2.72	2.14	1.66			Urban Transport (Caracas only)
1996	Uruguay		1.10	1.10	0.29			National Road Network Analysis (1996–1999 Plan)
1996	Ukraine				0.15			Urban Transport
1993	Tunisia		1.07		0.48		0.48	Urban Transport II
1983	Tunisia	0.33	0.33	0.33	0.33	0.33		Urban Transport II
1975	Thailand	1.00	1.50		0.50			Bangkok Traffic Management
1990	Sri Lanka	0.41	0.82		0.16	0.16		Colombo Urban Transport
1993	St. Lucia		1.14	1.49	0.91	1.10		West coast road study
1994	Russia				0.35			Urban Transport
1993	Perú	0.69	0.69	0.69	0.69	0.69	0.69	Transport Rehabilitation (Road Component)
1995	Lebanon		1.72	2.59	1.24			National Roads
1995	Latvia				1.80			Municipal Services Development (Riga UT component)
1994	South Korea		2.57		1.70			Pusan Urban Transport Management
1987	South Korea	$0.50 to $1.5 per passenger-hour for work-related trips						Kyonggi Regional Transport
1984	South Korea		1.65		0.45	0.90		Seoul Urban Transportation
1995	Kenya		1.24	0.24	0.24			Urban Infrastructure
1993	Jordan							Transport III
1992	Jordan							Swaileh–Queen Alia International Airport Road
1983	Jordan	1.26	1.26	1.26	1.26			Amman Transport and Municipal Development
1985	Indonesia		2.06	2.06	0.42			Regional Cities Urban Transport
1996	India		1.00		0.75			Andra Pradesh State Highway

(*continued overleaf*)

Table A5.3.1 (*continued*)

Year	Country	Motor-cycle	Car	Pick-up	Bus	Truck	Rail	Project
1994	India	0.58	0.62		0.56/0.24			National Highway III
1991	Honduras		0.60	0.60	0.14			Road Rehabilitation and Maintenance
1992	Guatemala		0.80	1.00	0.28			Road Maintenance Program
1995	Ghana		0.05	0.05	0.05	0.05		Highway Sector Investment Program
1996	Dominican Republic		0.73					National Highway
1981	Côte d'Ivoire	0.67	0.67	0.67	0.67	0.67		Urban II
1995	Colombia		1.72		0.32	0.32		Bogota Urban Transport
1996	China	0.12	0.12	0.12	0.12	0.12		Tianjin Urban Development and Environment
1993	China	0.33	0.33	0.33	0.33	0.33		Shanghai Metropolitan Transport II
1990	China	Working time at $0.20/h and nonpaid time at $0.05/h						Medium-Sized Cities Development
1989	China	0.20	0.20	0.20	0.20	0.20		Shanghai Metropolitan Transport I
1987	Cameroon		1.47		1.47			Urban II (Douala Infrastructure Component)
1989	Burkina Faso		0.63		0.63			Urban II
1995	Brazil		4.46		1.28		0.78	Recife Metropolitan Transport Decentralization
1979	Brazil		0.71		0.15		0.22	Urban Transport II (Porto Alegre)
1993	Bangladesh		0.91	0.91	0.35			Jamuna Bridge
1990	Bangladesh		0.57	0.43	0.23	0.23		Road Rehabilitation and Maintenance II

Source: Gwilliam (1997).

Table A5.3.2 Values of Crew Travel Time ($/h)

Year	Country	Car	Pick-up	Mini-bus	Bus	2-Axle Truck	3-Axle Truck	>3-Axle Truck	Project
1992	Venezuela	1.39	1.39	1.39	1.39	1.39	1.39	1.39	Urban Transport (Caracas only)
1993	Spain		42.29		21.14		25.36	22.86	Catalunya Highway Maintenance and Rehabilitation

(*continued overleaf*)

Table A5.3.2 (*continued*)

Year	Country	Car	Pick-up	Mini-bus	Bus	2-Axle Truck	3-Axle Truck	>3-Axle Truck	Project
1991	Sierra Leone				0.47	0.47	0.47	0.47	Road Rehabilitation and Maintenance
1993	St. Lucia		2.49	2.49		2.99	3.46	3.94	
1993	Nigeria		0.25	0.25	1.41	0.47	0.47	0.98	Multistate Roads II
1987	Niger		1.05	1.05		1.73	1.73	2.79	National Transport Investment Program
1994	Nepal		0.40		0.84	0.54			Road Maintenance and Rehabilitation
1992	Mexico	1.33			3.87	1.67	3.33	3.33	Trunk Roads Network Maintenance Strategy
1995	Lebanon				2.79	2.67	2.67	2.67	National Roads
1995	Kenya	0.51	0.65		0.98	1.31	1.93		Urban Infrastructure
1993	Jordan				1.02	1.81	1.81	1.81	Transport III
1992	Jordan	1.02	1.02	1.02	1.02	1.81	1.81	1.81	Swaileh–Queen Alia International Airport Road
1996	India	0.40			1.80	1.80	1.80		Andhra Pradesh State Highway
1994	India		0.44		1.02	0.87	1.04	1.04	National Highway III
1991	Honduras		0.39		0.96		0.96	1.35	Road Rehabilitation and Maintenance
1992	Guatemala		1.00	1.50	1.90	1.25	1.25	1.25	Road Maintenance Program
1995	Ghana	0.28	0.28		0.56	0.56	0.56	0.56	Highway Sector Investment Program
1996	Dominican Republic				1.09	0.93	1.09	1.09	National Highway
1989	Chile		1.00		3.00	1.20	1.80		Road Sector II
1985	Chile		1.00		3.00	1.20	1.80		Road Sector I
1987	Cameroon	5.52							Urban II (Douala Infrastructure Component)
1994	Brazil				3.29	2.32	2.32	2.81	State Highway Management II
1993	Bangladesh				0.84	0.70			Jamuna Bridge
1990	Bangladesh	0.46	0.46	1.03	1.03	0.83	0.83	0.83	Road Rehabilitation and Maintenance II
1994	Algeria				2.96	2.76	3.57	3.37	Highway VI

Source: Gwilliam (1997).