Table 8.1 Capital Recovery Factors

	Rate of interest, in percent (*i*)										
N Years	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
1	1.0100	1.0150	1.0200	1.0250	1.0300	1.0350	1.0400	1.0450	1.0500	1.0550	1.0600
2	0.5075	0.5113	0.5150	0.5188	0.5226	0.5264	0.5302	0.5340	0.5378	0.5416	0.5454
3	0.3400	0.3484	0.3467	0.3501	0.3535	0.3569	0.3603	0.3638	0.3672	0.3707	0.3741
4	0.2563	0.2594	0.2626	0.2658	0.2690	0.2723	0.2755	0.2787	0.2820	0.2853	0.2886
5	0.2060	0.2091	0.2121	0.2152	0.2183	0.2215	0.2246	0.2278	0.2310	0.2342	0.2374
6	0.1725	0.1755	0.1785	0.1815	0.1846	0.1877	0.1908	0.1939	0.1970	0.2002	0.2034
7	0.1486	0.1515	0.1545	0.1575	0.1605	0.1635	0.1666	0.1697	0.1728	0.1760	0.1791
8	0.1307	0.1336	0.1365	0.1395	0.1425	0.1455	0.1485	0.1516	0.1547	0.1579	0.1610
9	0.1167	0.1196	0.1225	0.1255	0.1284	0.1314	0.1345	0.1376	0.1407	0.1438	0.1470
10	0.1056	0.1084	0.1113	0.1143	0.1172	0.1202	0.1233	0.1234	0.1295	0.1327	0.1359
11	0.0965	0.0993	0.1022	0.1051	0.1081	0.1111	0.1141	0.1172	0.1204	0.1236	0.1268
12	0.0888	0.0917	0.0945	0.0975	0.1005	0.1035	0.1065	0.1097	0.1128	0.1160	0.1193
13	0.0824	0.0852	0.0881	0.0910	0.0940	0.0971	0.1001	0.1033	0.1065	0.1097	0.1130
14	0.0769	0.0797	0.0826	0.0855	0.0885	0.0916	0.0947	0.0978	0.1010	0.1043	0.1076
15	0.0721	0.0749	0.0778	0.0808	0.0838	0.0868	0.0899	0.0931	0.0963	0.0996	0.1030
16	0.0679	0.0708	0.0737	0.0766	0.0796	0.0827	0.0858	0.0890	0.0923	0.0956	0.0989
17	0.0643	0.0671	0.0700	0.0729	0.0759	0.0790	0.0820	0.0854	0.0887	0.0920	0.0954
18	0.0610	0.0688	0.0667	0.0697	0.0727	0.0758	0.0790	0.0822	0.0855	0.0889	0.0923
19	0.0581	0.0609	0.0638	0.0688	0.0698	0.0729	0.0761	0.0794	0.0827	0.0861	0.0896
→ 20	0.0554	0.0582	0.0611	0.0641	0.0672	0.0704	0.0736	0.0769	0.0802 ✓	0.0837	0.0872
21	0.0530	0.0559	0.0588	0.0618	0.0649	0.0680	0.0713	0.0746	0.0780	0.0815	0.0850
22	0.0509	0.0537	0.0566	0.0596	0.0627	0.0659	0.0692	0.0725	0.0760	0.0795	0.0830
23	0.0489	0.0517	0.0547	0.0577	0.0608	0.0640	0.0673	0.0707	0.0741	0.0777	0.0813
24	0.0471	0.0499	0.0529	0.0559	0.0590	0.0623	0.0656	0.0690	0.0725	0.0760	0.0797
25	0.0454	0.0483	0.0512	0.0543	0.0574	0.0607	0.0640	0.0674	0.0709	0.0745	0.0782
26	0.0439	0.0467	0.0497	0.0528	0.0559	0.0592	0.0626	0.0660	0.0696	0.0732	0.0769
27	0.0424	0.0453	0.0483	0.0514	0.0546	0.0579	0.0612	0.0647	0.0683	0.0719	0.0757
28	0.0411	0.0440	0.0470	0.0501	0.0533	0.0566	0.0600	0.0635	0.0671	0.0708	0.0746
29	0.0399	0.0428	0.0458	0.0489	0.0521	0.0554	0.0589	0.0624	0.0660	0.0698	0.0736
30	0.0387	0.0416	0.0446	0.0478	0.0510	0.0544	0.0578	0.0614	0.0651	0.0688	0.0726
31	0.0377	0.0406	0.0436	0.0467	0.0500	0.0534	0.0569	0.0604	0.0641	0.0679	0.0718
32	0.0367	0.0396	0.0426	0.0458	0.0490	0.0524	0.0559	0.0596	0.0633	0.0671	0.0710
33	0.0357	0.0386	0.0417	0.0449	0.0481	0.0516	0.0551	0.0587	0.0625	0.0663	0.0703
34	0.0348	0.0378	0.0408	0.0440	0.0473	0.0507	0.0543	0.0580	0.0617	0.0656	0.0696
35	0.0340	0.0369	0.0400	0.0432	0.0465	0.0500	0.0536	0.0573	0.0611	0.0650	0.0690
36	0.0332	0.0361	0.0392	0.0425	0.0458	0.0493	0.0529	0.0566	0.0604	0.0644	0.0684
37	0.0325	0.0354	0.0385	0.0417	0.0451	0.0486	0.0522	0.0560	0.0598	0.0638	0.0679
38	0.0318	0.0347	0.0378	0.0411	0.0445	0.0480	0.0516	0.0554	0.0593	0.0633	0.0673
39	0.0311	0.0341	0.0372	0.0404	0.0438	0.0474	0.0511	0.0549	0.0588	0.0628	0.0669
40	0.0305	0.0334	0.0365	0.0398	0.0433	0.0468	0.0505	0.0543	0.0583	0.0623	0.0665
41	0.0229	0.0328	0.0360	0.0393	0.0427	0.0463	0.0500	0.0539	0.0578	0.0619	0.0661
42	0.0293	0.0323	0.0354	0.0387	0.0422	0.0458	0.0495	0.0534	0.0574	0.0615	0.0657
43	0.0287	0.0317	0.0349	0.0382	0.0417	0.0453	0.0491	0.0530	0.0570	0.0611	0.0653
44	0.0282	0.0312	0.0344	0.0377	0.0412	0.0449	0.0487	0.0526	0.0566	0.0608	0.0650
45	0.0277	0.0307	0.0339	0.0373	0.0408	0.0445	0.0483	0.0522	0.0563	0.0604	0.0647
46	0.0272	0.0303	0.0335	0.0368	0.0404	0.0441	0.0479	0.0518	0.0559	0.0601	0.0644
47	0.0268	0.0298	0.0330	0.0364	0.0400	0.0437	0.0475	0.0515	0.0556	0.0598	0.0641
48	0.0263	0.0294	0.0326	0.0360	0.0396	0.0433	0.0472	0.0512	0.0553	0.0595	0.0639
49	0.0259	0.0290	0.0322	0.0356	0.0392	0.0430	0.0469	0.0509	0.0550	0.0593	0.0637
50	0.0255	0.0286	0.0318	0.0353	0.0389	0.0426	0.0465	0.0506	0.0548	0.0591	0.0634
60	0.0222	0.0254	0.0288	0.0324	0.0361	0.0401	0.0442	0.0485	0.0528	0.0573	0.0619
70	0.0199	0.0232	0.0267	0.0304	0.0343	0.0385	0.0427	0.0472	0.0517	0.0563	0.0610
80	0.0182	0.0215	0.0252	0.0291	0.0331	0.0374	0.0418	0.0464	0.0510	0.0558	0.0606
90	0.0169	0.0203	0.0240	0.0280	0.0323	0.0367	0.0412	0.0459	0.0506	0.0554	0.0603
100	0.0159	0.0194	0.0232	0.0273	0.0316	0.0362	0.0408	0.0456	0.0504	0.0553	0.0602

Source: [8.1, p. 150].

naturally will be higher. Using Table 8.1 we obtain a $CRF = 0.0872$ or 8.72 percent. Consequently, in each year (0.0872) (\$20,000) = \$1,744 must be paid.[11]

Similar examples could be generated in regard to transportation facilities with the CRF used in the determination of average yearly costs. A CRF usually is not calculated for benefits. Instead, the benefits are appraised for a year which lies in the middle of the time span between construction and the end of the service life. This procedure is based on the assumption that the change in benefits over time is approximately linear.

8.1.2 Comparison of Benefits and Costs

By using the capital recovery factor and the assumption of a linear change in benefits over time, we are capable of making a direct comparison of dollar benefits and costs from a new facility. This is usually done in the form of a ratio known as the benefit-cost ratio. If reference is again made to the example used up to this point in the chapter, it will be remembered that the difference in future benefits between the old highway from cities A to B (Fig. 8.1) and the new one is $B_n - B_o = \Delta B$. The corresponding difference in costs can be calculated as follows:

Let K_n = the total capital costs for constructing the new facility;
M_n = the average yearly maintenance cost of the new facility; and
M_o = the average yearly maintenance cost of the old facility.

Then the difference in average yearly costs is

$$\Delta C = (CRF_{i,N})K_n + M_n - M_o \tag{8.13}$$

The comparison of benefits and costs thus becomes

$\frac{1}{2}(C_4 - C_6)(V_6 + V_4)$

$$\frac{\Delta B}{\Delta C} = \frac{B_n - B_o}{(CRF_{i,N})K_n + M_n - M_o} \tag{8.14}$$

Naturally, it is desirable that the change in benefits associated with the new highway (in comparison to the old one) be large enough to cover the costs (plus interest) involved, so that the ratio in Eq. (8.14) should be greater than or equal to one. If it is not, the change in costs would exceed the change in benefits and would make the project of dubious value.

If more than one new facility were being proposed, we would have to evaluate each one separately but in relation to the present facility. The one with the greatest $\Delta B/\Delta C$ ratio theoretically should be the one to be built. However, there is another aspect to consider when evaluating multiple projects. It may turn out that a low cost facility may have a high $\Delta B/\Delta C$ ratio whereas a high cost facility may not. At the same time, it may be possible that the difference in cost for the more expensive facility over the less expensive one may be matched or even exceeded by the increase in benefits of the former over the latter. The conclusion then would be that, if the budget permits, it would be better to build the more expensive facility since the extra investment still would bring a return exceeding the costs involved. In other words, an investor should continue to invest as long as he can get a return greater than he can get any place else.

To make the indicated comparison among acceptable ($\Delta B/\Delta C \geqslant 1.00$) alternatives, all that one does is to use the lowest cost alternative as a base and calculate a benefit-cost ratio in a manner similar to that done in Eq. (8.14). The only difference in this case would be that there would be a capital cost, associated with the low cost alternative, that would have to be included along with its corresponding maintenance cost in the denominator of Eq. (8.14).[12] An example of this procedure along with that of the entire benefit-cost concept will be given as part of the next section of this chapter.

8.1.3 Example of the Benefit-Cost Approach: The AASHO Procedure

AASHTO Procedure

The foregoing discussion has set the theoretical framework for the evaluation of alternative proposals using the benefit-cost technique. It has been employed for many years, and, in particular has formed the framework for the much used procedure outlined by the American Association of State Highway Officials in the Red Book. The material in this section has been taken almost verbatim from that publication and demonstrates a rather detailed application of the technique. This application also provides a basis for a succeeding discussion of the many limitations and problems associated with benefit-cost evaluation.

A road user benefit analysis for highway improvements is a comparison of annual costs of alternates. For each alternate the annual road user costs and the annual cost of improving, maintaining, and operating that portion of the highway are determined for a selected period of time. Then the alternates are compared arithmetically to express a benefit-cost ratio, or quotient of the differences, similar to that in Eq. (8.14).

The annual road user cost is the total of a computed vehicle operating cost and annual time cost. The highway improvement is divided into as many sections as there are significant variations in the major analysis elements. Summation of these sectional vehicle operating and time costs give the annual road user cost for that highway alternate. Road user costs include all traffic directly involved or affected by the improvement. One alternate may include road user costs for vehicles operating on a new or improved route and also those continuing to operate on one or more parallel or connecting routes on which the traffic flow is affected by the improvement.

---

[11] The concerned student should note that interest payments in this case amount to about 75 percent of the capital costs. Thus, the magnitude of interest payments can be a relatively important consideration in transportation planning.

[12] There generally is no capital cost associated with the present highway, of course.

The annual highway cost is the total of the annual capital cost and the annual cost for maintenance and operation of the highway and its appurtenances. The annual capital cost is the annual amount required to amortize the total highway improvement cost plus interest. Usually separate average life values are used for right-of-way, grading and drainage, pavement, and major structures. The annual road maintenance and operations costs are estimated by study of actual costs for similar highways and conditions.

8.1.3.1 Calculation of road user costs for continuous operation Charts presented in this section give combined unit vehicle operating and time costs in terms of the running speed and other condition variables. For any alternate considered in an evaluation, the annual vehicle operating and time benefit, B, is calculated using a version of Eq. (8.10) revised to take into account the lengths of the sections under consideration and the use of a *daily* volume, V, instead of yearly volume (v). The revised equation is

$$B_n - B_o = \tfrac{1}{2}(C_o l_o - C_n l_n)(V_n + V_o)(365) \qquad (8.15)$$

The n subscript denotes the new facility and the o the old. Each unit cost, expressed in dollars per vehicle mile of travel, is multiplied by the length of the section in miles to get the cost for each vehicle trip over the entire highway. The V's, which are annual average daily volumes for the period of evaluation (a period in which reasonable accuracy can be expected in the estimation of future traffic), are multiplied by 365 days per year to get the yearly volume. The incorporation of these two changes allows for the calculations of future yearly benefits accruing for the entire facility.

If more than one section for a facility is involved (with a different unit cost), the product of C and l for each section is summed to get the total cost of a trip over the facility. If there are different travel volumes on each section, the calculations become quite complex and Eq. (8.15) cannot be utilized directly. The reader is referred to the AASHO Red Book for examples of procedures in these two kinds of situations.

8.1.3.2 Value of V Three steps are necessary to determine the value of V for each alternative in an evaluation:

1. Estimate the annual average daily traffic that will use the facility upon its completion;
2. Determine the number of years for which the analysis is to be made and the expansion factor for traffic on the facility during this period; and
3. Calculate an expanded annual average daily traffic volume that is a representative or average value for the period of analysis. This is the V value in Eq. (8.15).

Current traffic data are essential for any road user benefit evaluation. Those basic traffic data must be of a form to permit separation of the volumes operating on each section used in the analysis. Also, studies as to the expansion of traffic are necessary to determine the expanded traffic volumes for this period of time used in the analysis. This period of time should not be greater than that for which traffic can be estimated with reasonable accuracy. Many administrators believe a time period of 15 to 25 years to be a maximum for which they can estimate traffic with desired accuracy. The traffic forecast period is independent of the average life values used for calculating annual capital cost, as explained under the section on calculation of highway costs.

In most instances it will be necessary to separate the traffic data by vehicle types, since different unit road user costs must be used for each. Light trucks, such as pickups, delivery wagons, etc., that have the general size, weight, and performance characteristics of passengers cars should be included in the latter class. All heavier and larger trucks and buses should be considered separately. For practical purposes trucks and buses with manufacturers' rating for gross vehicle weight of 9,000 pounds or more can be considered in the truck and bus class. Where capacity is the basis of rating, a capacity of 1.5 tons or more should be considered in the truck or bus class. A rule of thumb that may be used without appreciable error is to consider all vehicles with dual-tired driving wheels in the truck and bus class.

8.1.3.3 Value of l For purposes of road user benefit analysis the highway route should be divided into sections of convenient length. As a first control, there should be a separate section for each significant variation in traffic volume. As a second control, there should be a separate section for each variation in the major analysis elements. The latter are of two types: (a) the physical changes such as number of lanes, profile conditions, or type of surfacing, and (b) the vehicle operational changes as determined jointly by the highway conditions and volumes.

In general, short sections should be avoided. Sections need not be established unless their separation serves to increase the practical accuracy of the analysis as a whole. Sections of considerable length can be used if the conditions throughout are nearly the same.

8.1.3.4 Value of C Figures 8.9 through 8.12 show values for combined unit vehicle operating and time costs for tangent (straight section) roadways, as based on national average current prices. They are in a form for direct use in Eq. (8.15). The proper C value for any section is read from the appropriate figure after the following conditions are established for that section, usually in the order listed:

a. Number and arrangement of lanes (type of highway).
b. Type of surface; with (a) above this determines which of Figs. 8.9 to 8.12 is applicable.
c. Grade of profile type (gradient class); determines which curve or group of curves in the figure is applicable.
d. Running speed; determines where to enter the group of curves on the lower axis.
e. Type of operation; determines which curve or group of curves is applicable.
f. Alignment features; determines correction factor (Fig. 8.12) applied to tangent alinement costs obtained from Figs. 8.9 to 8.12.

Table 1 w. Manual IRC SP: 30 - 2009

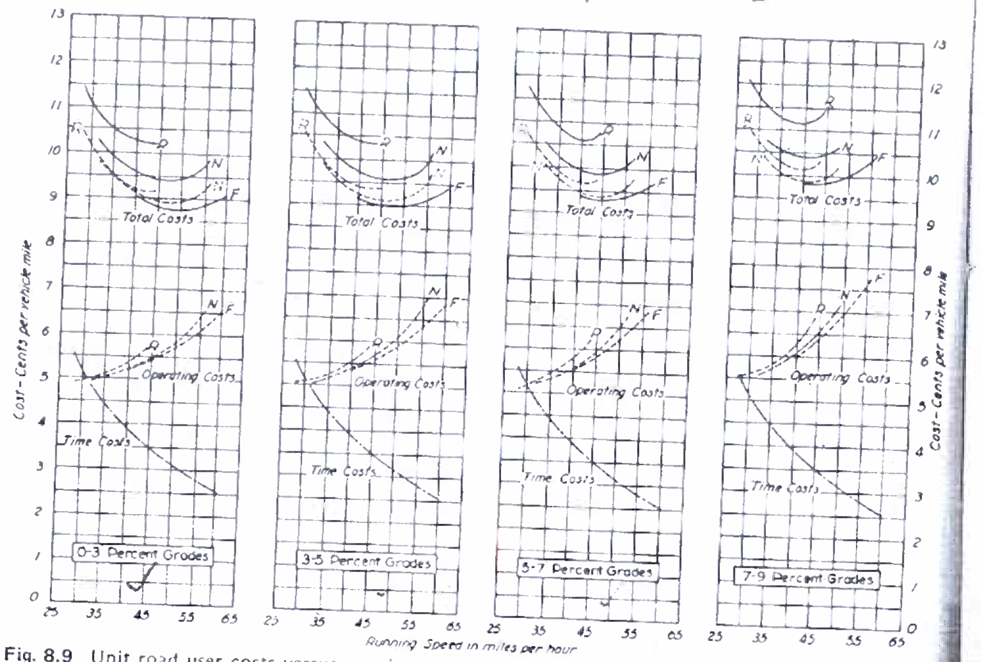


Fig. 8.9 Unit road user costs versus running speed for passenger cars in rural areas on tangent divided highways with pavements in good condition. [8.1, p. 20].

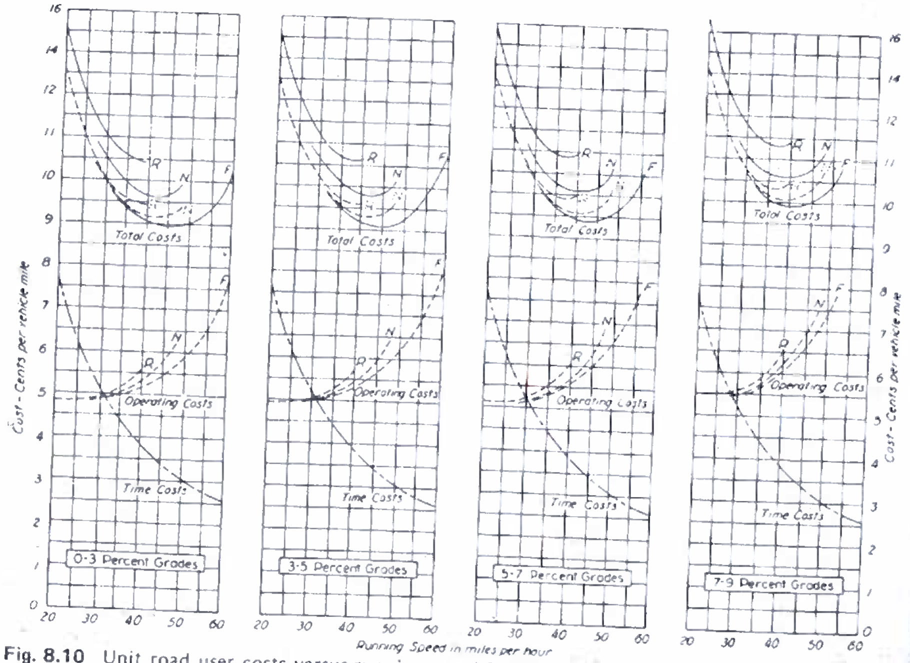


Fig. 8.10 Unit road user costs versus running speed for passenger cars in rural areas on tangent two-lane highways with pavements in good condition. [8.1, p. 21].

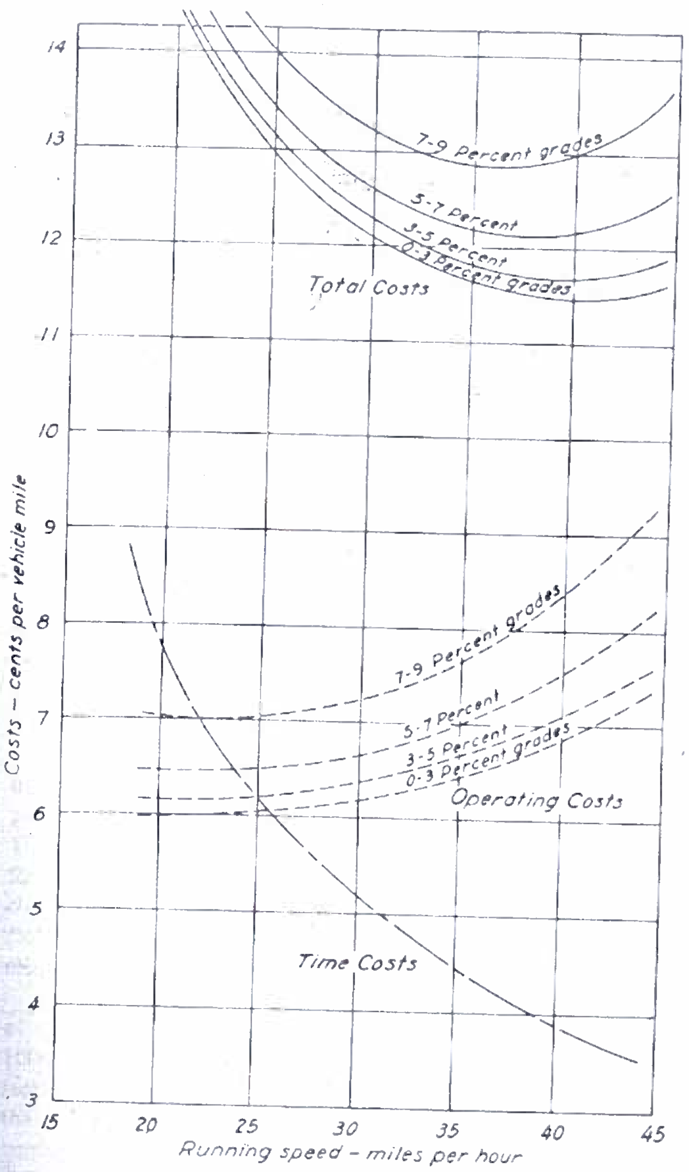


Fig. 8.11 Unit road user costs versus running speed for passenger cars in rural areas on tangent, loose surface highways in good condition. [8.1, p. 22].

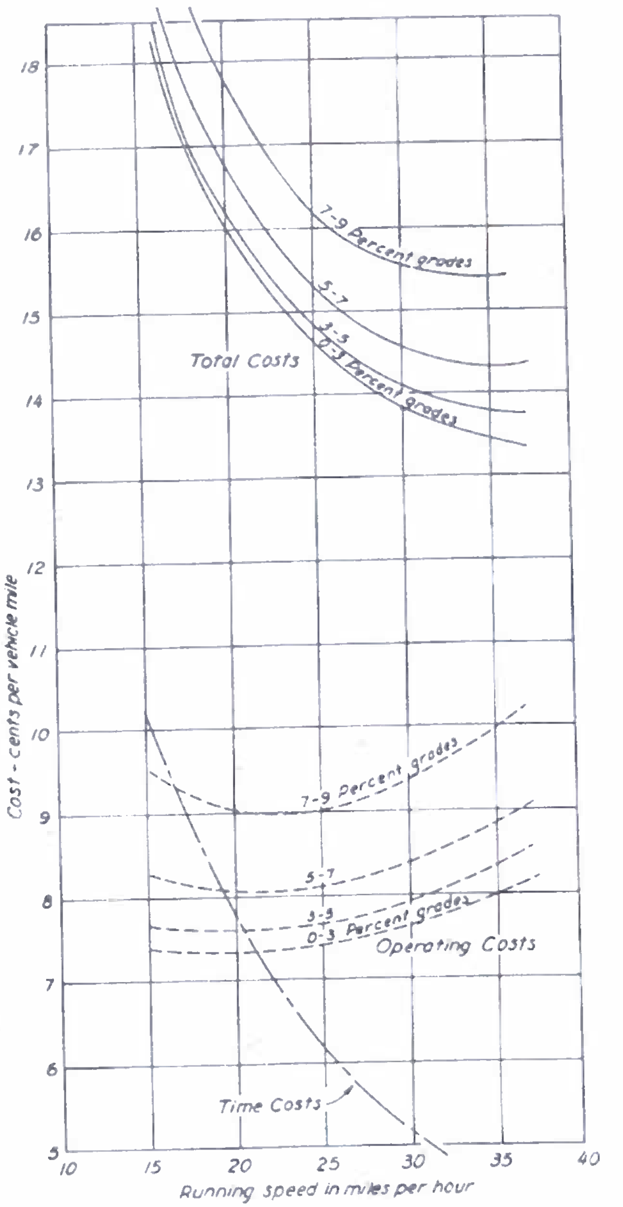


Fig. 8.12 Unit road user costs versus running speed for passenger cars in rural areas on tangent, unsurfaced roads. [8.1, p. 23].

The unit costs obtained from Figs. 8.9 to 8.12 include the combined effects of all the above variables except alinement.

a. Number and arrangement of lanes. For the same terrain and geometric design details a somewhat different effect from other variables can be expected on a divided highway than on a two-lane highway with pavements in good condition. Unit cost values for these two types of rural highways are shown separately in Figs. 8.9 and 8.10. Running speeds on three-lane highways and on four-lane undivided highways are about equal to or only slightly greater than on two-lane highways for comparable conditions, and the effects of other variables are only slightly different.

Accordingly, the preparation of separate charts for unit costs on these types of highways is not warranted. Unit costs on three-lane highways can be assumed to be nearly the same as those on two-lane highways and unit costs on undivided highways of four or more lanes can be approximated as values between those for two-lane and divided highways. The differences are small and of little consequence for running speeds of 40 mph or less.

b. Type of surface. Regardless of geometric design, the type of surface has pronounced effects on unit costs. Unit road user costs are separated for three types: (i) paved surfaces, either rigid or flexible, (ii) loose surfaces, primarily all-weather gravel, and (iii) unsurfaced. Each analysis section can be classified accordingly. The data for paved and loose surfaces are representative for surfaces in good condition. Unit costs for paved surfaces in fair to poor condition can be obtained by interpolation between the "paved" and "loose" values. Likewise, values for gravel surfaces in poor condition can be estimated by interpolation between "loose" and "unsurfaced."

c. Grade of profile type. Running speeds and resultant unit costs are affected by the profile type and gradients involved. The unit cost data are separated for four gradient classes: 0 to 3 percent, 3 to 5 percent, 5 to 7 percent, and 7 to 9 percent. These classes indicate an average grade along the highway and the unit cost values for them include the momentum effect for operation in rolling terrain. The gradient class must be determined for each analysis section. This determination can be made from profile data by any one of several methods without significant error in the resulting unit cost.

A simple method, conforming closely to the source cost data, is the calculation of average gradient for the analysis section by summation of actual grades for each 100-foot section or at every other 100-foot section and dividing by the number of sections in the summation or by dividing the total rise and fall by the length. Where the profile varies considerably in the length of an otherwise suitable analysis section, the section should be divided into two or more subsections each of a different gradient class. Such precision usually is necessary on long sections only.

d. Running speed. The running speed must be representative for the whole length of the analysis section, for all vehicles of the type to which it applied, and for the whole of the period used in the analysis. Running speed is lower than the typical "average" speed, which is a spot speed determined on an open section of the highway. The running speed must be representative of the terrain, curvature, gradient, sight distance, traffic volume, and other affecting conditions on the section. Where comparable highway conditions exist, it is most conveniently determined by dividing the total length by the total running time for representative operation. To be fully representative, the running speed so determined should be adjusted to include dark as well as daylight hours, typical inclement weather conditions, and anticipated future operations.

Where comparable measurement is not possible, an estimate for running speed on two-lane highways can be made from design speed and traffic volume data.

e. Type of operation. The traffic volume operating on a certain section of highway will decidedly affect the running speed and consequently the unit cost. While data are not complete enough to permit positive accuracy, they are sufficient to establish the effect of type of operation on operating cost. The general combined effects of terrain, type of highway, control of access, and traffic volume are grouped into three types of operation: (a) free, (b) normal, and (c) restricted, each determined by a relation of the 30th highest hourly traffic volume of the year to the volume at level of service *D*.[13] While these operating conditions are relative rather than precise, they serve as a practical means of distinguishing a complex combination of factors. For this method of analysis it is necessary to rate the operating conditions as being in one of these three classes:

Type of operation	Ratio of the 30th highest hourly traffic volume to volume at level of service *D*
Restricted	Greater than 1.25
Normal	0.75 to 1.25
Free	Less than 0.75

f. Alignment features. The values in Figs. 8.9 to 8.12 are prepared for open or high type alignment. For conditions of curved alignment a correction is made by increasing tangent costs in accordance with the percentage obtained from Fig. 8.13. To use Fig. 8.13 it is necessary to determine both the sharpness and the percent of length of significant curvature. Little error results in using the average degree of curvature and average superelevation (banking) for the section being analyzed, weighted on the basis of length.

Upon determination of the above six factors, the proper value of *C* is selected for each section from Fig. 8.9 to Fig. 8.13.

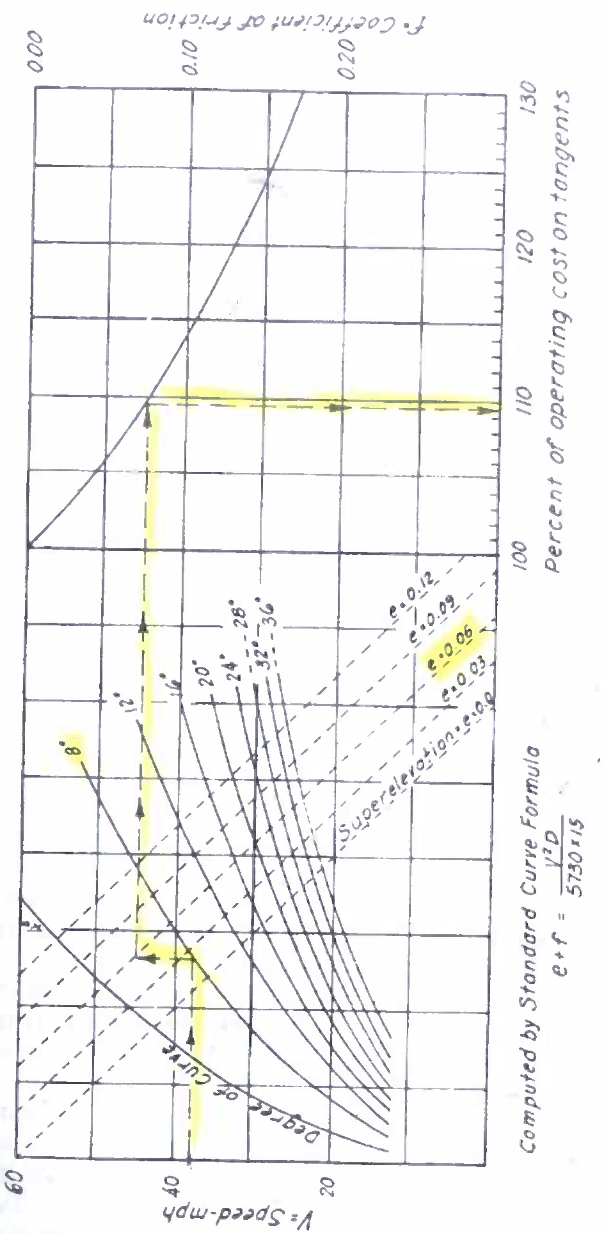
The unit cost values given herein are representative on a nationwide basis.[14] They were established by use of the following cost factors:

Gasoline	32 cents/gallon
Oil	45 cents/quart

---

[13] The phrase "practical capacity" was used in the AASHO Red Book; however, this phrase no longer is employed and we have chosen the words "volume at level of service D." See Chap. 5, Sec. 5.2.5 for an elaboration of the "level of service" concept.

[14] These figures are 1959 costs and should be updated accordingly for present conditions.



Example: Assume 38 mph operation on 8° curve, 0.06 superelevation. Follow arrows and read 109.50 % as the factor to apply to correct the tangent road user cost values.

Fig. 8.13 Relation between operating costs on curves and on tangents. [8.1, p. 24].

Tires	$100 initial cost per set
Car repairs	When operating on good pavements: 1.2 cents/vehicle mile On loose surfaces: 1.8 cents/vehicle mile On unimproved surfaces: 2.4 cents/vehicle mile
Car depreciation	1.5 cents/vehicle mile
Time	$1.55 per hour
Comfort and convenience	Paved highways: 1.0 cents/vehicle mile for restricted operation, 0.5 cents for normal operation, and 0.0 cents for free operation Loose surfaced highways: 0.75 cents/vehicle mile Unsurfaced highways: 1.0 cents/vehicle mile

8.1.3.5 Calculation of highway costs The total highway cost for road user benefit evaluation is the sum of the capital costs expressed on an annual basis and the annual cost of maintenance. The total cost for an improvement usually is obtained from an engineer's estimate based on preliminary plans. As necessary, the total capital cost of each highway alternate may be separated into the costs for (1) right-of-way, (2) grading, drainage, and minor structures, (3) major structures, and (4) pavement and appurtenances. The total annual highway cost is calculated as follows:

$$C = CRF_{i,N}K^{(1)} + CRF_{i,N}K^{(2)} + CRF_{i,N}K^{(3)} + CRF_{i,N}K^{(4)} + M \qquad (8.16)$$

where C is the total annual highway cost; $K^{(1)}$, $K^{(2)}$, $K^{(3)}$, and $K^{(4)}$ are the capital costs of the items above enumerated; $CRF_{i,N}$ are the capital recovery factors for a known rate of interest, i, and amortization of total cost of each of the above items based on its average life, N; and M is the annual cost for maintenance of the improved highway.

The computation of total annual capital costs based on the summation of the annual costs of the individual items of improvement is the "proper and accurate method" (AASHO wording), but, for quick analysis and for projects with similar ratios of costs of individual items to total costs, an estimate of total overall cost and overall life provides adequate accuracy. In this case the formula would be reduced to $C = CRF_{i,N}(K) + M$ in which K is the total cost of all the items of improvement and N is the overall estimated average life of the improvement.

In most cases, the capital costs, $K^{(1)}$, $K^{(2)}$, $K^{(3)}$, $K^{(4)}$, of the separate items of improvement, or, if satisfactory, the overall capital cost (K), can be calculated directly for the entire length of a highway alternate being analyzed without dividing it into sections as may be needed for the computation of road user costs. To weigh the advantages of sections of the improvement for stage construction, it will be necessary to estimate the sectional costs.

In most cases of main highways the average life period for each of the four major items of capital cost (or a representative composite) will be greater than the period used for traffic forecasting. For road user benefit evaluations it is not necessary that these periods be the same. Use of the shorter traffic forecast period as the basis for the analysis makes the resulting benefit-cost ratio correct insofar as the traffic data can be established.

At the end of the analysis period, the improvement still has value, the complete capital cost items not yet being amortized. Expression of the capital cost as a summation of the annual costs of construction and maintenance gives a proper value for any period of time. For analysis of a low type highway where the surface life may be less than the usual traffic forecast period, the shorter period would be used for the traffic estimate and analysis.

The factor M is the annual cost to cover all work necessary to keep the improved highway in good condition and the other operating charges as for striping, signs, lighting, etc. Suitable current average costs per mile per year generally can be obtained or estimated. These must be adjusted to include all costs anticipated within the weighted average life of the improvement, such as resurfacing work a number of years hence. The product of the adjusted annual cost per mile and the total length gives the desired annual cost for maintenance and operation of the highway.

8.1.3.6 Calculation of benefit-cost ratio The general equation for calculating the benefit-cost ratio now can be expressed as

$$\frac{\Delta B}{\Delta C} = \frac{B_n - B_o}{C_n - C_o} \qquad (8.17)$$

where C_o is the annual cost (usually for maintenance, M_o, only) of the old facility. With substitutions from Eq. (8.15) and the shortened version of Eq. (8.16), the above equation becomes

$$\frac{\Delta B}{\Delta C} = \frac{\frac{1}{2}(p_o l_o - p_n l_n)(V_n + V_o)(365)}{CRF_{i,N}(K_n) + M_n - M_o} \qquad (8.18)$$

The same formula is used for a second alternate by designating the total annual road user benefits from that alternate as B_{n2} and the total annual facility costs as C_{n2}. Similar benefit ratios are calculated for all other alternatives, each compared with the basic condition. By so doing, the several ratios can be compared directly as to their relative value. A benefit-cost ratio less than one indicates that in a road user benefit sense the basic condition is to be preferred over the alternate improvement.

Case study
Grade correction for Pune - Nashik Road Project

8.1.3.7 Numerical example Assume a relocation project where by heavy grading work on new alignment it is possible to reduce the length between two points on an existing highway. The existing highway is to be abandoned if the new alignment proves economical. Present traffic on the existing route is 1,500 vpd, and it is estimated that the average traffic for the next 20 years, the analysis period, will approximate 2,500 vpd on the new route and 2,000 vpd on the

Table 8.2 Data for Example Problem

	Existing sections		Proposed sections	
	1	2	1	2
1. Future volume (vpd)	2,000	2,000	2,500	2,300
2. 30 HHV (vph)	375	375	450	425
3. Service volume, level D (vpd)	450	450	715	700
4. Ratio	0.83	0.83	0.63	0.61
5. Type of operation	Normal	Normal	Free	Free
6. Design speed (mph)	50	50	60	60
7. Running speed (mph)	37	34	42	44
8. No. lanes	2	2	2	2
9. Length (miles)	2.0	0.4	1.5	1.5
10. Grade class (%)	0–3	3–5	0–3	5–7
11. Surface and condition	Paved–Good	Paved–Good	Paved–Good	Paved–Good
12. Curvature	50% –4°	50% –4°	Negligible	Negligible
13. Unit cost (¢/veh-mile)	10.24	10.24	9.01	10.18
14. Estimated pavement life (yr)	–	–	20.00	20.00
15. Estimated R.O.W. life (yr)	–	–	60.00	60.00
16. Estimated life, other (yr)	–	–	40.00	40.00
17. Pavement cost ($)	–	–	66,000	10,000
18. R.O.W. cost ($)	–	–	33,000	5,000
19. Other cost ($)	–	–	451,000	300,000
20. Annual pavement cost ($)	–	–	5,290	5,600
21. Annual R.O.W. cost ($)	–	–	1,740	260
22. Annual other cost ($)	–	–	26,290	17,500
23. Total annual capital cost ($)	–	–	33,320	23,360
24. Maintenance cost ($/mile)	1,100	1,100	880	880

Note: vph = vehicles per day, HHV = highest hourly volume, mph = miles per hour, R.O.W. = right-of-way (land and buildings).

old.[15] This traffic is composed of passenger cars with a very small proportion of trucks. Due to the character of the trucks, a distinction between them and the passenger cars is not considered necessary. Assignment of type of operation is made on the basis of the indicated ratios of 30th highest hourly traffic volume to the volume at level of service D. The proposed facility contemplates a pavement width of 20 feet compared with 18 feet on the existing facility. This factor, together with improved alignment and grades, permits distinction between a free and normal operation, respectively. Table 8.2 shows the data used to arrive at this differentiation.

The curvature proposed on the new facility is generally flat, with a minor portion approaching the design speed limit. This is to be properly superelevated (banked), so a correction for curvature can be ignored. However, the existing highway has a large number of curves approaching the maximum for a 50 mph design speed. It is estimated that 50 percent of its length will have an average curvature of about four degrees with superelevation negligible. From Fig. 8.13a correction of between 7 and 8 percent is read for the speeds considered. Since only one-half of the roadway is curved, the correction is halved to 4 percent and applied for the whole of the route to the values from Fig. 8.10. The calculated unit cost can be found in the thirteenth row of Table 8.2.

From Eq. (8.15) the average annual road user benefits are calculated as follows:

$$B_n - B_o = \tfrac{1}{2}\,[(2.0)\,(0.1024) + 0.4\,(0.1061) - 1.5\,(0.0901)]\,(2{,}500 + 2{,}000)\,(365) = \$92{,}000 \quad ✓$$

The average annual unit maintenance cost on the existing route is estimated to be \$1,100 per mile or a total of 2.4 (1,100) = \$2,640, and that of the proposed route to be \$880 per mile or a total of 1.5 (\$880) = \$1,320.

The total estimated cost of the proposed improvement is \$550,000 and the prevailing local interest rate is 5 percent. This interest rate is applied with reference to the cost and life expectancy of the individual items of improvement to compute the annual cost. Capital recovery factors, $CRF_{i,N}$, are selected from Table 8.1 and turn out to be 0.0802, 0.0528, and 0.0583 for each capital item respectively. With these, the total annual capital cost of the new alignment comes out to be \$33,320.

The benefit-cost ratio for the proposed improvement is computed from Eq. (8.17) as follows:

$$\frac{\Delta B}{\Delta C} = \frac{\$92{,}000}{\$33{,}320 + \$1{,}320 - \$2{,}640} = 2.88$$

Ex. 2

The analysis indicates that the annual benefits are almost three times the annual project costs. From this it appears to be a worthwhile project as far as road user benefits are concerned and one that should be slated for early construction.

Suppose now, that as another example, a second project is proposed. This new alignment is generally the same as the first one proposed except for volume, grades, and several other items shown in the right hand column in Table 8.2. Proceeding in a manner similar to that done for the previous proposal, we can determine the benefit-cost ratio through the following steps:

1. Calculate unit cost: Fig. 8.10 gives 10.18¢/veh-mile
2. Calculate benefits: Eq. (8.15) gives

$$B_n - B_o = \tfrac{1}{2}\,[(2.0)\,(0.1024) + 0.4\,(0.1061) - 1.5\,(0.1018)]\,(2{,}300 + 2{,}000)\,(365) = \$12{,}000$$

3. Calculate annual capital costs: (same $CRF_{i,N}$'s as in previous case)

$$C_n = 0.0802\,(70{,}000) + 0.0528\,(5{,}000) + 0.0583\,(300{,}000) = \$23{,}360$$

---

[15] Most of the examples given in the Red Book assume equal volumes of future traffic on both the old and new route. This type of occurence is highly improbable, of course.

4. Calculate $\Delta B/\Delta C$ ratio

$$\frac{\Delta B}{\Delta C} = \frac{\$72{,}000}{\$23{,}360 + \$1{,}320 - \$2{,}640} = 3.28$$

The benefit-cost ratio from the last calculation seems to indicate that the second proposal will create high economic returns, even higher than those for the first alternative. However, it is at this point that the statements made in section 8.14 should be emphasized. The second alternative has a lower capital cost than the first: \$23,360 versus \$33,320; but it also brings fewer dollars of benefits, \$72,000 versus \$92,000. The question then arises as to whether it would not be wise to build the first alternative in spite of its relatively low benefit-cost ratio. After all, if the additional funds required for the first project can bring in an equivalent or greater amount of benefits, then why not build it?

Capital costs

B/C Ratio ??

To determine if the extra expense for first alternative is in fact worthwhile, it is necessary to calculate a benefit-cost ratio between proposal one and two. Thus, if $n1$ is used to designate proposal one and $n2$, two, then

$$B_{n1} - B_{n2} = \tfrac{1}{2}\,[1.5\,(0.1018) - 1.5\,(9.01)]\;(2{,}500 + 2{,}300)\,(365) = \$15{,}400$$

$$C_{n1} - C_{n2} = \$33{,}320 + \$1{,}320 - \$23{,}360 - \$1{,}320 = \$9{,}960$$

$$\frac{\Delta B}{\Delta C} = \frac{\$15{,}400}{\$9{,}960} = 1.55$$

From these figures it can indeed be concluded that the extra expenditure for the more costly proposal will give a return 55 percent greater than the outlay. Therefore, any wise investor who had the necessary funds would be more than willing to put them into the first alternative, evaluating it as the most desirable one. Likewise, public officials and decision makers should find the first alternative "best" from an economic investment standpoint.

8.2 COMMENTS ON THE BENEFIT-COST APPROACH TO EVALUATION

Benefit-cost approaches to evaluation and decision making have been used extensively in the past by many different agencies and companies. The technique offers the distinct advantage of neutrality: the numbers used as inputs lead to an exact determination of the alternative which is best, and there can be no inference made that the evaluation process has been interfered with for personal or political reasons.

In this light, the benefit-cost technique is extremely valuable in that, if the theory behind it is agreeable to everyone, the outputs which come from it also must be accepted. In general, it gives the appearance of a certain mathematical purity—a purity that cannot be tampered with and is instrumental in providing the decision maker with results unbiased by emotional factors.

The benefit-cost approach does have many difficulties nevertheless. Some are technical in nature, while others stem directly from its failure to take into account many "human factors." Each of these types of difficulties will be discussed in turn in succeeding paragraphs.

8.2.1 System Effects

One of the foremost difficulties that arises in the utilization of the benefit-cost approach in any real world situation is that proposed alternatives generally are part of a system and do not stand by themselves as in the previous example problem. A change in a route alignment between two points or a decrease in travel time between two points often affects travel not only on that route but on many other nearby routes.

After construction of a new facility from D to C, people traveling from A to C and presently using the section of highway from B to C, may rearrange their route, going to A to D to C instead of from A to B to C. The result is that the number of trips on the sections from A to B and B to C is reduced *because* of the change in the route from D to C. The effects of improvements on one route thus permeate over other routes and present the evaluator with a difficult problem in accounting for *all* the benefits.

8.2.2 Unequal Alternatives

Alternatives, by definition, are different ways for accomplishing the same objective or solving the same problem. Quite obviously, we would not treat proposals for rapid transit either in Los Angeles or in Atlanta as alternates for the present mass transit situation in Minneapolis. The former two do not serve the same populations or the same travelers nor would they necessarily result in the same type of physical system as in Minneapolis. But do any transportation alternatives ever serve the same purpose?

Referring back to the example problem used for benefit-cost calculations, we see that the three facilities (including the existing one) really do not serve the "same" population of travelers, the major difference being in the *number* served. There are 2,000, 2,500, and 2,300 vph, respectively, for each alternative. Thus, the construction of either of the two new facilities changes the travel situation and, in effect, produces a new problem to be solved. The main point to be made here, however, is that benefit-cost ratios developed for evaluating alternatives rarely compare "equal" situations because the problem under study usually is modified by the alternatives proposed.[16]

---

[16] The creation of unequal alternatives is not a difficulty related to the benefit-cost technique per se, but is common to almost every evaluation procedure.

8.2.3 Risk and Uncertainty

Inherent in all evaluation techniques, including the benefit-cost approach, are problems of risk and uncertainty. Wohl and Martin [8.5, p. 223] make the distinction between these two entities as follows:

1. Problems of *risk* are those whereby the future outcomes or consequences have a known probability of occurrence; thus while the chances of a particular outcome may be known, no assurance can be given about which particular outcome will take place.
2. Problems of *uncertainty* are those whereby even the probabilities of the future outcomes or consequences are unknown and whereby the probabilities can be determined only subjectively.

The determination of whether an outcome is subject to risk or uncertainty is a difficult matter. Yet, what is important here is that almost all of the entities used in a benefit-cost calculation--the unit costs, the travel volumes, the interest rates, the service lives, and the capital and maintenance costs--have to be predicted for the future and therefore fall prey to inaccuracy.

Capital costs, for example, usually are thought of as being easily predictable, but factors such as inflation and unanticipated expenses resulting, perhaps, from the discovery of rock to be excavated or, in another situation, from the need for funds for drawn out legal cases, make even cost predictions hazardous. As a consequence, if the uncertainty (or risk) is anticipated to be great, the evaluator should take this feature into account, either by weighing each outcome by its probability of occurrence or, as is done in many cases, by increasing the interest rate so that the investor gets a larger and quicker return to make up for the riskier situation. Such techniques can be incorporated as part of benefit-cost procedure, but are rather cumbersome and data consuming.[17]

8.2.4 Inclusion of Various Benefits and Costs

The benefit-cost approach demands that the set of benefits and costs to be included be identified explicitly. This is desirable, yet the problem arises as to how to make an accounting of *all* benefits and costs. How about disbenefits or diseconomies resulting from increases in noise and air pollution levels? How about engineering, planning, and administration costs? The first question is more difficult to answer, mainly because we often are not sure of the extent of the effect of transportation on the two entities.

It may be, for instance, that air pollution in a certain sector of a city is created mostly by an industrial plant there and not by automobiles, trucks, buses and so forth, so that air pollution should not be counted as a disbenefit of transportation. Even a prominent item like travel is not caused by the transportation system alone, but is a function of land use and other factors.[18] From these example situations we can conclude that an accounting of benefits should include only those attributable to the particular alternative under study but that such an approach would require the identification of cause and effect relationships about which, in many cases, little is known.

Another aspect of the benefit and cost identification problem is that of the inclusion or noninclusion of benefits or costs passed from one level of government to another. Wohl and Martin [8.5, p. 181] pose an interesting example of such a situation:

> Should a state highway agency, in deciding among various highway projects (including the null alternative), consider only the consequences to the state highway users or those to the entire state populace or should it adopt a broader national point of view? Also, should the state highway agency consider the economic feasibility of only the *state* expenditures on construction, maintenance, and administration, or should it be concerned with the feasibility of total outlays, whether federal, state, or local?

Most people would argue for the national point of view, but the vote would be far from unanimous.

8.2.5 Measurement of Benefit Factors

If, for purposes of evaluation, an attempt were made to list all of the factors affected by a given transportation alternative, a major difficulty to be faced would be that of measuring (or actually defining) the factors. Of course, travel time and number of trips are two entities which are fairly easy to measure, but, as the time-worn argument goes, beauty is not easy to gauge.

We might try to utilize such individual measures as color (wavelength), hue, contrast, brightness, and so forth[19] in combination, but to date no one has originated a single, mutually satisfactory measure of beauty. The problem which this situation creates for the evaluator is that, without an acceptable definition of beauty, he cannot predict whether an alternative transportation system will in fact add or detract from the appearance of the setting into which it is thrust, and, as a consequence, he cannot predict some of the system's benefits (or disbenefits). Lack of a measurement device thereby implies a possible miscalculation of benefits (and sometimes also costs).

8.2.6 Commensuration

Earlier in this chapter the problem of "mixing apples and oranges" was presented in the context of putting benefits in dollar terms. Assigning a "value" to travel time is a good example of this problem. The AASHO Red Book uses $1.55 per vehicle hour, or roughly $1.00 for each hour of a person's time, as the value. Haney [8.9], in a survey of the studies made before 1961, found assumed dollar values of time up to $2.74/person/hr.

---

[17] For more information on handling risk and uncertainty, see [8.11] and [8.22].

[18] See Chap. 5.

[19] That these factors are somewhat related to beauty is demonstrated by the presence of knobs for their control on color television sets.

By far and away the most cogent example of an attempt to put benefits in dollar terms is that found in a National Safety Council memo and adopted for the *Traffic Engineering Handbook*. There [8.23, p. 249], the statement is made that:

> The calculable costs of motor vehicle accidents are wage loss, medical expense, overhead cost of insurance and property damage. In 1964, these costs for all accidents (fatal, nonfatal, injury, and property damage) averaged about $175,000 per death. This "per death" total includes the cost of one death, 36 injuries, and 235 property damage accidents. The unit costs are:

Death	$34,000
Nonfatal injury	1,800
Property damage accident	310

Obviously, any attempt to put all benefits, such as reduction in deaths, on a common monetary basis will attract the label of "mercenariness," and, to some extent, this charge rings true. Nevertheless, if the evaluator does not endeavor to make all benefits commensurate, either in terms of dollars or "utiles" of utility or with some other unit, he runs the risk of *implicitly* assigning a value way out of proportion to its actual worth. If, for example, a highway costing $10 million and resulting in five deaths during its lifetime is chosen over a mass transit facility costing $2,000,000 and resulting in one death in the same period, then, all other factors being equivalent, the price of four deaths (five minus one) has been implicitly set at $8 million ($10 million minus $2 million), or at $2 million per life. This value, most people would agree, is too high. But the point is that many transportation planners and decision makers are faced directly with the unenviable task of deciding on the relative worth of the life of each citizen in the population.

Another interesting aspect related to attempts at commensuration is that values associated with a given item often vary according to the quantity of the item and the kind and amount of substitutes available. As an example of the first case, if 1 hour of travel time were saved from use of a new transportation system, it may be worth only $1 (per hour) to the traveler. Yet, if 2 hours were saved, they may be worth $4 total, or $2 per hour. As an example of the second case, suppose that in the previous illustration a second transportation system were built which also saved the traveler 2 hours. Because there now can be a choice in route of travel and because of the corresponding increase in dependability (if one route is closed, the other can be taken), the travelers may devalue the importance he attaches to travel time to, say, $1.50 per hour. These, then, are some of the considerations which make commensuration a difficult task.

8.2.7 Perceived versus Actual Benefits and Costs

A very perplexing decision to be made in most evaluation procedures is that of whether to use actual benefits and costs which accrue as a result of transportation systems or the ones *perceived* by the people affected by the system. Travel time again provides an interesting example. Suppose that, through verifiable calculations or empirical studies, the engineer or planner determines that 50 minutes are saved on a given journey over a new transportation system. The user, however, feels that he is saving less time,[20] say, 40 minutes and judges the worth of the system using this figure. Which figure should the evaluator use?

On the cost side of the picture, there also might be significant differences between actual and perceived costs. In fact, these differences are used to advantage by many business operations through the use of the charge account. The lesson is all too clear: it is much less agonizing to charge a $10 item than to pay for it in cash. The perceived cost of a cash payment is much higher.

It is important at this point to note the *significance* of the differences between perceived and actual costs and benefits. If a comparison were made between highway and mass transit facilities, for example, we probably would find that vehicle purchase costs generally are *not* considered as part of travel costs (prices) by the highway user[21] but that vehicle costs for transit would be important since they must be included in the fare, which is all too prominent. Because automobile travel *appears* less expensive, more tripmaking is done by that mode and less by transit, a situation which naturally affects the stability of transit service.

8.2.8 Discounting of Benefits and Costs

When considering the capital and maintenance costs associated with a transportation system, we described briefly the role of the interest rate in economic evaluations. Its purpose, generally speaking, is to indicate that with all other factors being equivalent, the expenditure of funds for present projects must be greater than that for future projects since money is worth more now than in the future. Similarly, benefits are worth more now than in the future. Almost everyone, when given the choice, would take $1,000 now instead of, say, $1,300 ten years from now.

It is the *unevenness* over time of the streams of benefits and costs that causes most practical discounting difficulties. The amoritization of costs over time may be fairly uniform and end after a period of 40 to 50 years, and amoritization costs, of course, would continue as long as the facility existed. But, on the other side of the ledger, benefits may continue to accrue way into the future, perhaps even at an increasing rate (Fig. 8.8).

An interesting example of this type of situation is the famous Appian Way (Appia Antica). Opened by Claudius Appius in 312 B.C. and running outside the ancient walls of Rome, this facility still is providing service benfits to travelers after some 2,300 years of use.[22] The prolonged nature of this service brings to the fore the question of how to compare in a correct manner the different time-sequenced and widely divergent streams of benefits and costs.

---

[20] In most cases, those affected by a transportation system do not have the opportunity to determine *exactly* how they are being affected.

[21] The mode choice model presented in Chap. 6 indicates this clearly. Automobile and insurance costs are *not* shown to have an effect on choice of mode of travel.

[22] Information taken from A. Storti, *Rome: A Practical Guide*, E. A. Storti, Venice, Italy, 1965.

The difficulty in the AASHO approach to benefit and cost comparison is this: if the period of benefit analysis is chosen to be relatively short, say 20 years, then the probability exists that a large amount of benefits will be ignored. Suppose, for example, that people value a dollar's worth of benefits today at 94¢ a year from now. Under this circumstance, it turns out the benefits 20 years from now are still worth 31¢. Thus, despite difficulties in estimating benefits at such a future date, it appears to be important not to overlook them since they are significant from an absolute standpoint (because of the probable increase in benefits over time) as well as from a percentage standpoint. Discounting of benefits and costs to their present worth, as done by most economists, is one possible solution to this problem.

8.2.9 Double Counting of Benefits and Costs

Another perplexing problem facing the evaluator or decision maker is that of the possible double counting of benefits and costs. It would not be correct, for instance, to include both the service station charged price for gasoline *and* the tax on gasoline as components of the unit cost of operating an automobile on the highway. This would be an obvious case of double counting since the tax already is incorporated in the service station price. Other opportunities for double counting are not quite as obvious, however, and stem basically from the transfer of benefits[23] from one person or group of persons to another. Mohring and Harwitz [8.8, p. 12] give the following example of a transfer:

> . . . completion of an expressway which reduces the time and dollar costs of travel to the center of an urban area may enable a suburban apartment house owner to charge higher rents to his commuting tenants than would otherwise have been possible. To the extent that he is able to do this, he has, in effect, extracted some of the highway benefits initially received by these tenants. He has, that is to say, forced them to transfer some or all of their highway benefits to him.

The conclusion to be drawn from this example is that it would be improper from an accounting standpoint to include both decreases in travel costs and increases in apartment rents (and thus in land values) as benefits from the expressway. They are "two sides of the same coin." Likewise, it would be improper to count any benefit or disbenefit until it has been shown to be a separate and distinct entity from any of the others under consideration. To make the distinction, however, is extremely difficult.

8.2.10 Determining Who Benefits

Perhaps the most critical comment that can be made of benefit-cost and similar approaches to evaluation is that they do not indicate who is receiving the calculated benefits. The benefits are totaled but nothing is said about their distribution among the poor or the rich; the young or the old; the user or the nonuser; the truckers or the railroads or the airlines; the whites or the blacks; those who live in one part of the city or region or those who live in another; or others. Needless to say, the question of who benefits is an important one. As John A. Volpe, President Nixon's original Secretary of Transportation, has stated:

> I would submit to this group (the Greater Dallas Planning Council) tonight—as I have done before the President and before my Cabinet colleagues—that all the job training centers, employment opportunities, health facilities, educational institutions, recreational areas and housing projects—all things that are needed in virtually all of our cities—will never be fully utilized if the people cannot get to them inexpensively, safely, and efficiently.
>
> We must have a new mobility in this nation if we are to fulfill our pledges to the disadvantaged, the young, the poor, the elderly, and the physically handicapped.[24]

In regard to evaluation involving various groups of persons, one observation which must be made and given strong emphasis is that by *not* looking at the types of groups affected by a given change in a transportation system, that is, by taking the attitude of "letting the chips fall where they may," the evaluator may *inadvertently* (and disproportionately) benefit one group at the expense of another.

An example of such a situation may be that of comparative highway benefits for the poor and rich in, say, Virginia's cities. *The U.S. Census of Housing: 1960* [8.29, Table 16] shows that the percentage of those occupied city housing units not having an automobile available ranges from 15.5 percent in Hampton to 38.5 percent in Richmond. And in the District of Columbia the percentage is 47.3! The meaning of these figures is fairly clear: if family members do not have access to an automobile (and most of the poor would fall in this category), they would have difficulty benefiting from any highway improvement, at least as compared to the gains they would receive from a mass transit improvement. As a consequence, any plan which, either by design or indifference, stresses highway construction and not mass transit can be expected to produce more benfits for the wealthier elements of society than for their poorer counterparts. The question of who gains or loses thus has great social significance, yet is rarely encountered in benefit-cost studies.

8.2.11 Criterion Form

If the engineer and planner are in fact concerned over the welfare of certain individuals or groups in society, then they cannot be interested solely in the amount of benefits, but also in their distribution. Winch [8.10, p. 33] is particularly critical of benefit-cost analysis for just this reason; he even goes so far to say that

> . . . unless we make some assumption about interpersonal comparisons, economics can offer no help in problems of policy such as that of highway planning. Our assumption is simply that if one person derives a benefit of $10 and another of $15 between them they are $25 better off; and that this situation is preferable to one which would make two other people $20 better off between them. It cannot be proven that from the standpoint of the community as a whole it is better to make one group of people $25 better off rather than another group $20 better off, since community welfare depends on the distribution of

---

[23] To be discussed in more detail in Sec. 8.2.12.

[24] Remarks prepared for delivery by Secretary of Transportation John A. Volpe before the Greater Dallas Planning Council, Tuesday, September 9, 1969, Dallas, Texas.

wealth as well as its total. It might well be better to have a smaller cake fairly divided than a larger cake unfairly divided.

The form of the criterion or objective function used in evaluation thus is of extreme importance.

Other forms of objective functions besides the maximization of the benefit-cost ratio certainly are available. Hitch and McKean, [8.2], for example, in their analysis of military evaluation discuss those of (1) maximizing the *difference* between gains (benefits) and costs, (2) maximizing gains with cost fixed, (3) minimizing costs with gains fixed, and (4) maximizing the minimum gains. Most of these and other functions have their analogs in the highway evaluation field,[25] but the choice as to which one to use appears to have been extremely subjective in the past. The point is that this *subjective* decision between criterion forms has a significant effect upon the evaluative decisions that come out of the *objective* technique (such as benefit-cost) and consequently cast some doubt on the supposed objectivity of the entire procedure.

8.2.12 Transfer of Benefits and Costs

Assume for the moment that we have settled on a particular criterion form and have, in effect, identified those individual groups whom we would like to see benefit from or pay for a new transportation system. How can we insure that they will, in fact, be the ones who receive the benefits or make the payments? The problem is that on the surface it may appear that certain groups are assimilating benefits (or costs), but that in actuality they are forced (or are able) to transfer them to some other group.

Suppose, for instance, that in the Mohring and Harwitz example presented earlier, it had been decided to attempt to direct as many of the benefits as possible to the expressway user. This attempt would have resulted in failure. The users are the *first* recipients of the benefits of reduced operating and travel time costs, but are forced to pay equivalently higher rents in order to live close enough to the expressway to get the travel benefits. In the end, the user has no actual gain in capital, services, or land to show for himself. Instead, the landlord has made the gain (assuming that he also is not forced to pass it on).

Quite obviously, this transference of benefits and costs creates a perplexing situation for the evaluator and, to make matters worse, there really has not been enough research to provide a basis for predicting the ultimate recipients and their shares of such transfers.

8.2.13 Multiplier Effects

Besides being perplexing, the transfer of benefits (and costs) performs a possibly valuable function: it allows for the multiplication of benefits. Many studies have shown that investments in transportation facilities, especially highways, do have this multiplier effect.[26] Decreased travel costs associated with a new transportation system allow the user to take the money saved and invest it elsewhere at a profit greater than the total of the reduced travel costs. Then this profit is invested in another, more profitable venture, and so the cycle goes. This creation of new benefits (or possibly disbenefits) is one of the major reasons why many people are interested in having new transportation systems in their region—their benefits generally permeate the whole area and grow rather significantly at the same time. Unfortunately, the benefit-cost approach to evaluation does not, in its present form, take into account multiplier effects.

8.2.14 Conformance with Goals

The final problem with benefit-cost and similar techniques for evaluation is one which is somewhat representative of the underlying nature of most of the problems discussed in this section. It has to do with conformity to goals. If we were to return to Chap. 4, we would see that a considerable amount of energy was expended in an attempt to develop goals for transportation not only for direct service factors but also for other factors external to the system but still affected by it. The effect was seen to be both broad and pervasive, playing a role in changing such diverse factors as ecology, business sales, and even church attendance in some cases. As a consequence, goals had to be set up for these and many other factors to insure that the impact of transportation "improvement" was guided in the most advantageous directions. Viewed in the light of this wide scope of intent for transportation, the benefit-cost approach as currently employed seems to have an extremely short range of concern.

To highlight some of the differences between factors taken into account in the AASHO benefit-cost approach and factors relating to likely transportation goal sets, we have developed ten goals of probable general importance to transportation (see Table 8.3). Along side each of these is a subjective assessment of whether or not the goal is recognized in the AASHO approach. Naturally, there can be difference of opinion over each assessment, but the point is that many goals are not covered. For example, the rather significant goal of safety, for both the user and nonuser (goal 9) alike, is not considered at all in the AASHO benefit-cost procedure, nor is the goal of reduced air pollution (goal 10); and other goals are given only partial recognition. Moreover, as has been emphasized throughout the discussions in previous sections, we must not be concerned only with the *extent* of the benefits but also with such matters as the time at which they accrue, the amount by which they are multiplied in passing from one person to another, and finally, and perhaps most important, the nature of the ultimate recipients of the benefits (and costs).

Of course, the amount of effort involved in the type of evaluation implied above should be recognized. It would require gathering data and making predictions for an extremely wide range of factors, much wider than has usually been the case. In fact, one of the main reasons why techniques such as benefit-cost have been

---

[25] Examples are the annual cost method, the rate of return method, and others.

[26] See, in particular, the summary by Isard [8.14].

Table 8.3 Extent of Consideration in AASHO Benefit-Cost Procedure of Goals of Probable General Importance to Transportation

Goals	Taken into account in AASHO benefit-cost procedure?
Goals for direct transportation service factors	
Provide a transportation system that will:	
1. Offer low door-to-door travel time (with emphasis on low waiting and transfer time).	Yes
2. Have a low door-to-door travel fare and/or cost of operation (if user owned).	Yes
3. Offer adaptability and flexibility in routes, schedules, types of goals hauled, etc., to meet variations in demand of different sorts.	Partially
4. Be dependable in all weather, traffic conditions, etc.	Partially
5. Enable the greatest returns on investments.	Yes
Goals for factors affected by transportation	
Provide a transportation system that will:	
6. Better the economic position of each and every individual.	Partially
7. Cause the development of more and better activities and facilities.	No
8. Offer a reduced need for land of various types.	Partially
9. Offer a high level of safety to those in contact with the system.	No
10. Not add to air pollution or give off toxic gases externally.	No

utilized so much in the past has been the *relative* ease of data collection and prediction. But the present procedure of collecting land use, travel, and transportation system data still is a fairly time and money consuming one, and it appears that, in relation to the overall pervasiveness of transportation, only a limited set of the effects associated with desired goals have been gauged.

8.3 THE COST-EFFECTIVENESS EVALUATION TECHNIQUE

In reviewing the preceding comments and criticisms on benefit-cost and similar evaluation procedures, one has to be somewhat dismayed with the seemingly overwhelming complexities facing the decision maker. One also gains some appreciation for the position of the politician or manager who must react to and give solutions for these types of problems every day. The question, then, is what, if anything, can be done to improve decision-making procedures as they exist today? A partial answer lies in the cost-effectiveness technique developed originally to aid the military in making their extremely important decisions.

The cost-effectiveness technique actually is a much less sophisticated procedure than one might at first suppose. It works on the basic premise that better decisions will arise if clearer and more relevant data are supplied to the decision maker. No specific attempt is made to put all benefits and costs in common units such as the dollar. As Thomas and Schofer [8.4, p. 218] remark on the cost-effectiveness approach:

> Because many of the consequences and outputs from the transportation system are intangible and otherwise difficult to value in some common metric, the decisions regarding the conversion to a single dimension—and hence the plan selection decisions—are necessarily subjective in nature, at least at the present time. . . .
>
> What might be more useful at this time is a technique for providing the kind of informational support for the selection of alternative plans which recognizes the complex nature of these transportation decisions. Such a decision supporting framework would not attempt to *make* decisions, but instead *would structure the information required for making a subjective but systematically enlightened choice* (our underlining). At the same time, however, the framework . . . must be sufficiently flexible to permit the adoption of more sophisticated techniques, such as analytic methods for realistically implementing benefit-cost analysis or ranking schemes, when such techniques are appropriate.

In conjunction with these remarks, Thomas and Schofer specify three criteria which any framework for evaluation should satisfy:

1. It should be capable of assimilating benefit-cost and similar methodological results *in addition* to other informational requirements.
2. It should have a strong orientation toward a system of values, goals, and objectives.
3. It should allow for the clear comparison of *tradeoffs* or compromises between objectives by making explicit the relative gains and losses from various alternatives.

These criteria also can be inferred from the criticisms in the preceding section of this chapter and tend to reinforce the needs brought out there. The cost-effectiveness approach, as a later example will show, seems to satisfy all three of the criteria.

8.3.1 Description of Cost-Effectiveness Framework

In the application of cost-effectiveness analysis, the attributes of the alternative relevant to the decision are separated into two classes—costs and indicators of effectiveness. Costs are defined as the monetary outlays necessary to procure all of the resources for the construction or purchase, operation, maintenance, and so forth of the facility during its useful life cycle. Of course, this assumes that the pricing mechanism operates so that all items expended on the project can be valued in terms of dollar prices. Where this is not possible, it may be necessary (and entirely realistic) to consider costs in other units of measure, such as hours of labors and tons of steel, as well. This approach to costing is contrary to that in most present evaluation schemes and allows for a certain flexibility in cost analysis.

Effectiveness is defined as the degree to which an alternate achieves its objectives. The definition, by itself, helps to overcome one of the major objectives to the benefit-cost approach in that goals are specified explicitly and are not covered by an all encompassing "benefit" term. In the AASHO case, for example, "benefits" are related to reductions in user operation costs, user time, tax payments and so forth, but in a particular situation these factors may be of only minor concern. The objectives to be met may be akin to an entirely different set of factors.

Information regarding the costs and effectiveness of the alternatives is presented to the decision maker who, in turn, makes the subjective choice of the one which seems best to him. While the planner and engineer may provide all the supporting data and estimates from these data, and may even suggest what alternative appears best to them, the ultimate choice is left to the duly appointed decision maker(s). No hard and fast decision rules, such as those inherent in the benefit-cost approach, are permitted to make the selection "automatically." It is quite permissible, of course, to provide the decision maker with information concerning the benefit-cost ratio and the like; however, these are and should be kept from being the sole determinants of choices among alternatives.

The value of the cost-effectiveness approach lies in several areas:

a. It stimulates, to some extent, the process by which actual decisions are made.
b. It allows for the clearer delegation of responsibilities between analyst and decision maker.
c. It makes it easier to provide the type of relevant information, structured in an understandable form, so that the choice process is simplified.

8.3.2 Cost-Effectiveness: An Example

The example of the cost-effectiveness approach that follows is based on an article by Millar and Dean [8.30] describing one part of the *Manchester (England) Rapid Transit Study.* While the article itself did not deal directly with cost-effectiveness as an evaluative technique, it did seem to fit very neatly into the framework described in the preceding section.

The government agencies concerned with the transit problem in Manchester made several recommendations to the study group before a detailed investigation was initiated. As quoted from Millar and Dean [8.30, p. 155]:

> The Ministry of Transport recognized that this study would not only be of value in the context of providing a *well-balanced* and *economical* overall transport system for Manchester, but would also yield information of wider application and interest.

Moreover:

> It was stipulated that this evaluation should investigate the characteristics of any system which could be *built by 1972;* that the *quality of service* which each could give should be assessed; that the likely *environmental effects* be explored; and that reliable estimates should be provided of the *capital and operating costs.* (emphasis ours)

The underlined statements can be thought of as general goals toward which the decision regarding a rapid transit system should be directed. Thus, in a general sense, the evaluation was goal oriented, as is desired in a cost-effectiveness approach.

After preliminary elimination of some candidate transit systems (mainly because they could not be built by 1972), the study group settled on four possible alternatives: (1) Safege monorail, (2) Electric railway (duorail), (3) Westinghouse skybus, and (4) Alweg monorail. These systems are pictured collectively in Fig. 8.14. We will not detail their technical characteristics here.

Data were gathered on each system. The first items collected were responses to direct questions. Could the system be built by 1972? Did the system have a route capacity of 7,500 persons per hour (pph)? Would the system fit in with the present British Rail system? As seen in Table 8.4, the answers to the first two questions were "yes" for all alternatives. However, only the duorail system would be compatible with British Rail.

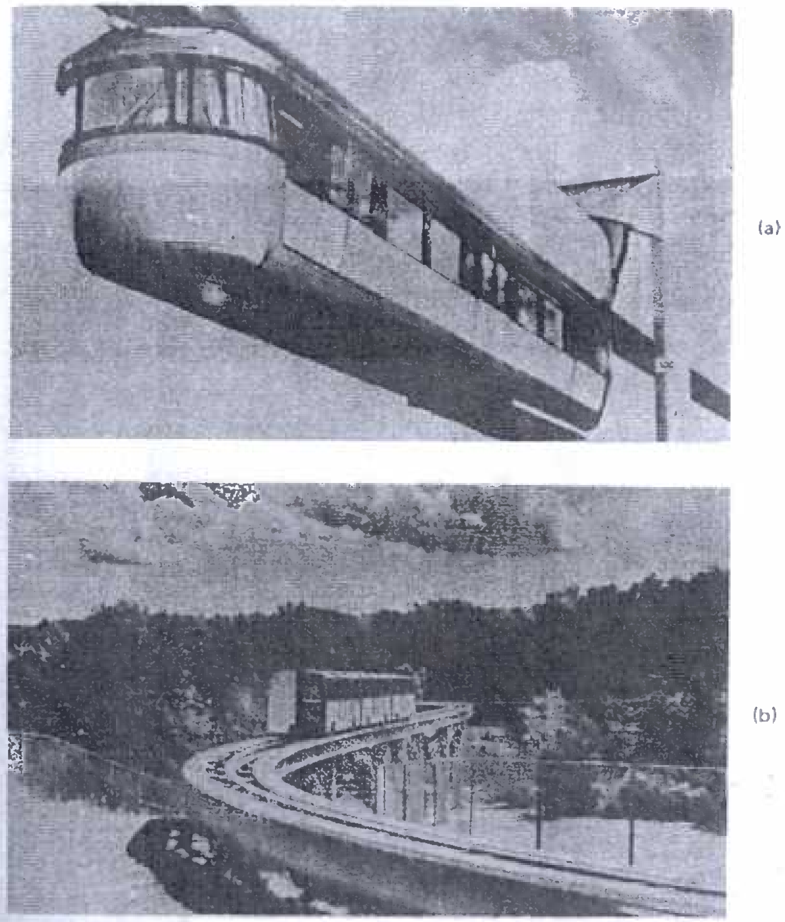
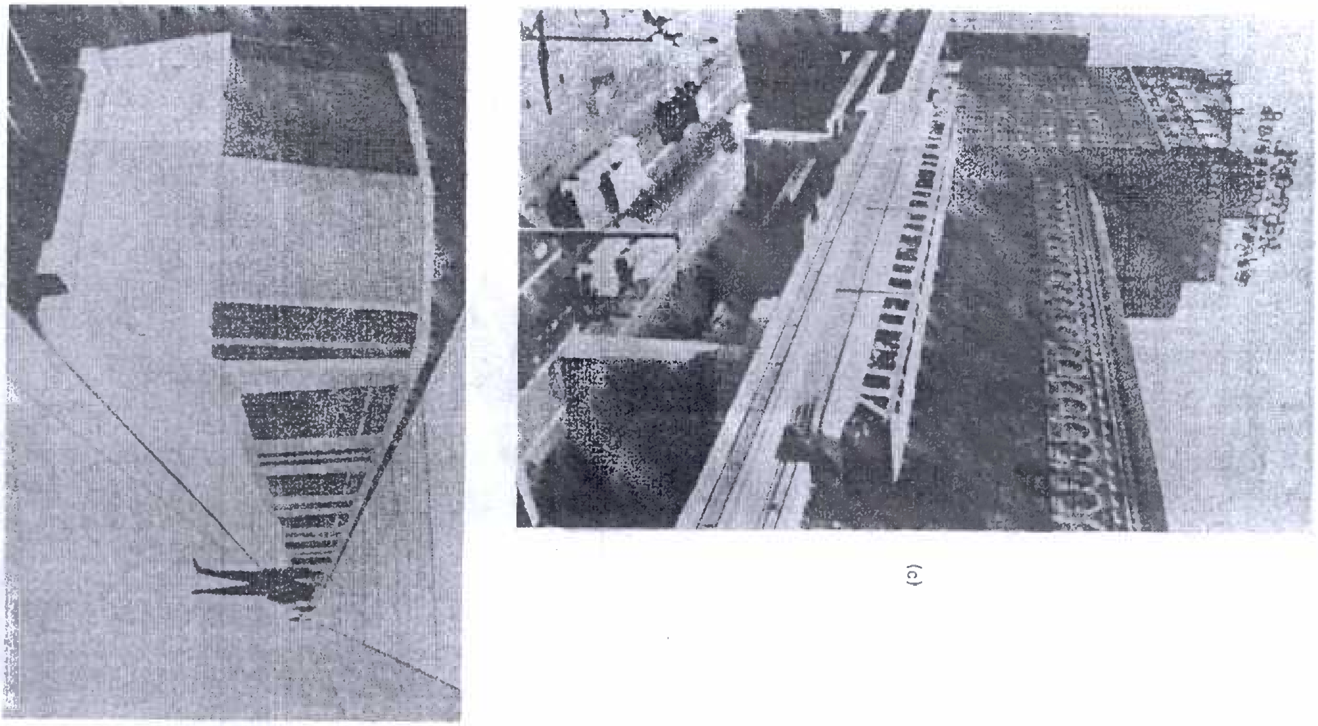


Fig. 8.14 Four transit system alternatives: (a) Safege monorail, (b) Electric railway or duorail. (*Continued*)


(c)

(d)

Fig. 8.14 (*Continued*) Four transit system alternatives: (c) Westinghouse skybus, and (d) Alweg monorail.

Table 8.4 Effectiveness and Cost Characteristics for Four Possible Rapid Transit Systems for Manchester

Effectiveness measures	Safeage monorail	Duorail	Westinghouse skybus	Alweg monorail
Could be built by 1972?	yes	yes	yes	yes
Route capacity of at least 7,500 mph PPHPD	yes	yes	yes	yes
Compatible with existing British rail system	no	yes	no	no
Maximum speed (mph)	50	60	40	50
Mean acceleration rate (mph/sec)	3.3	3.0	2.3-3.0	2.7
Car capacity (person)	173	279	120	360
Height of guideway above ground (ft)	over 16.5	16.5	16.5	16.5
Beam span (ft)	104	60	60	65
Width of elevated span (ft)	30.3	27.5	19.8	15.5
Use at ground level	Suspended	On ground	On ground	On ground
Tunnel diameter (ft)	17.0	15.6	14.0	18.3
Switching	Slow	Fast	Undeveloped (?)	Slow
Noise level (internal) dB(A) over drive unit	68	71	*	81
Noise level (external) dB(A) 25 ft away	81	88	*	80
Total car requirements for				
10,000 pph	72	44	110	70
20,000 pph	144	88	220	135
30,000 pph	216	132	330	204
Train headway (min) at				
10,000 pph	2.65	2.84	2.87	3.64
20,000 pph	2.65	2.84	2.87	2.76
30,000 pph	2.65	2.84	2.87	2.44
Costs				
Total capital costs (£)				
(at 30,000 design hour cap.)	81,110,000	61,090,000	66,240,000	66,920,000
Annual operation and maintenance costs (£)				
(at 30,000 design hour cap.)	2,040,000	1,410,000	1,800,000	1,760,000
Tota annual cost (£)	7,350,000	5,330,000	6,130,000	6,090,000

*Information not available.

The second set of data dealt with performance characteristics and structural dimensions. The main differences between systems appear to be that

a. The skybus has a slightly lower maximum speed and mean acceleration rate.
b. The Safege monorail, hanging below the guideway, would require a taller structure and would also need a major structure on ground level.
c. Switching would be easiest for the duorail.
d. The duorail and the skybus require the least diameter tunnel.
e. The Safege monorail could have the longest elevated beam span but also the widest.

Other characteristics did not seem to differ significantly.

Environmental considerations were reduced to two factors: noise levels and visual intrusion. The duorail was found to be somewhat louder than the others. No information was available at the time on noise levels from the skybus. (Note that evaluative decisions still must be made even in cases where some relevant information cannot be obtained). Visual intrusion, being a fairly subjective matter, was judged on the basis of reaction to a set of photomontages (Figs. 8.15 and 8.16) where mockups of the guideways of the four systems were superimposed over pictures of buildings and streets along the proposed route. The planners and designers felt there was no significant visual difference between systems based on these photomontages.[27]

The final set of data was the capital and operating costs for the four systems. On a total annual cost basis the duorail system was estimated to be least expensive, about 15 percent lower than that for the next lower system—the Alweg monorail. Capital costs for the duorail would be approximately £20 million (about $50 million) less than for the Safege monorail—the most expensive system.

The study group, in looking over the tradeoffs between different system characteristics apparently felt that, except for costs and adaptability to the British Rail system, all alternatives were essentially equal. The duorail, because it dominated the other systems on the two exceptional characteristics thus was chosen for recommendation for adoption.

8.3.3 Comments on the Cost-Effectiveness Technique

The preceding example has illustrated that an important characteristic of the cost-effectiveness technique is the manner in which information is presented to clarify relationships between alternatives and to outline tradeoffs or compromises that must be made to choose one alternative over the others. The cost-effectiveness framework does not indicate which system to select. It illustrates tradeoffs between alternatives, and it identifies dominated systems. It clearly lays out the expected accomplishment of each system and the related costs.

Whether the cost of additional effectiveness makes one alternative more worthwhile than another is a subjective matter and is therefore left to the decision makers. It can be argued that leaving this decision on a subjective level is not helpful and that what is needed is an approach which will determine the worth of additional effectiveness. However, it is just such information that cannot be provided, particularly in the evaluation of more complex transportation plans. To obtain such worth measurements involves much greater capabilities for working with large sets of interrelated objectives than is presently available. In the cost-effectiveness model, the decision makers just need to be sensitive to these issues and can then secure information indicating the cost and consequences of meeting a particular goal.

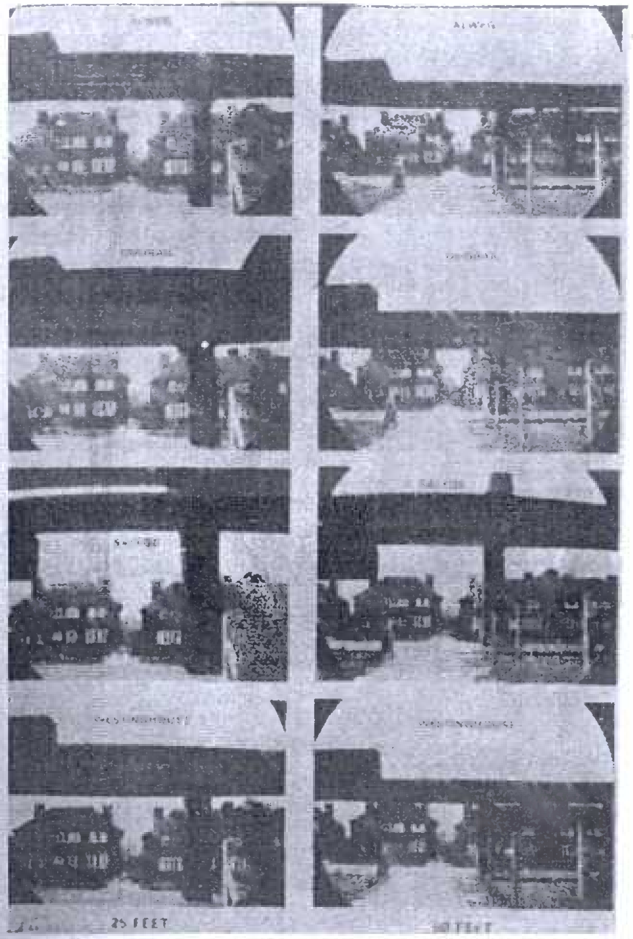


Fig. 8.15 Mockups of the guideways of the four systems superimposed over pictures of residential buildings and streets, at 25 and 50 feet. *Source:* DeLeuw Cather O hEoche, Manchester, England.

---

[27] This visual elevation was only of the structures, not the vehicles.

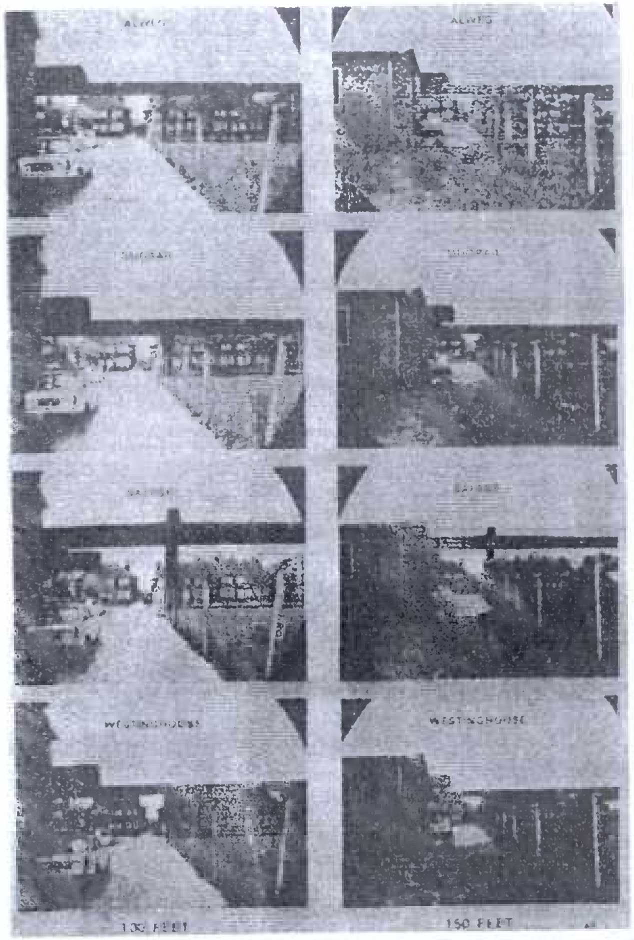


Fig. 8.16 Mockups of the guideways of the four systems superimposed over pictures of residential buildings and streets at 100 and 150 feet. *Source:* DeLeuw Cather O hEoche, Manchester, England.

The choice itself, if there are no other factors to consider, is made when the decision makers determine which of the alternatives results in a relation of cost to effectiveness acceptable to them. It is the decision makers, through the choice itself, who establish the relationship between cost and effectiveness, thus placing a boundary value on the measure of effectiveness.

In other words, if the duorail alternative were eventually chosen, the given level of effectiveness would be worth *at least* that particular cost. The duorail system is thus termed "cost-effective," for it provides decision makers with a level of effectiveness they deem satisfactory at what they consider to be a fair price. The

value of that level of effectiveness is merely bounded in that the decision makers might be willing to pay more than the cost of the duorail system for the same level of effectiveness. This amounts to a subjective consideration of the criterion of efficiency. The duorail results in sufficient returns on its resource costs to the decision makers at one point in time.

In many cases there will be other factors to consider, of course. For example, there may be a *required* level of effectiveness which must be achieved. When such a requirement is set in advance, it remains only to select the alternative which meets it at the lowest cost. Similarly, there may be a budget constraint which cannot be violated. In this case, the decision makers might try to achieve the highest level of effectiveness while staying within the budget constraint.

There are several aspects of the cost-effectiveness technique which are extremely valuable and should be presented briefly at this time. First, all forms of information, regardless of degree of sophistication of description, are admissible in the framework. Pictures, diagrams, and even sound tapes can be entered in the tally. Second, estimates of the extent of effectiveness factors and costs at various points of time in the future can be presented in a series of charts, thereby giving a much needed time orientation to benefits and costs and allowing for the all important weighting of effectiveness and cost according to time of occurence. Another important possibility is the breakdown according to different accounting schemes, that is, into different cost classifications. For example, the commonly used industry cost schedule might include such breakdowns as (1) research and development costs, (2) capital investments or fixed facility costs, and (3) variable or operating costs.

Costs classifications might also be developed whereby each individual outlay for various components of an alternative transportation plan is treated separately. For example, in the explanation of benefit-cost earlier in this chapter the categories were (1) right-of-way costs, (2) grading, drainage, and minor structure costs, (3) major structure costs, and (4) pavement and appurtenances costs.

An additional advantage of the cost-effectiveness technique is that, if desired, separate impact calculations for individuals or various groups of interest can be developed. A good example is found in a National Academy of Engineering report on *Technology Assessment* [8.31], which dealt with five alternatives for reducing noise at airports (see Table 8.5). Impacts were judged for airline passengers, airline operators, local taxpayers, and so on. Obviously, impacts will vary for different groups and, especially for implementation purposes, it may be useful in a cost-effectiveness application to determine who is being affected and to what extent.

Perhaps, the greatest advantage of the cost-effectiveness technique is that it is complimentary to the "values-goals-objectives-standards" format presented in Chap. 5. Looking back at Table 8.4, we see that the measures (or criteria) presented for evaluation of the Manchester rapid transit systems all flowed directly from the preliminary goals set up by the Ministry of Transport and others. Thus, the cost-effectiveness technique is a natural extension of attempts to plan using goals and objectives.

Table 8.5 A Characterization of the Impacts of Strategies 1 through 5 on the Set of Affected Parties

Affected parties	1 Continue methods used in 1967–1968	2 Relocate airports	3 Create a buffer zone around airports	4 Sound-proof residences	5 Modify aircraft hardware and flight profiles
Airline passengers					(±)
Airline operators	+	±	(±)		−
Airport operators	−	−	(+)	+	+
Airport and engine manufacturers	+	±	(+)		(+)
Airport neighbors	−	+	−	(−)	+
Local taxpayers		±	−	−	+
Local business	±	−	−	+	+
Local government	−	−	−	±	+
Federal government	+	±	−	±	−

Note: + or − represents favorable or unfavorable impacts, respectively; ( ) indicate that the impacts are judged to be uncertain even though they have been characterized; ± indicates favorable as well as unfavorable impacts. No entry is made where the impact is believed to be negligible or where no impact has been identified.

Source: [8.31, p. 84].

The major difficulty with the cost-effectiveness approach, and one which affects almost any evaluation technique, is that of overwhelming data requirements. This problem has been discussed earlier, but its importance cannot be overstressed. Many current transportation studies have found themselves inundated with data and subsequently unable to perform even some of the simple analyses required of them. This type of situation naturally is not desirable and requires extra effort on the part of analysts and decision makers to identify and extract only those factors of relevance to the evaluation.

8.4 ACTUAL TRANSPORTATION DECISION MAKING

Techniques such as cost-effectiveness have been found to be extremely helpful in guiding the decision making process. Yet any practitioner knows that there is a great difference between how decisions *are* made and how they *should be* made. Moreover, there surely is a significant difference between who actually makes and enforces decisions and who should be doing such. The purpose of this section is to present a brief exploration into several studies of real world decision making situations in order to highlight the differences mentioned above. Particular emphasis will be given to the actors and factors involved in urban transportation decisions.

8.4.1 BART: A Case Study Example

The San Francisco Bay Area Rapid Transit System (BART) became operational in 1972, but preliminary discussion on similar ideas began as far back as the Second World War. A unique and certainly provocative outlook on decision making relative to BART is presented by Beagle, Haber, and Wellman [8.32], who contend that its real purpose is to serve downtown banking and insurance interests:

> The second element in the [corporate metropolitan] strategy is the creation of a rapid transit network which will connect the central city to the outlying consumer markets and labor pools.
>
> The push for a rapid transit system in the Bay Area began in the early fifties with Carl Wente (chairman of the board of the Bank of America), Kendric Morrish (a Wells Fargo director) and Mortimer Fleishhacker (a Crocker Citizens Bank director connected with both BAC and the Blyth-Zellerbach Committee, a corporate group supporting urban renewal). These men initiated feasibility studies for what was to become the Bay Area Rapid Transit District (BART). In 1962 voters approved an initial bond issue for the construction of a high speed transit system embracing San Francisco, Contra Costa and Alameda counties and, ultimately, San Mateo and Marin.
>
> The first chairman of the BART board of directors was Adrian Falk, a retired vice-president of S&W Fine Foods and past president of the California Chamber of Commerce. According to Falk, BART's basic function was to make possible the centralization of certain executive functions in downtown San Francisco. "It's the only practical way," he told a local newspaperman. "Certain financial, banking, and industrial companies want to be centralized, want to have everyone near each other. They don't want to have to go one day to Oakland, the next day to San Jose, the next day to San Francisco."
>
> The major contributors to the public relations fund during the 1962 bond election were the three downtown banks plus a large number of companies which stood to benefit directly from construction contracts: Westinghouse, Kaiser, Bethlehem, Bechtel and the Downtown Property Owners and Builders. Bank of America's Carl Wente was head of the finance committee. BART was sold to the electorate as a crusade against the auto lobby. In fact, it ran into little trouble from this direction. The construction of thirty-two additional freeway lanes is projected for this area in the next ten years (there are forty-eight now). From the outset, BART was conceived of more as a commuter railroad than a true public transit system. It makes no pretense at carrying the great bulk of local traffic. Traffic on the Oakland–San Francisco Bay Bridge is still expected to reach the point of absolute capacity by 1975.
>
> BART will have many consequences: first, it will greatly encourage downtown congestion and density. It has already stimulated a substantial building boom. Almost immediately after construction began, the three major banks put up high-rise headquarters buildings downtown, and increasingly the downtown San Francisco landscape is spotted with new BART-oriented construction sites. According to the Chamber of Commerce, a "direct dividend" of BART's construction will be the new "Embarcadero Center," a Rockefeller venture of great ugliness. The Embarcadero Center will involve three high-rise buildings on the waterfront, and gradually plans are being announced for redevelopment of the entire waterfront area.
>
> More important, though, BART will guarantee the growth and renewed prosperity of downtown business. Essentially, it expands many times over the labor market area and the marketing area for goods and services. The "best workers" can be recruited for downtown jobs, choosing from the whole three-county area. And likewise, the richest, most discriminating consumers are given easy access to the prestige retailers of the downtown complex and the professional services in which it specializes.

> Also, property values all along the transit route will soar. In Toronto, they increased up to tenfold adjacent to the new subway line. And BART officials expect a comparable rise in their domain. Millions of dollars will be made by the public-spirited businessmen who pushed the plan and then made their services available to construct it. And the taxpayers will be stuck with paying off the bond issues and debts of $2 billion or more. That BART will actually be profitable, that it will contribute significantly to the retirement of its debt, is highly unlikely. BART has already run into financial troubles, spending far more than its initial capitalization. The public is about to pay for these profits, inefficiencies and costs of inflation out of a special hike in the sales tax.
>
> But the problem is not that business will make money off the construction and financing of public services; nor even that business will do a bad job and end up providing uncomfortable, ugly, and congested services. The problem is that it serves the rich and is paid for by the poor. By increasing the public debt and tax burden and by raising property values along the route, BART insures an increased squeeze on those least able to pay. Its effect on housing is obvious. Rents will be forced up as tax costs are passed on, and homeowners will be deprived of their property as the costs of ownership increase.
>
> BART doesn't even have the saving grace of helping workers from the black and brown ghettos get to industrial jobs outside the city. The trains do run both ways. But the routes link the central city with the rich suburbs, not the industrial hinterland. And the trains will pass through ghettos only incidentally: Hunters Point is not on the route, and there are no stations in the Oakland ghettos. BART will make little contribution to an anti-poverty policy of connecting poorer workers with jobs and a wider employment area.
>
> "The end result of BART is that San Francisco will be just like Manhattan," according to an influential insurance broker. "It's not a question of whether it's desirable," he continued, "but what's the practical matter. As a practical matter you can't have eighteen different banking and insurance centers. You have to concentrate them with all the various services around them. The people who run these centers want all their services—the people they work with—advertisers, attorneys, accountants—around them. It's a complete part of the way we do business in this country."

While we do not necessarily agree in total with the above statement, it certainly does indicate that decisions relative to transportation can be made at levels substantially different from those assumed, say, in the benefit-cost approach.

8.4.2 Actors and Factors in a Variety of Urban Transportation Decisions

The quote in the preceding section brought out some interesting aspects of urban transportation decision making in one situation. In this section we will attempt to broaden the outlook to include decisions made in urban areas throughout the United States.

Dickey and Stuart [8.33] surveyed 151 urban transportation decisions across the country. Their objective was to determine which actors and factors were predominant in these decisions. Eight hundred city planners, traffic engineers, public works officials, transit operators, and mayors were asked to report on a transportation project or problem of interest to them and to answer a series of questions about that situation. Biases in the questionnaires could not be avoided, of course, particularly since it was not possible to talk personally with each of the many respondents. The results of the study thus are subject to considerable ranges in interpretations. Nonetheless, the findings are presented here primarily to give some basic insight concerning the actors and factors most likely to be involved in urban transportation decisions.

The first set of analyses in the study concerned the actors in the various decision cases. These actors were divided into two classes: "professionals" and "participants." The former class consisted of planners, lawyers, engineers, and so on while the latter consisted of various governmental and nongovernmental agencies and people at different organizational levels. Governmental agencies included those on federal, state, metropolitan, county, and city levels. Examples of governmental personnel singled out were governors, national legislators, mayors, and city and county managers. Nongovernment groups included civic organizations, newspapers, and television and radio stations.

The mean number of *professional* types involved was surprisingly small, averaging only a little over three in each case. The number of all participants was much larger, with a mean near 14. This difference suggests that many nonprofessionals or similar professionals in different governmental agencies were heavily involved. We thus can conclude that with so many participants involved in each decision, a variety of roles will be taken and a certain amount of time will be needed to resolve the inevitable conflicts that arise. Urban transportation decison making therefore can not occur "instantaneously" (as is assumed in many evaluation techniques), but over an extended time period.

More information about the role of the actors in the various transportation problems cases is found in Table 8.6 and 8.7. The first table shows the number of cases, out of 151, in which different professionals were involved. Planners and traffic engineers dominate in their participation, but this was to be expected because they were the ones responding most often to the questionnaire. Moreover, they usually represent operating agencies most likely to be contacted in regard to urban transportation problems. Lawyers play a role in many cases, possibly indicating the increased use being made of the courts to help settle the more complex problems of relocation reimbursements, environmental damage, and so forth. Housing and renewal officals were engaged in as many as 28 of the 151 cases, perhaps showing the large incidence of joint development projects.

Table 8.6 Number of Urban Transportation Decision Cases in Which Each Professional Was Involved

Professional type	Cases	Professional type	Cases
Planner	117	Transit engineer	24
Lawyer	46	Traffic engineer	115
Educator	5	Other engineer	66
Architect	20	Housing or renewal official	28
City manager	47		
Transit manager	30	Welfare official	3

Note: Total number of cases is 151.
Source: [8.33].

Table 8.7 Number of Urban Transportation Decision Cases in Which Each Participant Was Thought to Be Influential

Participant type	Cases
Federal level	
Bureau of Public Roads	72
Urban Renewal Administration	28
Other	12
State level	
Governor	16
Legislator	20
Highway department	100
Planning agency	24
Other	17
Metropolitan level	
Transit operations	31
Special district	4
Regional planning, COG	57
Transportation planning	58
Other	7
County level	
Commissioners-legislative	29
Administrator	17
Traffic engineering	32
Other engineering/works	30
Planning	42
Health	2
Welfare	2
School	5
Other	5
City level	
Council/legislative	105
Mayor	97
Manager	53
Traffic engineering	103
Other engineering/works	75
Planning	113
Renewal	35
Health	2
Welfare	3
School	19
Police	28
Other	21
Nongovernmental	
Civic groups	79
Trade groups	41
Business/industry	53
Newspaper	73
TV/Radio	55
Individual citizen	73
Other	16
Other	5

Note: Total number of cases is 151.
Source: [8.33].

In Table 8.7 we find transportation agencies represented heavily at each level of the governmental hierarchy: the Bureau of Public Roads (now the Federal Highway Administration) in 72 cases, the state highway agency in 100, the metropolitan transportation planning agency in 58, the county traffic engineer in 32, and the city traffic engineer in 103. At present, then, there would seem to be almost equal representation from all levels.

Table 8.7 also seems to show the influence of many groups other than those directly responsible for transportation systems. At the federal level, the Urban Renewal Administration of the Department of Housing and Urban Development was connected with 28 of the 151 cases. The "other" federal agencies listed included the Urban Mass Transportation Administration and such diverse organizations as the Forest and Park Services, the Army Corps of Engineers, and the Department of Agriculture. At the state level and below, planning agencies start to make their impact felt. Moreover, at the lowest level (and the one generally closest to the citizen) there is an increase in the number of agency types to include schools, police, and public works as well as planning, renewal, and traffic engineering. It is also at this level that elected officials—mayors, city managers, and council members—are most responsive to the problems and influential in decision making regarding them.

The fact that the elected officials were so involved might indicate that transportation problems are of some concern to them and thus are not always left in the hands of the delegated agency. Many nongovernmental groups—civic, trade, business, newspaper, and TV/Radio—also were heavily involved at the local level, and individual citizens were influential in almost half (73/151) of the cases. It would seem that the voices of at least some nongovernmental actors were being heard directly and with about as much influence as various city agencies.

In the second part of the questionnaire, a list of factors of possible concern in urban transportation problems was presented to each respondent. These factors were divided into four classes: user-related, neighborhood impact, area-wide impact, and transportation management and planning. Room was left to add other factors not listed. Respondents were asked to determine whether each particular factor was (a) not considered, (b) considered but not important (i.e., "just considered"), or (c) important in the transportation decision being reported. A total of 39 factors were listed. Nine others were recognized in the answers added to the survey form.

The name of each factor and the number of times it was "just considered" or was important are displayed in Table 8.8. The nine additional factors are listed at the bottom. The distribution of factors in the four major categories was about equal, thereby indicating that *nonuser* considerations both on a neighborhood and area-wide level and management factors are of about equal concern as user factors.

The user factors taken into account in most transportation planning studies still were prominent, however. Travel time, user safety, and "presence of different modes of travel" all were just considered or important in a large number of cases. At the neighborhood impact level "local traffic circulation" rated highest in concern. "Access to economic activities" similarly rated high on the area-wide impact level, although this might be another indication of direct transportation needs. Another factor which often entered into the transportation decision making situation was that of facility appearance, "just considered" in 69 cases and important in 6 more. Noise, taxes, land values, and centralization and decentralization all were considered frequently. On the management side, costs were significant along with capacity. Interestingly, agency coordination was a matter of some concern, rating consideration in 69 cases and importance in 14. If this finding is representative, it would appear that many new problems are being generated for governmental organizations as they attempt to deal with the large numbers of factors listed in Table 8.8.

Table 8.8 Number of Urban Transportation Decision Cases in Which Each Factor Was Considered or Important

Factor	Cases just considered	Cases important
User related		
Travel time	76	14
User safety	77	13
Relief foot travel	20	1
Vehicle comfort	34	0
Weather protection	15	0
Signs, information	32	1
Dependability	19	1
Fares	22	3
Variety, novelty	17	0
Parking	39	5
No. of travel modes	54	8
Other	53	1
Nonuser-neighborhood impact		
Nonuser safety	54	6
Facility appearance	69	6
Air pollution	25	1
Noise	44	5
Taxes	37	1
Relocation	39	21
Local traffic circulation	100	19
Unusable land	33	1
Geographical boundaries	41	4
Land values	67	5
Multiple use	36	1
Other	31	1
Nonuser-areawide impact		
Access to economic activities	96	33
New economic activities	51	12
Access to social, cultural, educational activities	77	9
New social, cultural, educational activities	28	5
Centralization-decentralization	42	3
Natural features	32	0
Other	21	0
Transportation management and planning		
Costs	92	21
Capacity	83	19
Funding	47	22
Legal consideration	49	1
Agency coordination	69	14
Political feasibility	53	20
Type of management	31	5
Other	11	0
Added factors		
Emergency service	1	0
View from facility	1	0
Service frequency	2	1
Historical preservation	4	8
Temporary service	1	0
Removal	1	0
Vandalism, crime	1	0
Natural disorder	1	0
Psychological value	1	0

Note: Total number of cases is 151.
Source: [8.33].

Factors not included in the questionnaire but added by respondents involved such matters as services during emergencies, view from the facility, frequency of service, and preservation of historical and cultural sites. The only one of these that evoked consideration in more than three cases was the latter one.

8.5 SUMMARY

The broad aim of the chapter has been to present views on the manner in which metropolitan transportation system evaluation and decision making should be and are made. In the first section a fairly detailed presentation of the AASHO benefit-cost technique was given. Despite the fact that this technique is now losing favor as a *sole* decision making tool, it undoubtedly will continue to play a significant role in most future evaluation endeavors. The more subjective cost-effectiveness technique (Sec. 8.3), for example, is fashioned to accept benefit-cost ratios in the evaluative process. In addition, the cost-effectiveness approach overcomes many of the associated disadvantages of benefit-cost methodology (Sec. 8.2), especially that of the assignment of artificial weightings of importance to decision factors.

Actual decision making does not necessarily adhere to any particular methodology, however, although such actions are simulated to a degree by the cost-effectiveness technique. Benefit-cost ratios have been used heavily in the past and can be found in many reports. Yet in Sec. 8.4 it is suggested that at least some larger decisions (like for BART) are made by major business interests primarily for their own advantage and that benefit-cost ratios are simply unimportant afterthoughts. Whatever the situation, it does appear that in the many urban transportation decisions made across the country, many actors are participants and a great many factors in addition to user satisfaction are taken into account.

BIBLIOGRAPHY

8.1 American Association of State Highway Officials: *Road User Benefit Analyses for Highway Improvements*, Washington, D.C., 1960.

8.2 Hitch, G. H., and R. N. McKean: *The Economics of Defense in the Nuclear Age*, Atheneum Press, New York, 1966.

8.3 Kuhn, T. E.: *Public Enterprise Economics and Transport Problems*, Univ. of California Press, Berkeley, 1962.

8.4 Thomas, E. N., and J. L. Schofer: *Strategies for Evaluation of Alternate Transportation Plans*, Two Part Report, The Transportation Center, Northwestern Univ. Evanston, Ill., 1967.

8.5 Wohl, M., and B. V. Martin: *Traffic Systems Analysis for Engineers and Planners*, McGraw-Hill, New York, 1967.

8.6 Chapin, F. S., Jr. and S. F. Weiss (ed.): *Urban Growth Dynamics in a Regional Cluster of Cities*, Wiley, New York, 1962.

8.7 Meyer, J. R., J. F. Kain, and M. Wohl: *The Urban Transportation Problem*, Harvard Univ. Press, Cambridge, 1965.

8.8 Mohring, H. and M. Harwitz: *Highway Benefits: An Analytical Framework*, Northwestern Univ. Press, Evanston, Ill., 1962.

8.9 Haney, D. G.: *The Value of Time for Passenger Cars: A Theoretical Analysis and Description of Preliminary Experiments,* Final Report, vol. I, Stanford Research Institute, Menlo Park, Calif., May 1967.

8.10 Winch, D. M.: *The Economics of Highway Planning,* University of Toronto Press, Toronto, 1963.

8.11 Chernoff, H., and L. Moses: *Elementary Decision Theory,* Wiley, New York, 1959.

8.12 Jessiman, W. et al.: "A Rational Decision Making Technique for Transportation Planning," *Highway Research Board Record* 180, Washington, D.C., 1967.

8.13 Fishburn, P. C.: *Decision and Value Theory,* Wiley, New York, 1964.

8.14 Isard, W.: *Methods of Regional Analysis,* M.I.T. Press, Cambridge, 1963.

8.15 Bos, H. C., and L. M. Koych: "The Appraisal of Road Construction Projects," *Review of Economics and Statistics,* vol. 43, February, 1961.

8.16 Eckstein, O.: *Water Resource Development,* Harvard Univ. Press, Cambridge, Mass., 1958.

8.17 Galbraith, J. K.: *The Affluent Society,* Houghton-Mifflin, Boston, 1958.

8.18 Grant, E. L., and W. G. Ireson: *Principles of Engineering Economy,* (4th ed.), Ronald Press, New York, 1960.

8.19 Rothenberg, J.: *The Measurement of Social Welfare,* Prentice-Hall, Englewood Cliffs, N.J., 1961.

8.20 Ritter, L. F., Jr. and R. J. Paquette: *Highway Engineering,* (3d ed.), Ronald Press, New York, 1967.

8.21 Little, I. M. D.: *A Critique of Welfare Economics,* Oxford University Press, London, 1958.

8.22 Luce, D. R., and H. Raiffa: *Games and Decision,* Wiley, New York, 1957.

8.23 Baerwald, J. E. (ed.): *Traffic Engineering Handbook,* Institute of Traffic Engineers, Washington, D.C., 1965.

8.24 The Rand Corporation: *Measurement and Evaluation of Transportation System Effectiveness,* Federal Clearinghouse, PB-185 772, Springfield, Va., 1969.

8.25 Dodson, E. N.: "Cost-Effectiveness in Urban Transportation," *Operations Research,* vol. 17, no. 3, May-June, 1969.

8.26 Dorfman, R. (ed.): *Measuring Benefits of Governmental Investments,* The Brookings Insitution, Washington, D.C., 1965.

8.27 English, J. M. (ed.): *Cost-Effectiveness, the Economic Evaluation of Engineered Systems,* Wiley, New York, 1969.

8.28 Winfrey, R.: *Economic Analysis for Highways,* International, Scranton, Pa., 1969.

8.29 Bureau of the Census: *U.S. Census of Housing: 1960, Vol. 1, Virginia,* Washington, D.C., 1962.

8.30 Millar, J., and J. Dean: "Practical Considerations of Rapid Transit—A Summary of the Manchester Study," *Journal of the Town Planning Institute,* vol. 54, no. 4, April, 1968.

8.31 National Academy of Engineering: *A Study of Technology Assessment,* U.S. Government Printing Office, Washington, D.C., July, 1969.

8.32 Beagle, D., A. Haber, and D. Wellman: "Turf Power and the Tax Man," *Leviathan,* vol. 1, no. 2, 1969.

8.33 Dickey, J. W., and R. C. Stuart: "Actors and Factors in Urban Transportation Decisions," Presented to the Operations Research Society of America Meeting, Disneyland, Anaheim Calif., October, 1971.

9 Generation of Alternate Solutions

In using the phrase *generation of alternate solutions* we are attempting to portray a situation in which components such as vehicles, networks, terminals, and controls are brought together to form a complete system. Hopefully, when this system is evaluated it will be worthwhile or, in the most promising case, optimal in some sense. The objective of this chapter is to present some examples of the ways in which transportation solutions have been formulated or "synthesized."

The first section will deal with the general idea of creativity. The second section contains a discussion of different transportation technologies and their performance characteristics. This is followed by two sections in which more detailed descriptions of the processes by which actual transportation systems have been generated are presented. One section deals with a pedestrian mover system for a central city, the other with a metropolitan-wide system. In the last two sections, alternate approaches to the "using transportation to solve transportation problems" syndrome are discussed. In one approach, land use arrangements are altered to reduce the *need* for travel (and corresponding transportation systems). In the second, transportation is employed to create beneficial impacts on other types of development, in this case the mixing of families of different income types throughout a region.

No attempt will be made in this chapter to discuss all of the many ways in which transportation systems can be developed, simply because the variety and

Equation 5

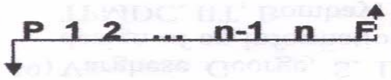
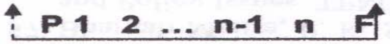
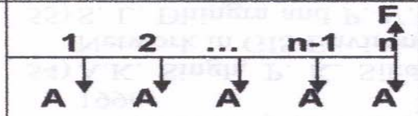
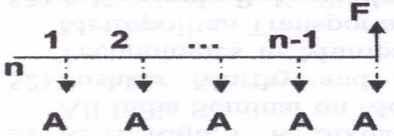
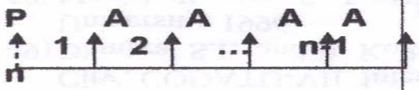
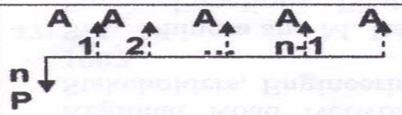
In the equation 3 the accumulated amount f, a single sum, may be converted into the present worth by multiplying the present worth single sum factor, thus

$$p = \frac{((1+i)^n-1)A}{i} \quad \frac{(1)}{(1+i)^n}$$

$$p = A\,\frac{((1+i)^n-1)}{i\,(1+i)^n}$$

Other equation will get by taking the reciprocal of these equations

Compound Interest Equations

S. no	Diagram	Equation	Factor
1		$F=P(1+i)^n$	$((1+i)^n$ Is known as compound amount factor (CA)
2		$P=F/(1+i)^n$	$1/((1+i)^n$ Is known as Present worth factor of single sum(PW)
3		$F=\frac{((1+i)^n-1)A}{i}$	$\frac{((1+i)^n-1)}{i}$ is known compound amount factor of uniform series (SCA)
4		$A=\frac{i\;F}{((1+i)^n-1)}$	$\frac{i}{((1+i)^n-1)}$ known as sinking fund factor (SF)
5		$P=\frac{((1+i)^n-1)A}{i(1+i)^n}$	$\frac{((1+i)^n-1)}{i(1+i)^n}$ is known present worth factor of uniform series(SPW)
6		$A=\frac{i(1+i)^n}{((1+i)^n-1)}\;P$	$\frac{i(1+i)^n}{((1+i)^n-1)}$ is known as capital recovery factor

Examples for Compound Interest Equations

- The future worth of Rest 1,00,000 at the end of 20 years invested at a compound rate of interest of 12% per annum

  CA(12%, 20 years) = 9.6463

  Future worth = 100000 * 9.6463

  = 964630.

- Present worth of a sum of Rs. 75,000 at the end of 10 years when the discount rate is 10 percent per annum

  PW(10%, 10 years) = 0.3855

  Present worth = 75000*0.3855 =28,912.50

- Annual cost of maintenance of a new road thrown open to traffic is Rs. 15,00,000. What is the future worth of this expenditure at the end of 10 years when the rate of interest is 15% per annum

SCA(15%, 10 years) = 20.3037

Future worth at the end of 10 years = 15,00,000 * 20.3037

= 304,55,550

- A major rehabilitation of a pavement will be done 10 years from hence at a cost of Rs. 100 lakhs. What should be the series of uniform annual payments that must be set apart to accumulate this amount, if the interest rate is 9% per annum

SF(9%, 10 years) = 0.0658

Amount of uniform annual payment = 0.0658 * 100 lakhs

= 6.58 lakhs

- Annual maintenance cost of a major bridge is Rs. 10,000. what is the present worth of this cost incurred for 10 years after the opening of the bridge? The discount rate may be taken as 12% per annum

SPW(12%, 10 years) = 5.6502

Present worth = 10,000* 5.6502

= 56,502

- The cost of construction of a new facility is Rs.100 crores at current price, and is met with by raising a loan. What is the annual payment of equal amount for 20 years to repay the loan, if the rate of interest is 10% per annum?

CR(10%,20) = 0.1175

Equal annual payment to repay the loan

= 0.1175 * 100 crores

= 11.75 crores

Methods of Economic Evaluation

- Equivalent Uniform Annual Cost Method (EUAC)
- Present Worth Of Cost Method (PWOC)
- Equivalent Uniform Annual Net Return Method (EUANR)
- Net Present Value Method (NPV)
- Benefit / Cost Ratio Method (B/C)
- Internal Rate Of Return Method

Equivalent Uniform Annual Cost Method (EUAC)

- **The equivalent uniform annual cost method combines all investment costs and all annual expenses into one single annual sum that is equivalent to all disbursements during the analysis period if spread uniformly over the period.**
- **When more than one alternative is being examined the one with the lowest EUAC is most economical.**
- **The present worth of this equivalent annual cost will give the same answer as obtained by the present worth of costs method.**

- EUAC = -I(CR-i-n) + T(SF-i-n) – K - U
- EUAC = -I(CR-i-n) + T(SF-i-n) – K - G_k(GUS-i-n)- U_E

Present Worth Of Cost Method (PWOC)

- **Present worth of cost method combines all investment cost and all annual expenses into a single present-worth sum, which represent the sum necessary at the time zero to finance the total disbursement over the analysis period.**

- **This present sum when multiplied by capital recovery factor will give the equivalent uniform annual cost obtained by EUAC**

- **PWOC = -I + T(PW-i-n) - K(SPW-i-n)**

  - U(SPW-i-n)

- **PWOC = -I +T (PW-i-n) - K(EPW-i-n)**

  - U(EPW-i-n)

Equivalent Uniform Annual Net Return Method (EUANR)

- **This method is EUAC plus inclusion of an income factor or benefit factor.**
- **The answer indicates the amount by which equivalent uniform annual income exceed the EUAC.**
- **The alternative having the greatest equivalent uniform cost net return of the one of greatest economy.**

- **EUANR = -I(CR-i-n) + T(SF-i-n) - K+R**

- **EUAC = -I(CR-i-n)+T(SF-i-n)-K - G_k(GUS-i-n)+R_G**

Net Present Value Method (NPV)

- In this method the stream of costs/ benefits associated with the project over an extended period of time is calculated and is discounted at a selected discount rate to give the present value.
- Benefits are treated as positive and cost as negative and the summation gives the net present value (NPV).
- Any project with positive NPV is treated as acceptable.
- In comparing more than one project, a project with higher NPV should be accepted.

- NPV= -I + T(PW-i-n) - K(SPW-i-n) + R(SPW-i-n)
- NPV = -I + T(PW-i-n) - K(SPW-i-n) - Gk(GUS-i-n)+R(EPW-i-n)

	Project			
	I	II	III	IV
NPB (#1000)	22759	25390	25856	26606
NPC (#1000)	20643	21958	21958	21958
NPV (#1000)	2117	3432	3899	4649
Ranking	4	3	2	1

1. **Project IV will have the greatest excess of benefits over costs**
2. **Project II has a greater excess than I, since the benefits last longer**
3. **Project IV's excess is more than project III's because the benefits come earlier in time.**

- **If the NPV of a project turns out negative, this would mean that discounted costs exceeded benefits, and thus the project should not be undertaken.**

Benefit / Cost Ratio Method (B/C)

- In this method all costs and benefits are discounted to their present worth and the ratio of benefit to cost is calculated.
- Negative flows are considered as costs and positive flows are benefits.
- If the B/C ratio is more than one the project is worth undertaking.

$$B/C = \frac{-(U_{GP}-U_{GB})-(K_{GP}-K_{GB})}{-(I_P-I_B)\,(CR\text{-}i\text{-}n)+(T_P-T_B)(SF\text{-}i\text{-}n)}$$

$$B/C = \frac{-(U_{GP}-U_{GB}) - (K_{GP}-K_{GB})}{-(I_P-I_B) + (T_P-T_B)\,(PW\text{-}i\text{-}n)}$$

	Project			
	I	II	III	IV
BCR	1.10	1.16	1.18	1.21
Ranking	4	3	2	1