6. Estimating the Cost of Accidents, 1981. National Safety Council, Chicago, Ill., 1982.
7. Discount Rates to be Used in Evaluating Time-Distributed Costs and Benefits. OMB Circular A-94. U.S. Office of Management and Budget, Washington, D.C., 1972.
8. FAA Based Benefit-Cost Computer Program. Environmental Science and Engineering, Inc., Gainesville, Fla., 1983.

Publication of this paper sponsored by Committee on Application of Economic Analysis to Transportation Problems.

# Quick Benefit-Cost Procedure for Evaluating Proposed Highway Projects

JOHN H. LEMMERMAN

ABSTRACT

There has been a need within New York State's Department of Transportation to quickly evaluate proposed highway projects from an economic standpoint. The ability to do so would be a valuable tool for use in deciding which projects deserve further consideration in setting priorities. The procedure described in this paper is a quick method of estimating operating and travel time costs under before and after project conditions (the difference is an approximation of benefits to be derived). These benefits can then be compared with the project's estimated construction costs for an evaluation of the project's worth. Accident costs must be considered separately because they are site specific and difficult to generalize. This quick benefit-cost procedure can be applied to a variety of project types, including closed and posted bridges, highway resurfacing, and major reconstruction.

A number of methods are used to evaluate the worth of proposed highway projects. The methods range from major corridor analyses, which use elaborate and detailed computerized networks and programs that simulate traffic under a variety of conditions, for urban areas, to a "back of the envelope" calculation for a little-traveled rural facility. Within the New York State Department of Transportation (NYSDOT) there was a need for a quick method of determining whether a proposed project was economically feasible, apart from other considerations that might be used to evaluate its need or worth. Such a procedure could serve as a first-cut filter to either eliminate projects that do not meet some minimum benefit level or to alert the project analyst that, for a project to be feasible, additional considerations (economic, social, or political) must be taken into account.

In New York State a highway project proposal is submitted by a regional office in the form of a Project Initiation Report (PIR). This report contains a description of the problem along with background, forecasts, maps, proposed solutions, and project cost estimates. However, an estimate of benefits to be derived is usually not available. Therefore, the quick benefit-cost procedure presented here was developed to provide this important input at an early stage in the project evaluation process. David I. Gooding, Planning Division, NYSDOT, developed an unpublished package of ten tables documenting costs of the various components and the aggregate operating and total time costs of highway travel for automobiles and trucks from 1967 through 1981. The procedure provides a fairly comprehensive estimate of vehicle operating costs and time costs. Accident costs are not considered because they are site specific and not amenable to the types of generalizations that can be drawn concerning the other two classes of costs.

## OVERVIEW OF QUICK BENEFIT-COST PROCEDURE

NYSDOT's Planning Division currently uses two highway user cost accounting programs in conjunction with its traffic simulation packages (1,2). Using the speed and congestion levels developed, the programs assign and summarize operating, travel time, and generalized systemwide accident costs. The quick procedure is a simplified manual version of this cost assignment process. It employs nomographs that can be entered with a minimum of information. To use this procedure, one needs only posted speed, average running speed, traffic with some estimate of vehicle mix, and highway section length for both the before and after conditions. Operating and travel time costs are calculated for both conditions and are then subtracted. The result can then be compared with the project costs by any of the various benefit-cost relationships.

In the nomographs (Figures 1-4), posted speed and average running speed are surrogates for facility

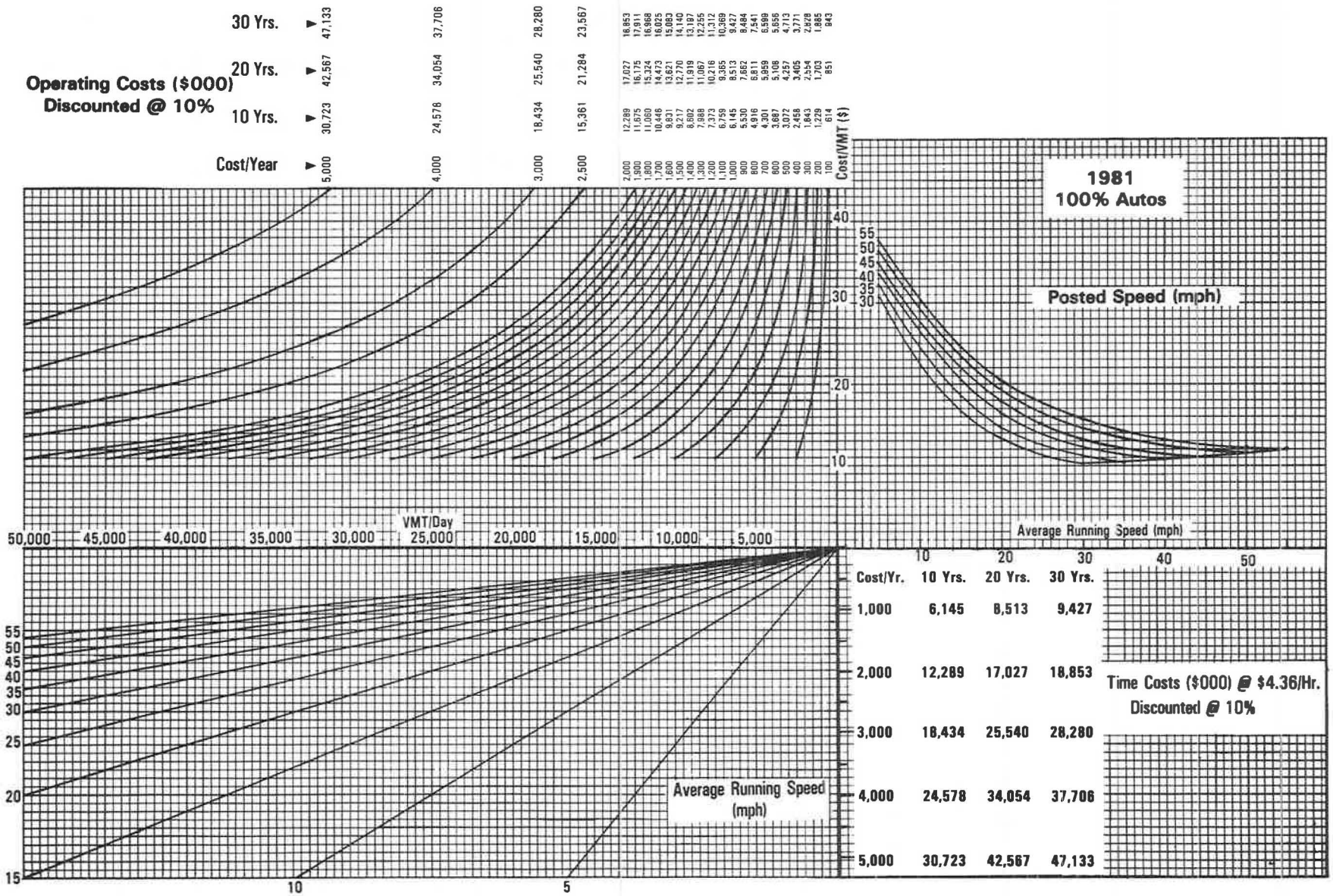



FIGURE 1 Nomograph for 100 percent automobiles.

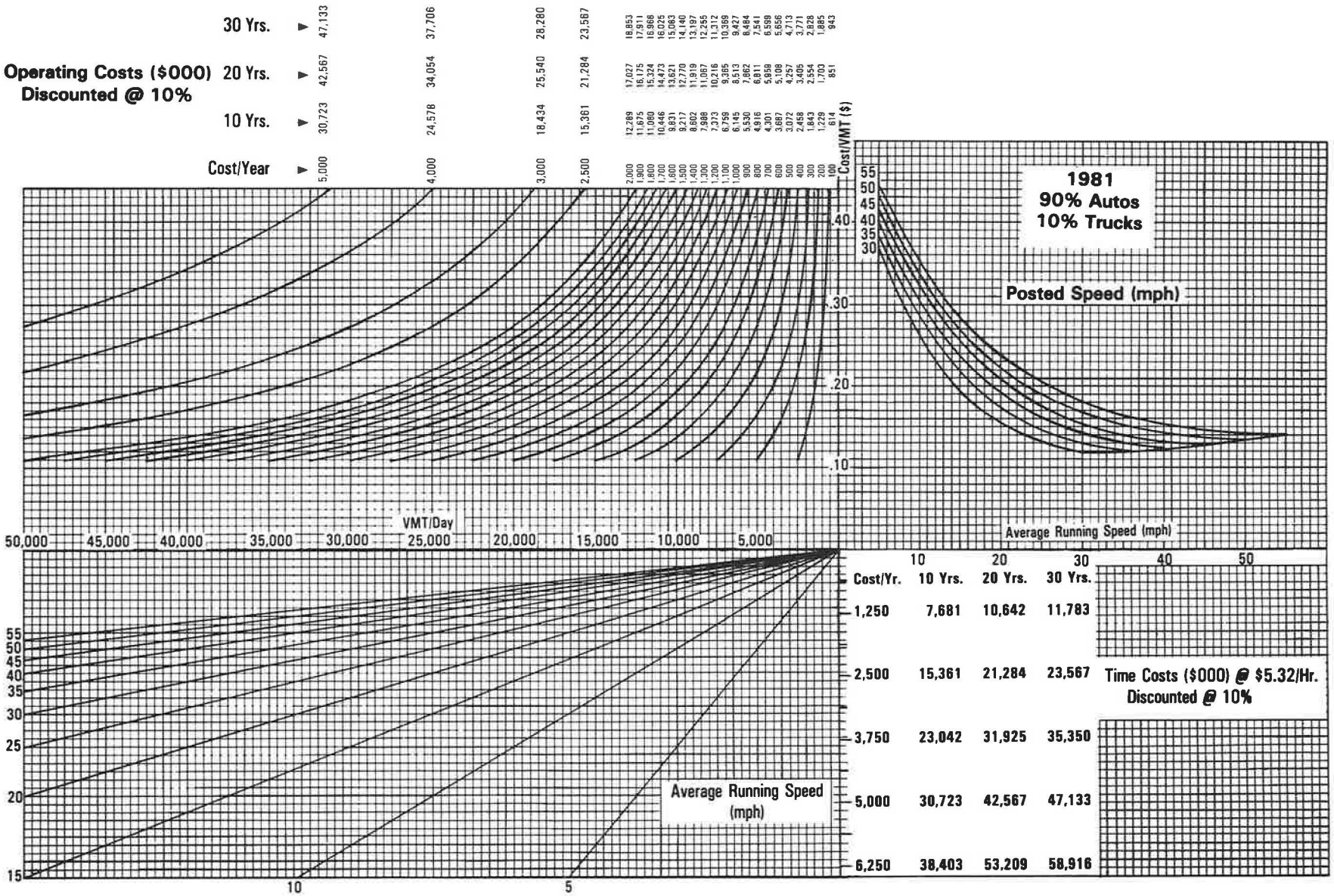



FIGURE 2 Nomograph for 90 percent automobiles, 10 percent trucks.

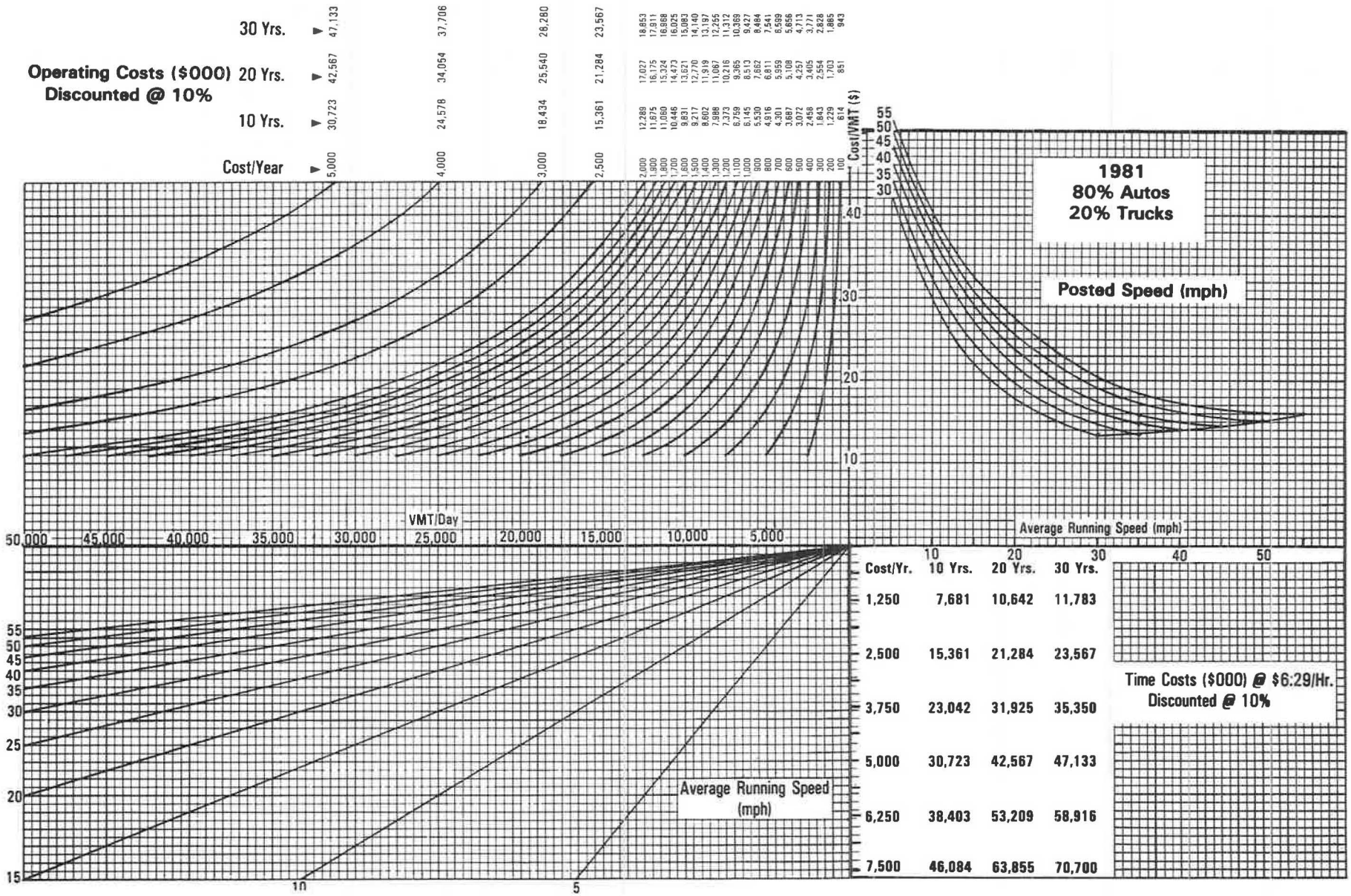
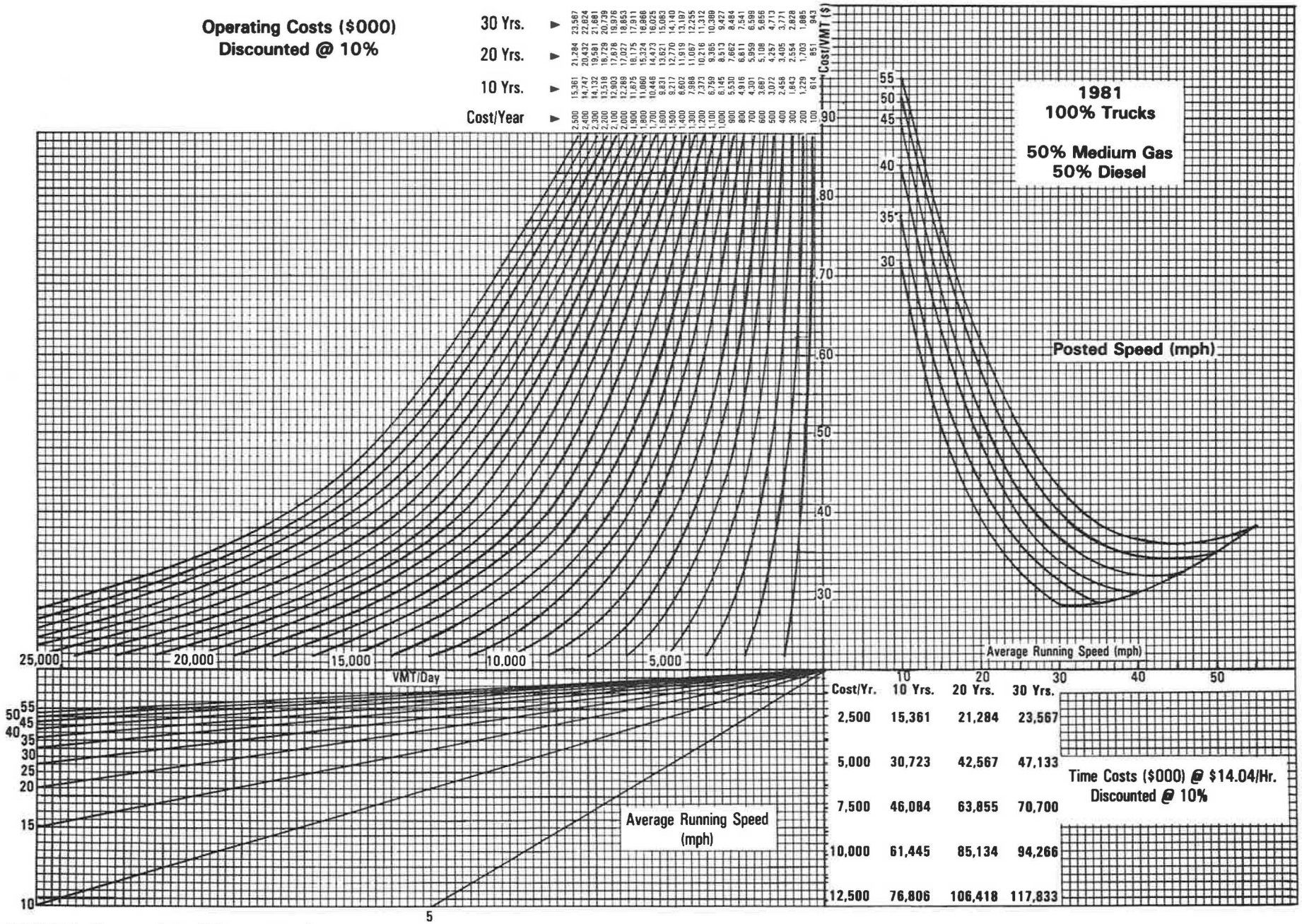



FIGURE 3 Nomograph for 80 percent automobiles, 20 percent trucks.




| Cost/Yr. | 10 Yrs. | 20 Yrs. | 30 Yrs. |
|---|---|---|---|
| 2,500 | 15,361 | 21,284 | 23,567 |
| 5,000 | 30,723 | 42,567 | 47,133 |
| 7,500 | 46,084 | 63,855 | 70,700 |
| 10,000 | 61,445 | 85,134 | 94,266 |
| 12,500 | 76,806 | 106,418 | 117,833 |

FIGURE 4 Nomograph for 100 percent trucks.

type and congestion, and the quick procedure makes use of an operating cost per vehicle mile traveled (VMT) relationship between those speeds as computed in the simulation models. That cost multiplied by VMT on each section under analysis gives the operating cost for that section for the condition under analysis. Travel time costs have also been developed, and, in conjunction with VMT and average running speed, travel time costs for a section can be computed. For ease of use, traffic is shown as VMT per day. This could be total VMT per day, peak hour VMT per day, and so on. Indeed, peak and off-peak periods might be analyzed separately. All costs shown, however, are annual (365 days). The input costs used in the models were developed separately for both automobile and truck travel. Therefore the automobile and truck operating and travel time costs can be computed separately depending on the percentages of each. For simplicity, or when only generalized approximations of vehicle mix are known, nomographs for a 90-to-10 or 80-to-20 ratio have also been prepared.

Although costs are incurred during implementation, benefits accrue during the life of a project. Maintenance costs are not considered in this procedure. Where they might be thought to vary substantially between the before and after condition, the analyst should procure this information from primary sources. Project costs are generally shown in the PIR in current dollars. Therefore only benefits need be adjusted. To facilitate this operation, both operating and travel time costs have been discounted at 10 percent and shown on the nomographs for estimated project lives of 10, 20, and 30 years. These periods should roughly approximate the life expectancies of most highway projects under consideration.

The quick procedure relies principally on differences in average running speed and congestion that result from highway improvements, with savings resulting from increased efficiency or decreased travel time. It is assumed that most projects will result in improvements in these areas, at least for current levels of traffic. When the improvements themselves, or normal growth patterns, would lead to an increase in traffic, the benefits can be applied to the average increase over the project life, at the same rate as they accrue to the base traffic, as long as such increases do not again create increased congestion and reduce average running speed. Should traffic and congestion be projected to increase beyond that point, the benefits, although less tangible in dollar value, might nevertheless be realized in the increased flow that has been made possible with little or no increased cost per VMT.

The possibility further exists that a highway project might be the cause of new, rather than diverted, traffic. The evaluation of any benefits to be derived from such induced travel, however, is beyond the scope of this quick procedure.

## ESTIMATING NEEDED INPUT

The type and scope of many projects lend themselves fairly well to a reasonable estimate of speed and congestion. For simple resurfacing projects, however, it may be difficult to estimate any such changes that might result. Some research has been carried out along these lines in an effort to relate speed to highway condition (3). It was found that at average speeds below 35 mph there is little measurable speed change that can be correlated with surface condition. However, at 35 mph and above, some correlation does appear to exist.

Table 1 can be used as a guide in estimating the magnitude of changes that might be expected as the result of a condition improvement. Surface score refers to the NYSDOT surface condition rating that is scaled from 1 to 10 (4). Assuming one of the initial deteriorated condition scores and a reconditioned average score of 9, the indicated speed change factor might be applied in the absence of any better information.

**TABLE 1 Surface-Related Average Running Speeds**

| Change in Surface Score | Speed Change Factor | Average Running Speed Before Improvement (mph) | | | | |
|---|---|---|---|---|---|---|
| | | 35 | 40 | 45 | 50 | 55 |
| 3.0 → 9.0 | .10 | 38.50 | 44.00 | 49.50 | 55.00 | 60.50 |
| 4.0 → 9.0 | .08 | 37.80 | 43.20 | 48.60 | 54.00 | 59.40 |
| 5.0 → 9.0[a] | .06 | 37.10 | 42.40 | 47.70 | 53.00 | 58.30 |
| 6.0 → 9.0 | .04 | 36.40 | 41.60 | 46.80 | 52.00 | 57.20 |
| 7.0 → 9.0 | .02 | 35.70 | 40.80 | 45.90 | 51.00 | 56.10 |
| 8.0 → 9.0 | .01 | 35.35 | 40.40 | 45.45 | 50.50 | 55.55 |

[a]Typical repair.

Vehicle mix data also may not be available to the analyst. The proposed project may be site specific--for example, an intersection, in which case the analyst would want to be aware of the prevailing conditions at the location. A 1982 NYSDOT study (5) reported the average values given in the following table. These may be used as a guide in estimating or as default values in cases where the percentage of trucks is not readily available.

Observed Truck Percentages on NYS Highways (percent of AADT)

| | Urban | Rural |
|---|---|---|
| Interstate | 11 | 26 |
| Non-Interstate | 13 | 16 |

Another estimated factor is the effect of a highway project on existing traffic on other facilities. It might be desirable to consider such effects with and without the proposed project in place. This is especially true in the case of a bridge or other facility that might be severely restricted or closed altogether.

Finally, as previously mentioned, because accidents tend to be very site specific and therefore difficult to generalize, no attempt has been made to estimate the reduction in accident costs attributable to a proposed project. However, the NYSDOT Traffic and Safety Division has developed a procedure for doing so based on previous accident experience and the type of improvement proposed. Therefore, to evaluate any benefit in reduced accident costs, Traffic and Safety's Safety Benefits Evaluation Form (TE 164) should be used.

## USING THE PROCEDURE

Use of the nomographs developed for this quick procedure is quite straightforward: Enter in the upper right quadrant with average running speed and go upward to the intersect with the curve for the posted speed on the section. From that point proceed left to the upper left quadrant to the VMT per day of the section and interpolate between the operating costs curves for 1, 10, 20, or 30 years. Likewise, for that same VMT value, proceed to the lower left quadrant to the line representing the average running speed. At that intersect, proceed right to the vertical travel time cost scale and interpolate for the 1-, 10-, 20-, or 30-year cost. The difference between the sums of the operating and travel time costs for the before and after conditions yields benefits that can be attributed to the project.

The quick benefit-cost procedure affords the analyst a means of estimating the major aspects of a project's worth while the project is still in the preliminary stages. The procedure provides a rationale for the initial priority ranking or the filtering out of projects early in the project development process. The procedure can be applied to a variety of project types, including closed and posted bridges, highway resurfacing, and major reconstruction. Table 2 gives the data needed for applying the procedure in these situations.

As previously mentioned, the procedure is based on average values for the various conditions and current proportions and dollar values in the computation of operating and travel time costs. Update would require recomputation (or possibly a simple factoring) of the nomograph in the upper right quadrant and of the vertical time-cost scale, or, in the simplest case, factoring of the resultant operating and travel time costs to current year. The use of nomographs is intended to keep the procedure simple, quick, and somewhat self-contained. It should also deter one from attributing too much precision to a procedure that uses averages and estimates as basic input.

Since the time this procedure was presented, a version has been programmed for the microcomputer. Input is cued and interactive, and much more flexibility is available in the application of interest rates, project life, and implementation dates. The need to interpolate, inherent in the use of nomographs, has also been eliminated. However, the previously stated caveat must still be kept in mind.

## EXAMPLES

### Example 1--Resurfacing

It is proposed to resurface a 2-mile section of two-lane highway at a cost of $2 million. The AADT is 5,000 of which 10 percent are trucks. The road is posted at 35 mph but congestion and the condition of the surface keep the average running speed to 20 mph. Resurfacing should increase the average running speed to 25 mph. Are the benefits to be realized from this project in line with the projected costs?

1. Using the nomograph of 90 percent automobiles and 10 percent trucks (Figure 5), start in the upper right quadrant at average running speed = 20 mph and go up to intersect with the curve for posted speed = 35 mph.
2. At that intersection, proceed horizontally to the left to the vertical line at which VMT per day = 10,000 (5,000 AADT x 2 miles).
3. This point is roughly 1/3 of the distance between the curves for $600,000 and $700,000 per year, roughly $633,000. Over the probable 10-year life of a resurfacing project, this can be interpolated as roughly $3,892,000 for operating costs.
4. At the 10,000 VMT per day line, go down vertically to the lower left quadrant to meet the 20 mph line. From the point of intersection, go right horizontally to the vertical time-cost axis and read the value: approximately $950,000 per year = $5,837,000 over 10 years.
5. Sum of before cost = $9,729,000.
6. Repeat steps 1 through 5 for the after situation: Operating costs = $530,000 per year = $3,257,000 over 10 years and time costs = $766,000 per year = $4,707,000 over 10 years. Total after costs = $1,296,000 per year = $7,964,000 over 10 years.
7. Substract total after costs from total before costs over the 10-year period to determine benefits to be accrued = $1,765,000.
8. Compared with the project cost of $2,000,000, the project is not cost-effective, but with a benefit-to-cost ratio of 0.88 it is not too bad.

### Example 2--Reconstruction and Widening

For the highway section described in example 1, as an alternative it has been proposed to reconstruct and widen the roadway to four lanes. This would allow traffic to travel at the posted speed (35 mph) as well as provide for future volume increases. This project would cost roughly five times the former and have an assumed life of roughly 20 years. How do projected benefits compare with the cost of such a project?

1. The before costs have already been computed; now that they must be summed over a 20-year period: operating costs = $5,392,000 over 20 years and time costs = $8,088,000 over 20 years. Total before costs = $13,480,000 over 20 years.
2. Using the same 90 percent automobiles and 10 percent trucks nomograph (Figure 5), start again in the upper right quadrant at average running speed =

**TABLE 2 Data Needed to Determine Operating and Travel Time Costs**

| | Proposed Project | | | |
|---|---|---|---|---|
| | | | Repair or Rebuild a Posted Bridge so Posting Can Be Removed | |
| Information Needed | Reconstruct or Rehabilitate on Same Right-of-Way with or without Widening or Other Capacity Improvements | Repair or Rebuild a Recently Closed Bridge | Automobiles | Trucks |
| Traffic | ADDT and percent trucks | AADT (that did or would use bridge) and percent trucks | AADT for bridge | Detoured traffic |
| Section length | Section length | Mainline section length from where detour leaves to where it reenters<br>Detour section lengths | Mainline section length affected | Detour section lengths for posted and operating speeds<br>Mainline section length from where detour leaves to where it reenters |
| Speed | Posted speed before and after<br>Average running speed before and after | Posted speed of mainline after<br>Posted speeds of detour sections | Posted speed of mainline before and after<br>Average running speed of mainline before and after | Posted speeds of detour sections<br>Average running speeds of detour sections |

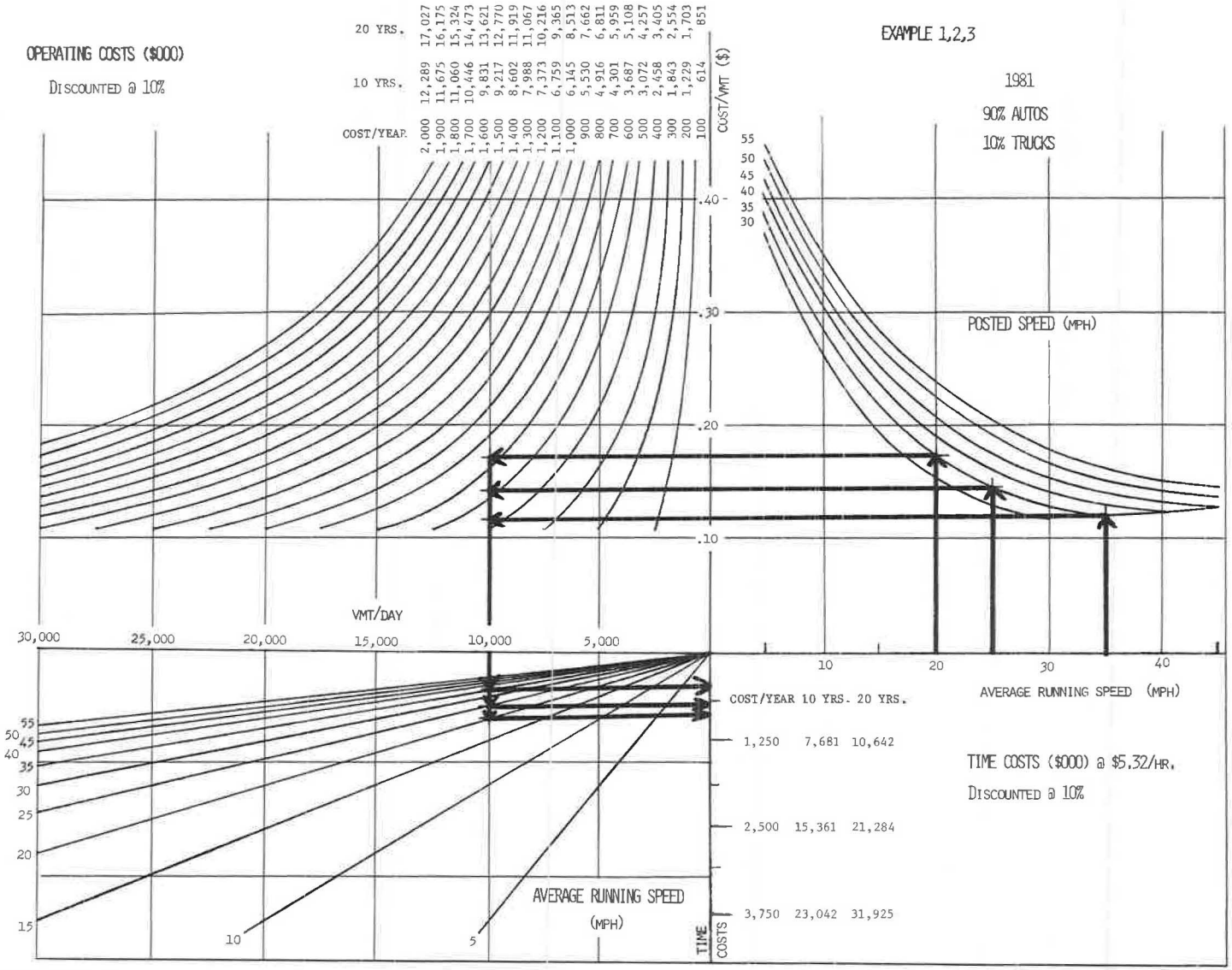



**FIGURE 5** Nomograph for examples 1, 2, and 3.

35 mph and go up to intersect with the curve for posted speed = 35 mph.

3. At that intersection, proceed horizontally to the left to the vertical line at which VMT per day = 10,000.

4. This point is roughly 40 percent of the distance between the curves for $400,000 and $500,000 per year, about $440,000. Over the 20-year life of a reconstruction project this can be interpolated as roughly $3,746,000 for operating costs.

5. Again, at the 10,000 VMT per day line, go down vertically to the lower left quadrant to meet the 35 mph line. From the point of intersection, go right horizontally to the vertical time-cost axis and read the value: approximately $500,000 per year = $4,257,000 over 20 years.

6. Sum of after costs = $8,003,000.

7. Subtract total after costs from total before costs over the 20-year period to determine benefits to be accrued = $5,477,000.

8. Compared with the project cost of $10,000,000, benefits over the life of the project would equal about half the project cost.

Example 3--Increased Project Cost

If the project used in example 2 were to cost $15,000,000, at what point would increased traffic justify the higher expenditure?

1. With VMT = 10,000 per day, total benefits = $9,747,000 over the life of the project.

2. Therefore total VMT/$15,000,000 = 10,000 VMT/$5,477,000. Total VMT = 27,388 VMT per day (traffic = 13,694 AADT) to justify the higher cost.

Example 4--Bridge Repair or Reconstruction

A bridge on a 55 mph highway, formerly carrying 5,000 AADT, was found to be structurally deficient and is now posted for 10-ton maximum loads. As a result, 250 trucks per day must now use a detour, posted at 40 mph and operating at 35 mph, which is 4 miles longer than the direct route across the bridge. In addition, the remaining bridge traffic must travel at a 45 mph average for bridge and approaches, a distance of roughly 0.1 mile.

The bridge could be rehabilitated to permit all traffic to use it again at about 45 mph for $2,000,000, or it could be reconstructed to allow all traffic to use it at 55 mph for $4,500,000. From an economic standpoint, what are the relative merits of the null versus rehabilitation versus reconstruction?

Part A--Trucks

1. Detour
   a. Because truck traffic is 250 vehicles per day for 4 miles of detour, the total truck volume of travel is 1,000 VMT per day. Because it is much easier to work at the 10,000 VMT per day scale, it is advisable to do so and then divide the answers by 10.
   b. Using the nomograph for 100 percent trucks (Figure 6), start in the upper right quadrant at average running speed = 35 mph and go up to intersect with the curve for posted speed = 40 mph.
   c. At that intersection, proceed horizontally to the left to the vertical line at which VMT per day = 10,000. This point is roughly 1/4 of the distance between the curves for $1,100,000 and $1,200,000 per year. That is approximately $1,125,000, or divided by 10, $112,500 per year. Over the 20-year life of a good rehabilitation, this can be interpolated as roughly $957,800 for truck operating costs over the detour.
   d. At the 10,000 VMT per day line, go vertically down to the lower left quadrant to meet the 35 mph line. From the point of intersection, go right horizontally to the vertical time-cost axis and read the value. The point falls about 1/6 of the distance between $1,250,00 and $2,500,000 per year. That is approximately $1,458,000 per year, divided by 10, equals $145,800 per year or $1,241,300 over 20 years.
   e. Add truck detour costs of $2,199,100.
2. Rehabilitation or reconstruction
   a. The truck traffic of 250 vehicles per day for 0.1 mile over the rehabilitated bridge amounts to 25 VMT per day. For ease in using the nomograph, especially the time-cost quadrant, this value is 1/40 of the truck VMT over the detour. Thus, it is possible to use the same VMT per day as in the previous calculations and divide the answer by 400 instead of by 10.
   b. Repeat the previous steps for the rehabilitation and reconstruction situations. For rehabilitation: operating costs = $3,300 per year = $28,100 over 20 years, time costs = $2,700 per year = $23,000 over 20 years, and total truck costs under rehabilitation = $6,000 per year = $51,100 over 20 years. For reconstruction: operating costs = $3,500 per year = $29,800 over 20 years, time cost = $2,200 per year = $18,700 over 20 years, and total truck costs under reconstruction = $5,700 per year = $48,500 over 20 years.

Part B--Automobiles

Using the nomograph for 100 percent automobiles (Figure 7) (an approximation because we know that light trucks still use the bridge), start in the upper right quadrant at average running speed = 45 mph (the first two cases), and 55 mph, respectively, and calculate operating and time costs for 475 VMT per day (4,750 automobiles per day for 0.1 mile). Use the 4,750 VMT per day scale and divide answers by 10.

For the before situation: operating costs = $21,300 per year = $181,300 over 20 years, time costs = $16,700 per year = $142,200 over 20 years, and total automobile costs before = $38,000 per year = $323,500 over 20 years. Rehabilitation for automobiles is the same as the before situation. For reconstruction: operating costs = $20,600 per year = $175,400 over 20 years, time costs = $12,500 per year = $106,400 over 20 years, and total automobile costs under reconstruction = $33,100 per year = $281,800 over 20 years.

Part C--Benefits

1. Before: automobile costs = $323,500; truck costs = $2,199,100; and total before costs = $2,522,600.

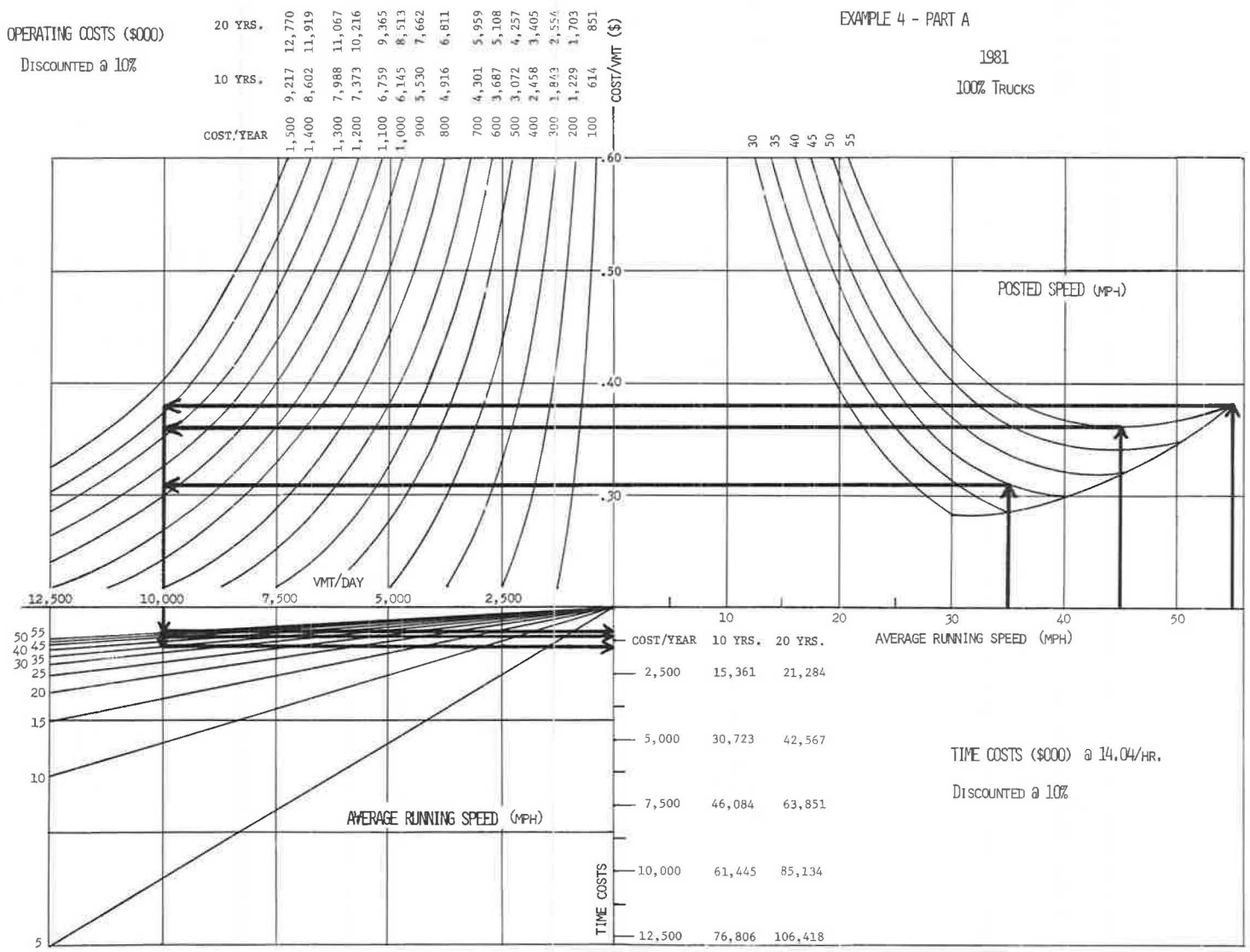



**FIGURE 6 Nomograph for example 4, part A.**

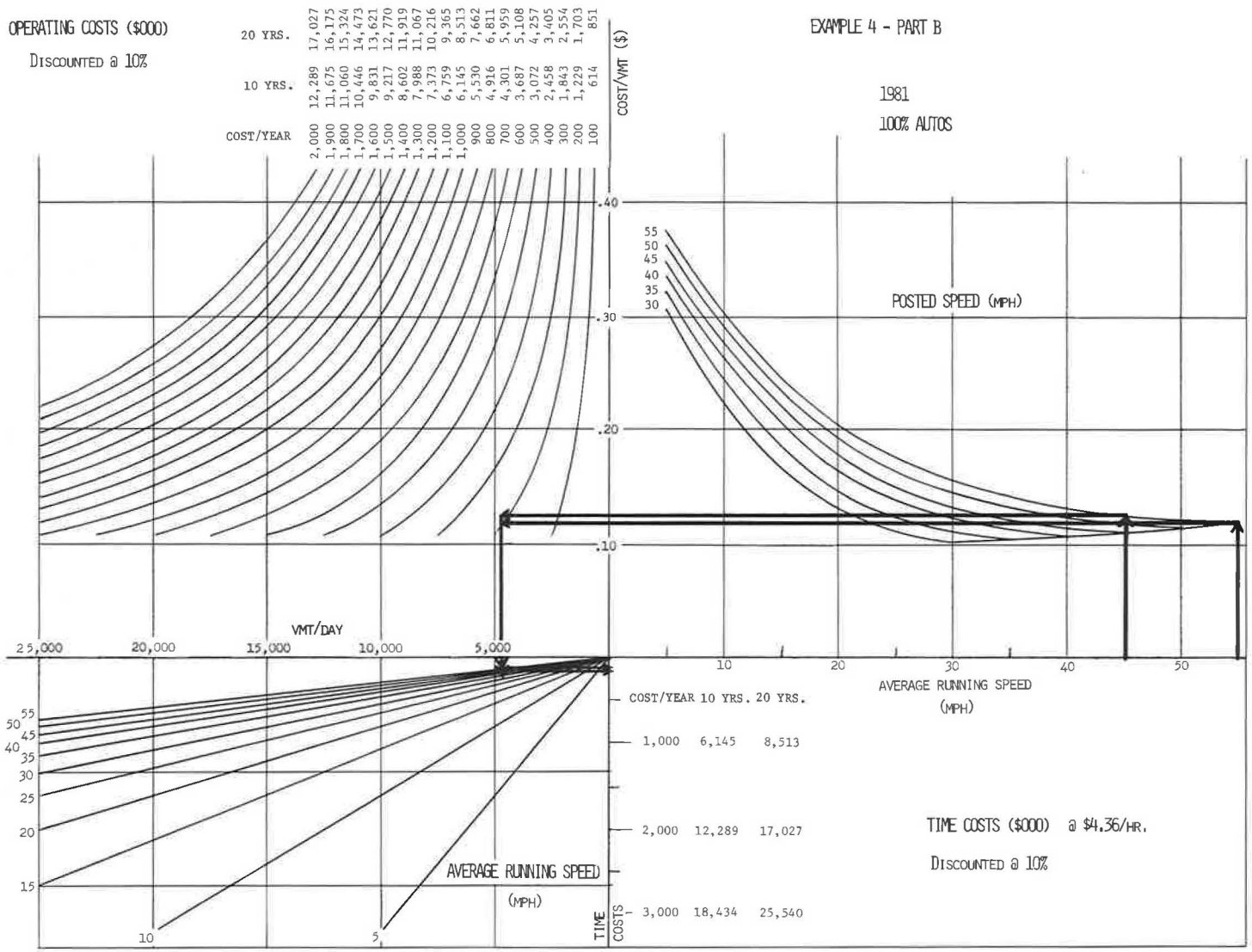



**FIGURE 7 Nomograph for example 4, part B.**

2. Rehabilitation: automobile costs = $323,500; truck costs = $51,100; and total costs under rehabilitation = $374,600. Benefits over before = $2,148,000 versus rehabilitation project cost = $2,000,000.

3. Reconstruction: automobile costs = $281,800; truck costs = $48,500; and total costs under reconstruction = $330,300. Benefits over before = $2,192,300 versus benefits over rehabilitation = $44,300 versus reconstruction project cost = $4,500,000.

REFERENCES

1. N.R. Schneider. Operating Costs for Passenger Cars on Three Facility Types: Arterials, Junior Expressways, Expressways. Preliminary Research Report No. 10. Planning Division, New York State Department of Transportation, Albany, N.Y., Aug. 1967.
2. P.A. Albin and J.K. Lussi. Documentation of the Highway User Cost Accounting Program. Preliminary Urban Planning Report No. 4. Planning Division, New York State Department of Transportation, Albany, N.Y., Nov. 1971.
3. J.P. Zaniewski, B.C. Butler, G. Cunningham, G.E. Elkins, M.S. Paggi, and R. Machemehl. Vehicle Operating Costs, Fuel Consumption, and Pavement Type and Condition Factors. Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., 1982.
4. D.T. Hartgen, J.J. Shufon, F.T. Parrella, and K.W.P. Koeppel. Visual Scales of Pavement Condition: Development, Validation, and Use. Transportation Analysis Report No. 1. Planning Division, New York State Department of Transportation, Albany, N.Y., March 1982.
5. A. Rapoli and D.C. Fifield. Truck Travel on NYS Highways. Planning Division, New York State Department of Transportation, Albany, N.Y., Oct. 1982.

Publication of this paper sponsored by Committee on Application of Economic Analysis to Transportation Problems.

# Transportation and High Technology Economic Development

GRAHAM S. TOFT and HANI S. MAHMASSANI

ABSTRACT

High technology industries constitute a major growth sector of the U.S. economy and have, as such, become the center of considerable attention from state and local economic development agencies and others concerned with national industrial competitiveness. These industries present spatial and production characteristics that differ from those of traditional manufacturing, including special transportation requirements, that have not received adequate attention to date from transportation planners and policy makers. The transportation implications of this major economic change within a framework that considers the stages of the industrial innovation process are discussed in this paper. In particular, implications for air transportation, for both passenger and freight demand, are outlined. Transportation-related measures for fostering high technology growth are addressed, and recommendations are made for further research to address unresolved theoretical and design issues.

There seems to be substantial agreement among economic and sociologic commentators that the United States is on the verge of (and probably already undergoing) an economic and technological transformation that, in the opinion of some, might rival the Industrial Revolution. Its key feature is the rapid movement of the economy away from a traditional heavy industrial base (e.g., steel, automobiles, rubber, textiles) to a knowledge-intensive base (e.g., electronics, telecommunications, biogenetics). The popular media as well as scholarly publications regularly report on the present and future consequences of this industrial realignment on job supply, job type, and job training. To date, however, little has been said about what this means for transportation. If the demand for transportation is largely a derived one, the implications of high technology-oriented economic growth may be significant for various aspects of the transportation sector, including freight movement, both domestic and international; intercity passenger travel; and urban commuting as well as for the trade-offs between transportation and telecommunications.

In this paper possible interrelationships between transportation and high technology economic development are explored, and the principal transportation issues related to this development are highlighted. The intent is to provide an initial framework within which to identify worthwhile areas for future research, and to alert research and practicing engineers, planners, and economic development specialists to potentially important transportation factors in economic development planning for high technology. High technology economic development means