

APPLICATIONS OF HIGHWAY ENGINEERING ECONOMY^{1/}

By

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Starting about 1950 there was renewed interest in the procedure for and the factors involved in the analysis of the economics of highway improvements. But much yet remains to be learned and much improvement in applying what we now know needs to be achieved before this economic analysis tool of management is used anywhere near to its potential use.

The authors are hopeful that this short statement about the application of the process of the analysis for the economy of highway improvements will lead to greater understanding and wider application of this aid to management decision and spur others to assemble the data needed which at present is lacking.

This discussion is primarily devoted to engineering economy, or road user consequences, as contrasted to the broader social and economic consequences of highway transportation.

Throughout the highway engineering profession the general thought prevails that the engineering economy analysis (e.g., a benefit-cost ratio analysis, a rate-of-return solution or one of the other methods of comparing input costs with output benefits) is applicable only to highway route location proposals or at least the practice is often to apply the analysis to only highway route location proposals. The truth is that the analysis for economy of investment of highway resources is applicable to every proposal for improvement, regardless of its character.

Another misconception is that the analysis for economy is used only in the sense of justifying on an economic basis the basic improvement proposed, i.e. project justification. An analysis for economy is just as equally applicable to the details of design, i.e. project formulation, which usually follows in the wake of the decision to construct the improvement. In the project formulation phase, the analysis for economy is applied to subfeatures of the justified project; i.e. the optimum desirable vertical gradient, the optimum elevation of a tunnel through a mountain, or the optimum schedule for a stage construction scheme.

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Of course, it is easy to say that all proposed investments in highway improvements should be analyzed from the standpoint of engineering economy, but quite another thing to get the required data to make the analysis. But this fact does not negate the necessity and usefulness of economy analyses, it only points up one of the weaknesses inherent in our statistical data gathering techniques.

Therefore, with the preceding thoughts in mind the authors have prepared a listing of examples of types of improvements adaptable to an analysis of economy and a listing of the factors necessary to a complete analysis. These two listings are as follows:

EXAMPLES OF TYPES OF IMPROVEMENTS ADAPTABLE TO
AN ANALYSIS FOR ECONOMY

I. Route Location

- A. Arterial and freeway system spacing and location
- B. Urban bypass location
- C. Rural route location
- D. Bridge vs. a longer no-bridge route^{1/}
- E. Special routes for selected traffic^{1/}
- F. Special conditions^{2/}

II. Geometrics and other details of design

- A. Travel distance
- B. Vertical gradients
- C. Horizontal curvature
- D. Uphill truck lanes
- E. Length and location of frontage roads
- F. Spacing of interchanges
- G. Elevated vs. depressed freeway
- H. Median and shoulder width
- I. Number of lanes
- J. Open cut or tunnel
- K. Grade crossing elimination, highway or railway
- L. Grade crossing protection
- M. Navigational clearance
- N. Size of culverts and bridge waterways
- O. Size and spacing of drainage inlets

^{1/} For example: routes which are to be used only by trucks, or parkways for passenger cars only.

^{2/} For example:

- a. Reconstruction of the existing route on essentially the same right-of-way.
- b. Existing route abandoned as a public highway.
- c. Existing route continued as a public highway, but may be transferred to another highway system.

III. Materials and types of design

- A. Type of bridge structure^{3/}
- B. Wood vs. steel vs. aluminum
- C. Roadway or pavement surface material

IV. Traffic controls

- A. Type of intersection control
- B. One-way traffic
- C. Reversible lanes
- D. Legal speed limit determination
- E. Computerized traffic signal controls

V. Modernization of highways and traffic relief improvements

- A. Change to higher type roadway surface
- B. Widen roadway and resurface
- C. Add lanes or develop new route
- D. Lengthen sight distances
- E. Lengthen and flatten horizontal curvature
- F. Widen shoulders
- G. Install median barrier
- H. Spot improvements to reduce accidents

VI. Stage construction and future provisions

- A. Buy rights-of-way now for future use
- B. Grade and drain now for future use
- C. Construct 4 lanes now vs. 2 lanes now and 2 lanes in the future

VII. Management policies

- A. Short contract time vs. long contract time
- B. Overtime and night construction vs. 40-hour week and one crew
- C. Length of haul from central plant to work site
- D. Handling traffic via detour route vs. routing traffic through construction
- E. Long mileage or large dollar volume construction projects vs. short mileage or small dollar volume projects
- F. Location and size of maintenance shops and service centers
- G. Desirable maximum dimensions and weights of motor vehicles

VIII. Construction and maintenance equipment and operations

- A. Replacement of automotive, machinery and other equipment
- B. Highway maintenance procedures and processes
- C. Substitution of electrical and mechanical devices for manual labor

^{3/} For example: Draw span, fixed span, tunnel, high level structure, etc.

FACTORS NECESSARY TO A COMPLETE ANALYSIS FOR ECONOMY

I. Highway design factors and roadway and traffic conditions

- A. Design factors
 - 1. Distance
 - a. Profile gradient section
 - b. Level tangent section
 - c. Horizontal curvature
 - (1) Degree
 - (2) Length
 - 2. Speed
 - a. Profile gradient
 - b. Horizontal curvature
 - c. Design

B. Roadway conditions

- 1. Pavement design
- 2. Type of surface
- 3. Condition of surface

C. Traffic conditions

- 1. Speed distribution for year
- 2. Average driver's speed
- 3. Stops
 - a. Number
 - b. Stopping speed
- 4. Speed changes
 - a. Number
 - b. Speed differential
- 5. Amount of idling time
- 6. Legal controls
 - a. Traffic controls
 - b. Legal speed limit

II. Traffic classification and volume

A. Vehicle classes

- 1. Function
 - a. Passenger carrier
 - b. Freight carrier
 - c. Special purpose
- 2. Physical
 - a. Weight
 - b. Size of body
 - c. Number of axles
 - d. Number of tires

3. Visual
 - a. Passenger car
 - b. Bus
 - c. Commercial delivery
 - d. Single-Unit truck
 - e. Combination vehicles

B. Traffic volume

1. Current
 - a. ADT
 - b. Volume distribution for year
2. Forecast
 - a. Normal growth
 - b. Accelerated growth
 - c. Generated growth

III. Highway costs

A. Construction

1. By geometric item
2. Averages per mile
3. Rural - urban comparisons
4. By traffic volume

B. Maintenance

1. By geometric item
2. Average annual
3. Forecasted increases
4. By traffic volume and character

C. Operations

1. Highway patrol
2. Lighting
3. Snow removal
4. ROW upkeep
5. Traffic control devices

D. Administration

1. Engineering design
2. Construction engineering
3. Overall administration

IV. Road user consequences

- A. Motor vehicle operating costs^{4/}
1. Type of operation
 - a. Average conditions
 - b. Rural highways
 - (1) County trunk highways
 - (2) State primaries
 - (3) Freeways
 - c. Urban highways
 - (1) Local streets
 - (2) Arterials
 - (3) Freeways
 2. Geometrics and traffic control
 - a. Profile gradient
 - b. Horizontal curvature
 - c. Speed changes
 - d. Idling engine
- B. Accident Costs
1. Severity by geometric item
 2. Forecasts of accidents
 3. Frequency of accidents
 4. Unit costs by vehicle type
 5. Unit costs by class of operation
- C. Time Value
1. Driver of vehicle
 2. Occupants of vehicle
 3. Average per vehicle
 4. Commercial vs. non-commercial
 5. Distribution of unit values of time
- D. Intangibles
1. Personal preferences
 2. Comfort and convenience
 3. Smoother ride
 4. Reduction in traffic hazards

^{4/} Motor vehicle operating costs should be in sufficient detail to show the effects that the various types of operations and the various geometric design items and traffic controls have upon each of the individual operating cost elements, i.e., fuel and oil consumption, tire wear, repair and maintenance, and depreciation, which in combination results in a unit cost of motor vehicle operation.

V. Community Consequences

- A. Land value increases
- B. Loss of taxable land
- C. Fire and police use
- D. Improved social communications
- E. Improved postal service
- F. Elimination of dust
- G. Noise reduction
- H. National defense
- I. Beautification
- J. General community consequences
- K. Recreational activity
- L. Other

The fifty listed examples of types of improvements are only illustrative and are not necessarily all-inclusive, e.g., economy analyses are also applicable for the entire gamut of studies which could be imagined in an urban transportation systems analysis. The actual positioning of the examples under the various major headings is arbitrary but does not detract from the main argument of the importance of the analysis of economy.

Some discussion is necessary relative to the factors necessary for a complete economy analysis, both as to those listed and those not listed, e.g., the interest rate, analysis period, etc. Some specific questions relating to the list of factors, which listing is not necessarily complete, are as follows:

1. Should each section of plus and minus grade be analyzed separately or can the profile gradeline be divided into grade intervals, e.g. 0-3%, 3 to 5, 5-10%, etc.?
2. In urban analyses, how should the turning movements at street intersections be handled?
3. Should the traffic stream be classified by vehicle types or may trucks be expressed as being equivalent to so many cars?
4. How do we measure the benefits, if any, accruing to generated traffic, transferred traffic, attracted traffic and other traffic over and above that which would be considered as existing traffic?
5. Whose time and what amount of travel time should be included in the analysis, and, if included, what unit value should be attached?
6. Should the items of highway operation and administration be included in the analysis, and if so, how? On a mileage basis?

In the accompanying table, the preceding lists of examples and factors are condensed and arrayed vertically and horizontally, respectively, producing a matrix. (The original lists would have resulted in a matrix 50 x 89 or 4,450 cells. Condensing the lists results in a matrix 15 x 26 or 390 cells.) A code letter is placed in each cell to (1) signify the extent of the applicability of the specific factor in the analysis for economy of the example improvement and (2) indicate the availability of data for that factor. The various letters and definitions used for each code are:

Factor Applicability

0 = Not applicable
1 = Generally not applicable
2 = Applicable

Data Availability

N = Data are not available
U = Available data are usable but not adequate
S = Data now available are satisfactory
A = Generally an assumed or estimated input value

Of course, the identification of each factor by specific code letters has been based on the authors' judgments. Great difficulty was experienced in coding many of the factors, partly due to the narrowness of the codes but also due to the inherent complexities of the factors. For example, how should the factors under traffic classification and volume be coded for Example VIII, construction and maintenance equipment and operations? It would not be unexpected if the current traffic volumes or traffic forecasts would affect the type of maintenance procedure or process. But how could these effects be handled in an analysis for economy for construction maintenance equipment and operations?

Another example reflecting the difficulty was encountered in assigning the data availability codes for speed, stops, and speed changes for Example 1 projects (route location). Although specific data could be obtained (through field tests) for these factors for the existing route or present conditions, no known references exist which give data for these factors for proposed alternates to the existing route or present conditions.

It may be seen in the table that of the total 390 cells, 64 are coded with a "0" which indicates that the factor is not applicable in an analysis for economy for that particular type of improvement. Of the remaining 326 applicable cells 261 are coded with a "2" indicating that the factor is applicable in an analysis for economy for that improvement. An investigation of the availability of data for the factors indicates that of the 326 cells where the factor is applicable, 27 are coded with an "A" indicating that the factor is one that is assumed in an analysis. Of the remaining 299 cells, 233 are coded with an "N" or "U" indicating that the data either are not available or are usable but not adequate. Therefore, of the 326 cells

where the factors are applicable in an analysis for economy only for 66 cells are the data satisfactory (approximately 20 percent).

In addition to all the questions raised pertaining to the listed "factors" there is also an equally large bundle of questions which could be addressed to those factors which are not listed but need to be decided upon before an analysis can be made; namely, those factors of: salvage value, analysis period and interest rate. Typical questions which could be asked about these factors are as follows:

1. Should items in the economy analysis be accorded a salvage value; and if so, which items and how should the salvage value be determined?
2. Should an analysis period be used as opposed to using the service life of the components or the forecasted economic life of the project?
3. What interest rate should be used in the analysis?

In summary, the authors hope that this short and maybe confusing discussion of the applications of economy analyses and the factors needed for a complete analysis will make the uninformed aware of the possibilities of the uses of engineering economy analyses and will direct the efforts of the informed to research on those factors where the data are skimpy or non-existent.

Table 1.--Degree of application and the availability of data for the factor-groupings needed for a complete analysis for economy for each of several types of examples of highway improvements.

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Factor groups Necessary for a complete analysis for economy.	Highway design factors and roadway and traffic conditions					Traffic classifica- tion and volume					Highway costs			Road user consequences			Community consequences								
	Design Factors			Roadway conditions		Traffic conditions			Vehicle classes		Traffic Volume		Construction	Maintenance	Operations	Administration	Motor Vehicle Operating Costs	Accident costs	Time value	Intangibles	Private	Public	Local	National	
	Distance	Speed	Cross-Section elements	Surface type	Surface condition	Speed	Stops	Speed changes	Legal controls	Functional	Physical	Visual													Current data
I. Route location a. Urban bypass location c. Rural route location	2S 2S	2A 2A	2A 2A	0 0	1S 1S	2U 2U	2N 2N	2S 2S	2S 2S	2U 2U	2U 2U	2S 2S	2A 2A	2S 2S	2U 2U	2U 2U	1N 1N	2U 2U	2N 2N	2N 2N	2U 2U	2U 2U	2U 2U	1N 1N	
II. Geometrics and other details of design D. Uphill truck lanes E. Spacing of interchanges K. Grade crossing elimination	2S 2S 1S	2A 2A 2A	2A 2A 1S	0 0 0	0 0 0	2N 2N 2N	2N 2N 2N	0 0 2S	0 1S 2U	2U 2U 2U	2U 2U 2U	2S 2S 2S	2A 2A 2A	2S 2S 2S	2U 2U 2U	2U 2U 2U	1N 1N 1N	2U 2U 2U	2N 2N 2N	2N 2N 2N	1N 1N 2N	1N 1N 2N	1N 1N 2N	1N 1N 1N	
III. Materials and types of design A. Type of structural material B. Type of structural design	0 0	0 2A	2S 2S	1S 0	1S 0	1N 2N	0 2N	0 2N	0 0	0 2U	2S 2S	2S 2S	2A 2A	2S 2S	2N 2N	2N 2N	1N 1N	2U 2U	2N 2N	2N 2N	2N 2N	1N 1N	1N 1N	0 0	
IV. Traffic controls A. Type of intersection control D. Legal speed limit determination	0 0	2A 0	1S 2U	0 0	0 1U	2N 2N	2N 2N	0 2N	0 2U	2U 2U	1U 2S	2S 2U	2A 2A	2S 0	2N 0	1N 2N	1N 1N	2U 2S	2N 2N	2N 2N	2N 2N	1N 2N	1N 2N	2N 2N	0 1N
V. Modernization of highways and traffic Relief improvements A. Improve highway surface B. Improve highway capacity	2S 2S	0 0	2S 2S	2S 2S	2S 2S	2N 2N	2N 2N	2N 2N	0 0	0 2U	2U 0	2S 2S	2A 2A	2S 2S	2U 2U	2U 2U	1N 1N	2U 2U	2N 2N	2N 2N	2N 2N	1N 1N	1N 1N	2N 2N	0 0
VI. Stage construction and future provisions	2S	2A	2S	2S	0	2N	2N	2N	0	2U	2U	2S	2S	2A	2S	2U	2U	1N	2S	2N	2N	2N	2N	2N	0
VII. Management policies A. Determination of length of construction contract G. Desirable maximum dimensions and weights of motor vehicles	0 0	0 1S	0 2U	0 2U	0 2U	2U 2N	2N 2N	2N 2N	0 2S	0 2U	0 2U	0 2S	2A 2A	2S 2S	2U 2N	2U 2N	1N 1N	2U 2U	2N 2N	2N 2N	2N 2N	2N 2N	2N 2N	2N 2N	0 1N
VIII. Construction and maintenance equipment and operations	0	0	0	1U	1U	1N	1N	1N	0	1U	1U	1U	1U	1A	0	2N	2N	1N	1N	1N	1N	1N	0	0	0

Legend: 0 = Not applicable
1 = Generally not applicable
2 = Applicable

N = Data are not available
U = Available data are usable but not adequate
S = Data now available are satisfactory
A = Generally an assumed or estimated input value