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Special Report 108

HIGHWAY ENGINEERING ECONOMY

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Special Report 108

HIGHWAY ENGINEERING ECONOMY

Report on a Symposium held
January 14, 1968
Washington, D.C.

Subject Area
15 Transportation Economics

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Foreword

Highway engineering economy has received increasing emphasis and interest in recent years. The literature published by the Highway Research Board and others has substantially increased. This Symposium was arranged by members of the HRB Committee on Highway Engineering Economy for the purposes of reviewing present practices in this area, discovering and exchanging techniques, and examining the socioeconomic and noneconomic considerations that are expected to have greater importance as time goes on.

Specialists in highway engineering economy who represented a variety of viewpoints attended the Symposium. They heard formal presentations and engaged in round-table discussions on the following topics:

1. Present practice of highway engineering economy;
2. Computers and computer approaches to highway economy studies;
3. Decision theory and other approaches proposed to replace or supplement existing forms of economy studies; and
4. Socioeconomic factors associated with decisions in highway planning, location, and design.

The Committee believes that this Special Report of Symposium papers will be of value to those who are interested in applying the principles of engineering economy to decisions regarding highway planning design and operation. Because of space limitations, only a small portion of the very productive round-table discussion could be included.

Possibly the most important single characteristic of the Symposium was that opinion among the participants differed strongly in several areas. Two of these concerned (a) the importance of detailed economy studies in the overall decision-making process and (b) the manner and degree of detail in which findings are presented to decision-makers.

Grateful acknowledgment is made to Robley Winfrey, John Suhrbier, Marvin Manheim, Floyd Thiel, and Bamford Frankland for preparing the position papers and leading the discussions in the individual topic areas.

Contents

Highway Engineering Economy Analysis

ROBLEY WINFREY, Bureau of Public Roads,
Federal Highway Administration, U.S. Department of Transportation

•HIGHWAY ENGINEERING ECONOMY, including value analysis, economic analysis, cost-benefit analysis, and cost-effective analysis, is often wrongly used, poorly understood, and poorly applied. It suffers also from the lack of much necessary input information. For example, the performance of traffic on the highway, the running cost of motor vehicles as affected by highway design and traffic, the rate and cost of traffic accidents, and the economic and social consequences of highway improvements all require added research to assemble the performance and cost data needed in highway economy studies. Although research on the relationships between the motor vehicle and the highway was started about 1920, the area has never been thoroughly and systematically covered. The result is that today more information is missing than is available.

Analysis of the economy of highway improvements was begun well over 100 years ago. Though few people realize it, the subject is to be found in school texts and in engineering handbooks printed in the mid-1800's. As an example, consider the following 5 quotations published in 1853 in a book on road-making by Gillespie (1):

> Any unnecessary excess of length causes a constant threefold waste; firstly, of the interest of the capital expended in making that unnecessary portion; secondly, of the ever-recurring expense of repairing it; and thirdly, of the time and labor employed in travelling over it. It will therefore be good economy to expend, in making topographical examinations for the purpose of shortening the road, any amount less than not only that sum which the distance thus saved would have cost, but, in addition, that principal which corresponds to the annual cost of the repairs and of the labor of draught which would have been wasted upon this unnecessary length (p. 26).
>
> A perfectly level road is thus seen to be a most desirable object; but as it can seldom be completely attained, we must next investigate the limits to which the slopes of a road should be reduced if possible, and determine what is the steepest allowable or maximum slope (p. 38).
>
> A minimum of expense is, of course, highly desirable; but the road which is truly cheapest is not the one which has cost the least money, but the one which makes the most profitable returns in proportion to the amount which has been expended upon it (p. 65).
>
> The more nearly, however, the road is made to approximate towards "what it ought to be," the more difficult will it be to satisfy the demands of economy. Some medium between these extremes must therefore be adopted, and the choice of it must be determined by the amount and character of the traffic on the road which it is proposed to make or to improve. For this purpose an accurate estimate is to be made of the cost of the proposed improvement, and also of the annual saving of labor in the carriage of goods and passengers which its adoption will produce. If the latter exceed the interest of the former, (at whatever per centage money for the investment can be obtained) then the proposed road will be "what it ought to be as to its cost." From these considerations it may be truly cheaper to expend ten thousand dollars per mile upon a road which is an important thoroughfare, than one thousand upon another road in a different locality (pp. 65-66).
>
> From these considerations it is also seen that a line ought not to diverge from the direct course between its extremities, and thus increase its distance, for the sake of the trade of a small town, for whose benefit the time and fare of all the passengers and freight on the whole line would thus be taxed. It would be preferable to make a branch track to the town (p. 271).

Gillespie dealt with real live horsepower or mulepower that cost at that time 75 cents per day per animal. This interesting book by Gillespie is proof that the art of road-building was born long before the coming of the motor vehicle; unfortunately, the art is still not as skillfully practiced as desired, particularly from the standpoint of economy of highway design and use, including both economic and social factors.

There is a need for a systematic fore-planned attack on the vacuum of data required to improve the economic analysis of highway transportation investments. The information needed can be obtained through well-directed research and observation. Its use in planning, particularly in economic analysis, will return a high payoff in studies of transportation.

NEEDS FOR BASIC INPUT INFORMATION

Traffic Performance

Data on speed distribution, speed changes, and, to a certain extent, traffic composition are almost completely lacking in the form needed by the analyst in computing the relative economy of different highway designs and special facilities. Information is especially lacking for urban streets. The motor vehicle running costs are markedly influenced by the speed of the vehicle and the extent and number of speed changes. Therefore, the analysis of alternative designs requires reliable information on speed and speed changes with respect to the basic type of highway, i.e., whether it has 2, 4, or 6 lanes, and with respect to the amount and composition of traffic. Speeds and speed changes need to be determined for the full year and for all vehicles, not solely for free-running vehicles. Likewise, a knowledge of the volume and kinds of vehicles for each hour of the year is needed so that speeds and numbers of vehicles can be put together in computing motor vehicle running costs on a yearly basis.

Motor Vehicle Running Cost

NCHRP projects will furnish information on fuel consumption, tire wear, and other factors for a range of highway designs and traffic conditions. It will still take some effort, however, to put these data in the proper form for use in highway engineering economy studies. In addition to knowledge of the specific performance of vehicles under specific elements of highway design, knowledge must also be obtained of the running costs for general conditions such as rolling grades, urban streets, and general classes of traffic volumes and kinds of vehicles. For example, fuel consumption is perhaps better expressed on a rise-and-fall basis for a rolling grade such as that found in southern Iowa than it is by gallons per mile on specific plus-and-minus grades. On the other hand, specific fuel consumption can be used for the longer grades in mountainous country.

Cost of Traffic Accidents

The large volume of data published on traffic accidents does not contain combined data on accident costs and accident frequencies related to elements of highway design. Kihlberg and Thorp (2) and Jorgensen (3) report on research that is a step leading in the right direction.

System Data

For urban transportation studies, motor vehicle performance including running costs should be compiled and reduced to forms applicable to system analyses.

Value of Travel Time

Travel time has a widely varying value for both passenger automobiles and the occupants. Haney (4), Thomas (5), and Lisco (6) have developed a technique and statistical procedure by which acceptable values of time can be determined. The next step is to apply these procedures to many other types of highways, to geographical locations, and to specific conditions in order to develop a range of values of time for specific applications.

IMPROVEMENTS IN PRACTICES OF ECONOMIC ANALYSIS

The Literature

Some writing was done in the 1920's on the subject of highway economic analysis, and since about 1950 many valuable contributions have been made to the technical literature. Unfortunately, however, highway officials and analysts are not applying this knowledge very widely. Individual economic analyses are still widely deficient in the principles and procedures of analysis, and are themselves not always understood. Additional education and practice are needed in this field to bring the level of performance up to an acceptable quality. Perhaps a series of workshops should be conducted across the country to achieve this improvement.

Relationship of Road User Consequences to Nonuser Consequences

In the past several years, many individuals have proposed some form of numerical rating system for evaluating or ranking general economic and social consequences. Some have wanted to combine road user consequences and nonuser consequences into one numerical index or ranking among alternatives as a means for indicating relative economic feasibility. Because road user factors are reliably priced on the market and because nonuser factors are most difficult to price on the market and vary widely from place to place, it seems to be unwise to combine these consequences into a single index, even if it could be done. No doubt advances can and will be made in developing guidelines, interpretations, and techniques that will aid the decision-maker in reaching his decision by some process of subjective evaluation of the nonuser factors. Decision-makers need a better understanding of how to use the results of the economic analysis as one of many tools and guides to the decision.

IMPROVEMENT OF PROCEDURES OF ECONOMIC ANALYSIS

Engineering Economic Procedures

Procedures to determine the economy of highway improvements are patterned after those developed for private industry. In general, these procedures are satisfactory, but some phases need additional study and some concepts need further development. These include the handling of terminal value, selection of the discount rate, identification and quantification of benefits, development of applications to systems analyses, and the handling of the increase in traffic volume as opposed to the existing traffic volume. Greater emphasis is needed on separating the analysis for economic evaluation from the analysis for project formulation.

The Engineer Versus the Economist

The literature in the economic and engineering fields indicates several differences in concept, theory, and application of economic analysis. It would be helpful if these two professions could get together and reach an understanding, even though they do not reach an agreement. One of the factors that leads to disagreement is that the function and use of highways are different from the function and use of those things for which capital expenditures are made by private industry. Most of the economists writing on this subject view the problem under the mantle of private business and monetary profit. This approach leads to statements hardly applicable to highways. Other factors needing discussion relate to the willingness to pay versus what is actually paid and the economic transfers, offsets, and adverse consequences. There are no accepted guides by which those nonuser consequences can be isolated and the economic worth of a proposed highway facility measured.

SUMMARY

This paper has briefly summarized the state of highway economic analysis from two standpoints: (a) the need for added meaningful data to fill the gaps in existing knowledge and (b) the need for more advanced approaches to analysis. It should be clear that much work must still be done.

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Discussion

Tillo Kuhn

I am very interested in international development work and would like to know the degree of standardization for vehicle costs on any particular road. How can we keep present motor vehicle running cost tables up to date as time goes on and as new road and vehicle designs come along?

Robley Winfrey

I do not like the use of the word standardizing unless you mean standardizing on a quality basis. We can measure fuel consumption, and we can measure tire consumption under certain conditions only; but other expenses of the vehicle, particularly general maintenance expenses, are most difficult to measure and to allocate to a specific feature of highway design or to a specific condition of traffic. So we have to attack the updating problem by working the basic tables out by theoretical methods through energy equations and power requirements. Another difficulty, however, is in getting the necessary traffic performance for the economic analyses. For example, we do not know speed distributions of traffic. We have been unable to measure many speed changes in urban traffic that increase fuel consumption and increase tire wear. These changes can and should be measured, but we have not found the right kind of reasonably priced instrumentation to do enough driving to get at this problem. In my book, Economic Analysis for Highways, I used a good deal of mechanics, dynamics, and other theory because I wanted to allocate fuel, tires, engine oil, vehicle maintenance and minor repairs, and vehicle depreciation to roadway surface, distance, plus grades, minus grades, horizontal curvature, and changes in speeds. When we are able to fill in the parameters for that sort of matrix, then I think we have a good representation of motor vehicle running costs as affected by those elements of the highway and traffic. Given these, we can adjust the vehicle running costs very easily, particularly as the prices change.

Clarkson Oglesby

Present costs have to be projected to some period in the future. Do we have any techniques that have been proven for projecting future traffic in either a developed or a developing nation?

Martin Wohl

I do not think we can really forecast well, and this is very crucial. We cannot assess the benefits or costs unless we know how many people and what kinds of vehicles are going to use the facilities consistently and what service and performance conditions will be desired. Even if we agree on how to carry out economic analysis, we still have the problem of forecasting; in a sense, it underlies everything we and a lot of other people do.

Wilson Campbell

There are many factors that influence traffic forecasts that forecasters cannot control. But I think that we can forecast reasonably well, on a 24-hour basis, traffic volumes on particular roadways in urban areas. It always makes me nervous when we have to provide design data, including specific turning movements, for 10 o'clock on Thursday morning in 1985. We do it just because there is no other information, and we recognize that the design engineer has to have numbers to determine the number of lanes and interchanges needed and other design features. We qualify our forecasts, however, by specifying the limits of accuracy so that he can use some judgment in his traffic engineering and design technique. I agree that forecasting is far from perfect, but we have come an amazingly long way during the past 10 years.

Marvin Manheim

One of the critical gaps in the analysis of proposed transportation technologies is an understanding of the fundamental relationships between the basic physical technological aspects of transport and its true economics. Therefore, we need basic power resistance relationships in order to segregate the effects of fixed facilities from vehicle effects, from operating-decision effects, and from traffic effects in such a way as to trace out the cost ramifications of each.

William Adkins

Forecasting is always somewhat inexact. On the other hand, perhaps the forecasters and the planners may have to give thought to the use of measures such as police power or land use zoning to control the amount and composition of traffic to ensure that forecasts are more or less met. As an example, when a bottling company turned 100 trucks loose on a rather high-capacity freeway during the peak hour, the effect was amazing, especially on the number of speed changes and time losses. If we had had the sense to keep this one bottler off the freeway, traffic would have been more like that forecast. Another less drastic example is ramp metering.

Clarkson Oglesby

In Great Britain there has been quite a bit of talk about road pricing and parking pricing to control the amount of traffic. Do you see this concept as being applicable in the United States?

Paul Wagner

Our attitude is that when a legal vehicle enters the highway the driver should be allowed to do anything he wants so long as it does not interfere with the rights of others. This idea of trying to control vehicles in order to plan the economy is not in line with our present thinking. We are trying to provide highways for the public's desires as they exist today; we are not trying to change those desires.

Tillo Kuhn

There are two defects in the pricing literature: (a) pricing is only a portion of the total economic decision; and (b) the influence of pricing on the road user may be very slight, because the user may not conceive what his total cost is or his sensitivity to cost may be very slight. So my inclination would be to organize the pricing problem within the broader context of systems analysis. The literature would have us believe that some loops in the road and a little pricing will solve all problems. In my opinion this is not so.

Paul Roberts

We already control the system in a number of ways. Lane markings, signs, and, of course, gasoline tax are forms of control.

Marvin Manheim

These comments imply that a bundle of options can be manipulated in any transportation problem. These options range from a choice of basic technology to the design of the network, location of links and their characteristics, design of the vehicle, and operating policies such as pricing and access control. In one context where state legislation does not allow segregation of traffic or control over access, or where the state decides that there is no real choice of technology, the key set of options to manipulate will be the detailed characteristics of the link, such as grade and horizontal curvature. In another context, e.g., in a developing country where the range of technologies is very wide, the decision may be to shift the technology from a rubber-tired vehicle on pavement to an off-the-road vehicle. In the urban context, the only available option may be user pricing schemes, e.g., parking charges and tolls. We need to be concerned with the full spectrum of options and should not be extreme advocates of either pricing policy or new technology as the answer to every transportation problem.

Robley Winfrey

The highway engineer is often blamed for all the ills of highway transportation. He should not shoulder that blame, because he has not had control of how the highway is to be used. He designed it for one kind of use, and because the public chose to use it differently we have transportation problems. What we need is a reconciliation of viewpoints. There are private interests, local interests, community interests, and national or state interests; they are not all compatible because they value certain concepts or certain goals differently. That is why the engineering economy aspects should be kept separate from the economic and social aspects.

Tillo Kuhn

Our task is to serve up particular choices, to prepare well-designed and well-researched options. In this process we must also document the social, aesthetic, and other consequences together with the road user, dollar-priced consequences. Therefore, we can say to a decision-maker, "Here is a system that has certain design characteristics with regard to speed and capacity and one that has various social and economic consequences."

Computers and Engineering Economic Analysis

JOHN H. SUHRBIER, Massachusetts Institute of Technology

•THIS PAPER describes, in summary fashion, the principal characteristics of advanced engineering computer systems, how these systems can contribute to improved engineering design and economic analysis, and some general engineering analysis methods that require computers for solutions. Much of the material contained in this paper is based on earlier publications (7, 13). The purpose is to communicate an idea of the kinds of engineering capabilities that are just now coming into actual practice and of the direction that developments will likely take. The discussion is oriented primarily to the problem of highway location and design, but most of the comments and conclusions are equally relevant to other problem areas such as transportation planning and structural design.

The entire engineering design process must be examined to learn how computers and computer methods can most effectively contribute to an engineering economic analysis. We take the broad view that the study of engineering economy must be concerned with the totality of the engineering design process; otherwise, we would be guilty of not adopting the proper systems approach with which this paper is concerned.

The problem of locating and designing a roadway facility is composed of a large number of smaller but complex and interrelated problems. This is indeed what makes the total or combined problem both interesting and challenging. For example, the total highway design process involves different levels of analysis such as network planning, link location, and final geometric design. Decisions at one stage must anticipate, and be made in awareness of, decisions at other stages. The highway design process can be characterized as being an information system in which large amounts of information are collected, stored, retrieved, processed, and displayed. Decisions are typically made under uncertainty. Determining the location of a proposed road requires more than just the consideration of construction, maintenance, and user economic consequences. Social, aesthetic, and political consequences must also be determined and accounted for in the decision-making process.

ROLE OF COMPUTER AND RELATED TOOLS IN DESIGN

Many basic changes have occurred in the use of computers since their introduction to engineering design in the mid-1950's. Initially, computers were used solely to relieve the engineer of tedious computational burdens. Earthwork end areas were calculated and averaged to obtain volumes of cut and fill. This initial idea of only using a computer as an exceptionally fast calculator fortunately changed with the tremendous increases in computational power introduced in the 1960's. R. W. Hamming (3) states:

> Another argument that continually arises is that machines can do nothing that we cannot do ourselves, though it is admitted that they can do many things faster and more accurately. The statement is true, but also false. It is like the statement that, regarded solely as a form of transportation, modern automobiles and aeroplanes are no different than walking. One can walk from coast to coast of the U.S. so that statement is true, but is it not also quite false: Many of us fly across the U.S. one or more times each year, once in a while we may drive, but how few of us ever seriously consider walking more than 3000 miles? The reason the statement is false is that it ignores the order of magnitude changes between the three modes of transportation: we can walk at speeds of around 4 miles per hour, automobiles travel typically around 40 miles per hour, while modern jet planes travel at around 400 miles per hour. Thus a jet plane is around two orders of magnitude faster than unaided human transportation while modern computers are around six orders of magnitude faster than hand computation. It is common knowledge that a change by a single order of magnitude may produce fundamentally new effects in most fields of technology;

thus the change by six orders of magnitude in computing have produced many fundamentally new effects that are being simply ignored when the statement is made that computers can only do what we could do for ourselves if we wished to take the time.

The design of a system, be it a transport system or an engineering computer system, involves 2 fundamental and highly interrelated steps: first, the design of the components of the system and, second, the design of the interaction among these components. Generally, these interractions are highly complex and difficult to quantify. The problem that was attacked in the precomputer age and also in the formative years of computer use was the component design problem. Component interaction was largely ignored. This forced the designer toward suboptimization. Although optimal components were realizable, total systems were not being designed. The computer is beginning to allow the designer to approach the total problem.

Three terms, almost always mentioned in connection with computers and engineering design, are computer-aided design, optimal design, and automatic design. When he is first introduced to computer methods, an engineer often has the notion that computers provide easy and direct optimal design, and if not optimal, then, at least automatic. This type of individual, generally, looks on the computer system as a replacement, not as a potential partner. The tremendous investment now being made in the development of integrated engineering design systems such as Integrated Civil Engineering System (ICES), however, is concerned not with automatically producing optimal or even feasible designs but with augmenting an engineer's creativity so as to enable him to produce better and more imaginative designs more efficiently. Most design problems associated with transportation, structural, and water resource systems are so complex and involve so many variables that improved design can best be achieved by permitting an engineer to investigate in some detail a large number of design alternatives. It is also clear that only when a large number of feasible alternative design configurations exist can engineering decision-making techniques be meaningfully and effectively utilized. The objective of computers and their related tools is to produce effective computer-aided design that will expand not only a designer's productivity but also his creativity.

Computers and computer models can be used for prediction, evaluation, search, or planning. Each use is different, and each requires a slightly different strategy. Perhaps most important, each use successively requires a more elaborate setting, a more extensive set of assumptions, and more detailed design.

Computer models are used most commonly for prediction. In this case, only performance measures are used, and output is mostly in physical terms such as trip distributions or geometry calculations. A great deal of engineering intervention can, and usually does, take place. The engineer can use his intuition and judgment to check the values that are obtained from the model. An experienced designer can sometimes intuitively evaluate the design and make appropriate corrections or additions to improve it.

A computer model that incorporates evaluation must by nature be more complex and more sophisticated. Unlike prediction that requires no point of view or definition of objectives, evaluation requires the identification of objectives by which goal achievement is determined. Values for various performance variables must also be defined. Evaluation is a great deal more exacting than merely predicting physical consequences.

Search or optimization involves still another level of complexity. To relate the model with the real world requires that controllable variables be identified and information obtained on how and over what range are they controllable, and to what extent will they actually produce real-world effects. To date, there have been few attempts on the part of highway engineers to "optimize" within the highway location process. Various applicable optimization techniques do exist, however, such as dynamic and mathematical programming. Both of these techniques depend on well-formulated and well-behaved computer models of the location process that, to date, are still largely unavailable.

A designer should approach the computer as though each use deals with a completely original problem, involving creative thinking and the application of judgment, imagination, intuition, and experience. The computer system should be designed not to produce solutions but to supply meaningful measures of the consequences of a decision. These responses provide the engineer with a basis for evaluating whether or not his decision has been a good one.

A number of characteristics of advanced engineering computer systems now being developed satisfy, at least in an initial significant step, the previously implied design requirements. Three of these capabilities described are problem-oriented languages, remote computing and time sharing, and graphics. A number of important capabilities associated with areas such as information storage and retrieval, data structure and transfer, and program and system modularity are equally as important and interesting, but these are not discussed.

ENGINEERING LANGUAGES

The designer must control the computer system and specify what information-processing operations should be executed and what results should be supplied. To perform this, he needs a flexible, efficient communication language to enable him to converse with the computer. This language should be oriented toward the designer and the problem he is solving rather than toward the computer or the programmer. Communication languages designed for the user of a computer system are commonly referred to as problem-oriented languages.

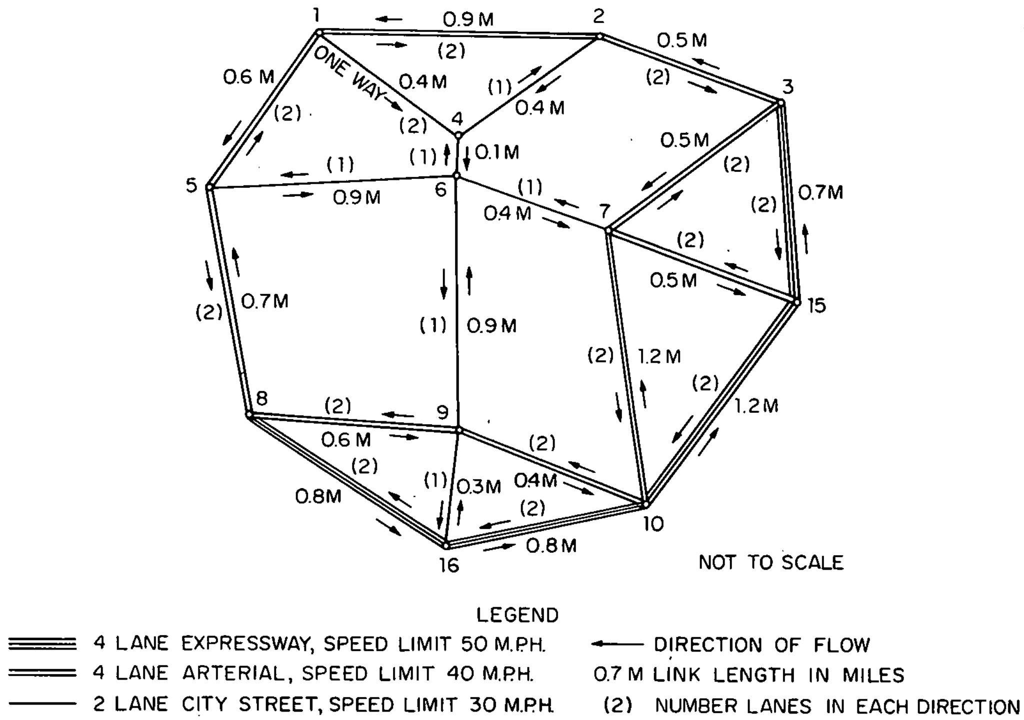
A problem-oriented language contains commands, each one a request to perform some design operation. The command vocabulary of an engineering problem-oriented language consists of technical terms that have meaning to the designer. By specifying a certain sequence of commands, the designer instructs the computer as to which operations should be performed and what information is desired. Problem-oriented languages are easy to learn and use, requiring no conventional programming experience. This idea is important because it can introduce computer systems to designers who might not normally take advantage of such capabilities.

Figure 1 shows an example from ICES TRANSET, a language for transportation network analyses. In TRANSET, it is possible to easily modify a network or to study a number of different networks to determine the effects of network changes on travel times and transportation costs. Because the basic interzonal travel demands may be uncertain, the effects of different demand matrices can be investigated to determine the sensitivity of a design decision to this uncertainty.

TRANSET is one example of a problem-oriented language. Many other languages have been developed for civil engineering as well as for other areas: ICES and STRUDL for structural design and analysis, ROADS for highway location and design, COGO for coordinate geometry problems, and TRAVOL for traffic volume data analysis.

An engineering, command-structured language provides more to the designer than ease of problem specification; it allows him considerable freedom in how he can use the computer and permits him to adapt the computer system to the requirements of his problem. A designer chooses which commands to use, the order of their use, and the associated data. Two designers might solve the same problem using totally different sequences of commands. With a problem-oriented language, the quality and efficiency of the computer usage is dependent on the ability of the user and the commands he chooses. An engineer can specify the known information, the operations to be performed on that information, and the desired results. Problem-oriented languages provide the designer with an effective way of communicating his operational requests to the computer.

The command structure of a problem-oriented language reflects the incremental nature of the design process. Designers build up a solution by performing incremental operations over a period of time. Each new operation is based on the results of the previous operation. The fundamental concept of a problem-oriented language is that all commands or operations are always available to a designer so that he can incrementally build up a solution by making operational requests in many different, unpredictable ways.

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TRANSET
$        FORM A NEW NETWORK BY ADDING LINKS TO THE UNLOADED NETWORK
MODIFY NETWORK 'UNLOADED', FORMING 'PROPOSED' ADD LINKS 2 6 0.6 2 2, 6 2 0.6 2 2
EDIT NETWORK
$        SET UP AND EXECUTE A TRAFFIC ASSIGNMENT
STORE NETWORK 'PROPOSED'
LOAD TRIP MATRIX 'TEST'
SAVE ASSIGNMENT RESULTS IN NETWORK 'DESIRE'
INTERMEDIATE PRINTOUT EVERY 100 ITERATIONS
SAVE RESTART DATA ON DISK
USE INCREMENT 10 TRIPS
REQUEST INTERMEDIATE LINK USAGE FOR LINKS 8 9, 2 4, 2 6
ASSIGN BY PATH MODE
REQUEST FINAL PRINTOUT OF LINK VOLUMES    FROM NETWORK 'DESIRE' FOR ALL LINKS
REQUEST FINAL PRINTOUT OF SYSTEM TRAVEL FROM NETWORK 'DESIRE'
$        SET UP AND EXECUTE SELECTED MINIMUM PATHS
OUTPUT PRINTOUT OF MINIMUM SEPARATIONS AND TRACES
SELECT MINIMUM TIME TREES, ORIGIN ZONES 3, 8
ERASE NETWORK 'DESIRE'
FINISH
```

Figure 1. Example of a problem-oriented computer language.

REMOTE ACCESS, TIME-SHARING

A designer must have the ability to interact freely with the computer system. He must be able to build up the design process in an incremental manner, solving portions of the problem, checking interactions of his system components, recycling, and so forth. This requires constant access to the computer during design.

Time-sharing is basically the use of a single computer by several people at essentially the same time. A number of engineers in different, remote locations may use the same computer in such a way that it appears to each that only he is utilizing the machine. The user converses with the computer by means of a console and receives output from the computer at the console. These remote consoles, which are basically some form of typewriter like a teletype machine, are linked to the computer via telephone lines. The individual users share the computer, not in the sense that each has access to a part of the machine but in the sense that each is given the whole machine for brief periods of time on a rotating basis.

Although typewriter console time-sharing is certainly convenient and efficient, many applications arise where more sophisticated input and output devices, perhaps of a graphical nature, may be useful. The extension of time-sharing to a highly sophisticated design input-output remote interactive station at which the designer can perform many different types of data manipulation and presentation is considered to be an important next step.

The most obvious advantage gained from time-sharing is the quick turn-around time provided, i.e., no long waiting periods between the submitting of input and the obtaining of results. The most important benefit of time-sharing, however, is not that it provides a convenience to the user but that it permits continuous man-machine interaction during the design process. This cannot be accomplished through a batch-processing mode of operation.

An essential fact implied by the term design is that the designer does not at first fully understand his problem. He solves it by an iterative process that involves the making of tentative decisions, the evaluation of the consequences by analysis, and then the changing of the original assumption or decisions. As the solution progresses, he defines the problem more precisely by adding to or modifying the original data. He must have a variety of analytical techniques available, so that the refinement of analysis can be increased as the problem description becomes more complete and the solution is approached. The use of a computer in this kind of flexible problem-solving environment becomes much more feasible through time-sharing. In a batch-processing mode of operation, the time delays between modifications in problem data or alternative analyses is a very restrictive factor, and the engineer is compelled to accomplish as much as possible in each computer run. Thus, partial solutions or the investigation of alternative designs are discouraged, and the engineer is often forced to accept something less than the best.

Although there are considerable benefits to be gained from time-sharing and problem-oriented languages when these capabilities are used separately, their real benefits are realized when they are combined. The flexible, efficient communication capability possible with problem-oriented languages coupled with the accessibility and interaction possible with time-sharing enables a designer to utilize computers more effectively in the design process.

GRAPHICAL DISPLAY AND PLOTTING

The results of most design studies are presented in the form of drawings for several reasons. First, graphics permit relationships to be visually appreciated. The overall picture is more readily apparent in a plot than in the obscurity of large masses of numerical information. Second, drawings tend to point out errors that otherwise might not be detected. Last, a graphical representation helps to convey to an engineer those design details that permit him to decide on modifications to improve an existing design.

Plotters and other input-output devices for engineering design and decision-making in conjunction with electronic computers have had an enormous increase in use during the past few years. A discussion of several aspects relating to the use of plotting devices may be helpful.

First, there are as many kinds of plots as there are draftsmen drawing them. Highway engineering plots include geometry or plan views, profiles, cross sections, and perspectives. Data presentation plots may include production functions in a 2- or 3-dimensional view and other linear information such as mass-haul ordinates, cumulative earthwork quantities, and local cost figures.

Second, computer-produced plots can be used for several purposes including final plans and engineering decision-making. Many of the cross-sectional plots are produced primarily for the set of construction drawings. Here, eye appeal, line quality, sheet layout, and aesthetics have been considered to be extremely important. Decision-making or sketch plots, on the other hand, are intended primarily to aid the designer and do not require a great deal of eye appeal and high-quality lines. The principal value of computer-produced plots comes from their use in decision-making.

Finally, an extremely wide variety of commercial plotting devices are available. These include line printers to produce fast, low-cost character plots; table and drum digital plotters to produce ink line drawings; and various types of low- and high-cost display scopes. Each type of plotter has a certain set of performance and cost advantages for a particular plotting application.

One of the most exciting, and probably the most important, developments in graphics is the use of a cathode ray tube (CRT) display scope in conjunction with a light-sensitive instrument called a light pen. A designer working at a CRT scope can directly input data to the computer by drawing on the face of the scope and can also have computed results presented to him in graphical form. Highway design is largely a graphical process and, as demonstrated, requires much iteration and interaction. It, therefore, serves as an excellent example as to how a CRT scope with light pen input might be utilized for engineering decision-making.

The display console is excellent for comparing designs. Alternate horizontal alignments may be shown on the same contour map; graphical results such as mass-haul diagrams may be shown side by side. The engineer can use the light pen to indicate the combinations of parts of several designs into a new design alternative. The cycling, changing, combining, and comparing process can be continued until the engineer is satisfied with his design. The design of the roadway templates could proceed in much the same manner. The computer automatically chooses templates when certain standard conditions are met, and the engineer designs or modifies for exceptional cases. Once the template design is complete, construction cost estimates and user costs can be calculated in detail. The engineer can take a simulated trip on the highway by having driver's eye views in perspective displayed on the console screen. Through such views, safety factors such as sight distance can be reviewed. The computer-aided process is much the same as the traditional design process except that the engineer can produce more alternative designs quickly and evaluate them in greater detail.

ADDITIONAL AIDS TO ENGINEERING ANALYSIS AND DESIGN

The major improvements in the use of computers for engineering design and analysis are likely to result from improved communication and accessibility. Significant improvements are also likely to be made in the range and capabilities of the engineering systems that are available.

Computer users in the past have been concerned primarily with a computational program or a routine. In the future, this concern is likely to be with an information-based system in which all project-related data are stored, and many individual routines are integrated. In solving any particular problem, an engineer may use only a small part of a system or he may use many different systems, automatically transferring data among different systems. ICES constitutes a significant step in this direction. A possible future ICES subsystem might be concerned with costing, economic analysis, and decision-making.

Existing programs and systems have been primarily concerned with the prediction of physical consequences in such terms as cubic yards of earth, pounds of structural steel, or minutes of travel time resulting from an alternative design. In the future, the range of applications will likely be broadened to include other steps in the design process such as evaluation, decision, and search.

Few, if any, highway location and design computer systems now include costing routines. Consequently, if costs are not immediately available, economic analysis routines are difficult to utilize. As management-oriented information systems are gradually introduced, improved cost data will become available and thus facilitate economic analysis and other quantitative decision-making methods.

A technique that appears to be very useful in the decision-making process is statistical decision theory. Statistical decision theory makes use of the Bayesian concepts of probability theory for the handling of uncertainty in connection with the prediction of future events. Decision theory is particularly useful in the context of hierarchical analysis. For instance, the design of a transport system is related to the design of a highway network, which is contained within the transport system, and the design of a highway network is dependent on the design of each of the roads in that network. Because the design of the higher level projects is fully dependent on the design of the lower level projects, decision-making at the higher levels cannot be undertaken without a degree of uncertainty as to the value of certain variables from the lower processes that have not yet been designed. Decision theory proceeds from higher to lower levels in a multistage process. At each state, the decisions are based on certain a priori values of the variables. The decisions made in the higher level processes are used to undertake lower level analyses. Through the use of more accurate predictive models, these prior estimates of the values of the variables are now subject to revision and improvement. Therefore, a review on the basis of these improved values is in order for the higher level decisions.

Simulation, both probabilistic and deterministic, is an example of a mathematical technique that is not possible manually but that has become increasingly useful with computers. Traffic simulation on a roadway attempts to model probabilistically the interactions and complexities of the theory of traffic flow. Traffic simulation can be used to investigate a large number of factors such as average speed, maximum capacity, average delay, deviations and distribution of delay among vehicles, number and types of vehicle interactions, queue lengths, and rates of formation and dissipation of queues. Values for parameters are obtained by randomly sampling from distributions and assigning these values to individual drivers. The drivers then perform according to rules determined by the values. The M.I.T. Vehicle Simulation System, originally developed by Lang and Robbins and now incorporated in ICES ROADS, is a deterministic simulation of a vehicle operation such as resistance versus speed, power, and fuel versus speed. The simulation is performed by incrementing either time, velocity, or distance and computing the resulting changes in the vehicle's operations. A third type of simulation model combining both deterministic and probabilistic elements is traffic assignment. Simulation often allows the building, for the same effort, of a much more complete model than one that can be obtained either through data collection or, in the case of probabilistic models, analytically.

An additional area in which computer usage is likely to increase is that of alternative searching and optimization. The search process in engineering is a very subjective one and is, therefore, difficult to model for a computer. On the other hand, countless alternatives exist in highway engineering and it is difficult if not impossible to distinguish among them. Searching for reasonable alternatives is within the realm of feasibility for computers. In fact, one can make a good case for the position that computers are more efficient at this process than man himself. Man is typically biased, and it is difficult in general for him to reassess a problem from a new standpoint. Good alternatives are frequently overlooked because they are hidden within a forest of permutations. The highway location problem is no exception. There are literally an infinite number of possible horizontal locations for a highway all within a given set of design standards. For each of these horizontal alignments, there is a large number of possible vertical alignments. It is difficult, if not impossible, for an engineer to distinguish all of these alternatives in his mind and to search out the one that is best.

Properly designed search algorithms can be formulated and can be successfully used in the search process. These range from heuristic search processes—a strategy, a simplification, or a rule that attempts to produce a solution that is good enough most of the time but not necessarily optimal—to more or less standard optimization techniques such as linear, integer, and dynamic programming.

SUMMARY

This paper has examined the role of computers and related tools in engineering decision-making and economic analysis. Emphasis has been placed on current computer systems advances and on new techniques of analysis now being implemented or under development. These techniques include problem-oriented languages, time-sharing, graphics, costing, decision-making, simulation, and search. The intent has been to present, and at the same time to give some background for, the current state and the likely trend of future developments in each of these areas.

ACKNOWLEDGMENTS

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Discussion

James Spencer

Would it be possible to give a thumbnail sketch as to how ICES approximates vehicle operating costs on a particular link or on a particular minimum time path between a pair of zones?

John Suhrbier

The vehicle performance capabilities in ICES ROADS consist basically of 2 models, a vehicle model and a driver-traffic model, that have been coordinated to produce results better and more comprehensive than those either could produce alone. No entirely new methods have been developed for ROADS; rather, a number of existing methods have been improved, made compatible, and linked together.

The vehicle model is based on a deterministic simulation of individual vehicles being driven along a roadway. Data used in the simulation include the horizontal, vertical, and cross-sectional geometry stored in the ROADS data tables; as much traffic volume information as is available; and additional roadway description items such as pavement type, passing limitations, and side restrictions. The model represents highway vehicles having internal combustion, gasoline piston engines. Vehicle performance is simulated at increments of time, Δt, and is based on balancing the forces acting on the vehicle.

The driver-traffic model is tabular in structure and is designed to predict the general effects of driver performance on factors such as average vehicle speed. This is accomplished through the use of generalized travel-time, traffic-volume curves.

Paul Roberts

About 3 years ago the Brookings Institution sponsored work at Harvard on the role of transportation in economic development, which led to the development of two specific models. One model, the macroeconomic model, behaves in the same way as the real economy of a country. The second, the transport model, responds like the transportation system. These two models are operated together. First, the macroeconomic model simulates the way the economy operates for a year; it then gives its regional industrial supply and demand information to the transport model. The transport model simulates transportation operations for a year, computing transportation costs to each of the industries. These industry costs are then given back to the macroeconomic model, which uses them in computing industry costs, profits, and a variety of other system-wide economic indicators. The macroeconomic model then repeats the cycle for the second year, and so on through time. In this way, the economy is simulated through time.

The most important aspect of the model is its response to externally applied stimuli. It will react if you do certain things to it. It is clear that one road does not make or break the country's economic development program, but it may be part of a system that does. We recently completed a study for the Colombian Government in which we developed a program of investment priorities for the next 10 years. The government's basic problem was to decide where it should spend its money, how much it should spend, and what would happen if it spent money in certain ways. We went to Colombia and gathered the necessary data; then, we calibrated the model so that it would replicate the actions of the economy over the years 1956 to 1965. Next, we fed into the model a series of alternative time-staged development plans. Finally, we compared these plans one with another to see which we liked the best.

Even though there are many operational problems in models like these, we have learned a great deal about that economy and what can be done to make it work as we want it to. We think these studies are useful. We also think simulation as a technique can be used to help solve a variety of problems at the national level, the city level, the regional level, or even at the level of a single highway, an isolated intersection, or a single parking lot. Of course, working at the national level, you could be preparing to invest $2 billion or so over 10 or more years, in which case computer studies make good sense. However, at the parking-lot level, you could spend $150,000 for computers, while the investment to be made is only $50,000. The example is contrived, but it indicates the range of models we could be using in economy analyses. Naturally, there is a level of detail beyond which you cannot go with this kind of model. You cannot say whether it is better to use chipstone or river-run gravel. The model can be used, however, to answer the larger questions about what is likely to happen as the system is changed.

Decision Theories in Transportation Planning

MARVIN L. MANHEIM, Massachusetts Institute of Technology

•THE PURPOSE of this paper is to present a very brief survey of some of the decision theories that may be applicable to transportation planning. These techniques have been developed in various fields, ranging from architecture to industrial management, economic planning, and statistics. Our use of the plural—decision theories—emphasizes that there is not just one single technique, but a variety of different techniques that come from many different disciplines and are applicable to transportation planning.

Several good survey articles have been written on decision theories and their applications (1, 2, 3, 4); only those most relevant to transportation are discussed here. Four groups of techniques are discussed: statistical decision theory, hierarchical structure, search techniques, and evaluation procedures.

STATISTICAL DECISION THEORY

We live in a very uncertain world. We tend to forget this, and become fascinated by the numbers produced by systems of complex models, such as the urban transportation planning systems, and elaborate calculations, such as benefit-cost analyses. In truth, however, we must concede that there are always uncertainties in every transportation analysis.

Uncertainties in transportation are of 3 types: demand, technology, and goals. No matter how elaborate a demand model we build or how much data we collect, there will always be uncertainty about our predictions of the future demand for transportation, because we do not understand very well the internal dynamics of the social and economic system with which we are concerned. In addition to the uncertainty about demand is the uncertainty about technology, not only about the pavement life and other characteristics of the particular highway or transit line we design but also about the transportation technologies that may be available a few years from now. Recent studies of urban transportation sponsored by the U.S. Department of Housing and Urban Development indicate that a variety of systems might be available in the near future. We are also uncertain about goals. In designing a metropolitan transportation plan or specific highways, we attempt to make decisions from the point of view of the body politic, but whose point of view? How are the interests of different groups balanced? The objectives of our society are continually evolving, and no single individual or group is able to fully express those objectives. We do our best, but inevitably the goals we use are uncertain.

Because the sources of uncertainty in transportation planning are many, they must be explicitly considered in our recommendations about specific actions. This is the task of decision theory: to provide a basis for reaching decisions in the face of uncertainty. The decision theory approach is indicated in the payoff matrix given in Table 1. To construct a payoff matrix, we first list all the alternatives open to us, in this case, an expressway, a high-level arterial, or the existing 2-lane road. Then we identify those things about which we are uncertain by listing the alternative "states." For example, we may be uncertain about the volume of the demand for a particular route; therefore, the alternative states are the alternative levels of demand that we consider might occur. Next, we determine the utility or desirability for each possible combination of an action and a state. For example, for each action and each level of demand, we can compute total annual cost (first cost plus user costs).

Such a table summarizes the decision problem: For each action, the utility or payoff depends on which particular state occurs. How should we choose an action in the face of uncertainty about which state will occur? There are a number of approaches

TABLE 1
PAYOFF MATRIX

Alternative State: Demand Levels	Alternative Action			Probabilities
	Expressway	Arterial	2-Lane	
	Expected Utility			
1,000	1.7	2.2	3.0	0.3
5,000	1.9	2.5	2.5	0.6
10,000	2.0	2.2	1.5	0.1
	Expected Value			
	1.9	2.4	2.6	

to this problem (5). Here we will treat only one, the statistical decision theory approach (6, 7, 8). In this approach, we assume that it is possible for the decision-maker to estimate a probability for each of the states.

These probabilities may be objective or subjective. Objective probabilities are derived from actual data; for example, we may have statistics on the variability of strength of pavements of a certain type. Subjective probabilities are derived by judgment; they reflect the engineer's estimation of the relative likelihood that a particular state will occur. For example, uncertainty about future demand may come from uncertainty about the growth rate of population and automobile ownership. Therefore, based on various estimates of population and automobile ownership growth rates, we can make judgments about the relative likelihood that future demand will be at certain levels. Then, we express our judgments in the form of probabilities 0.3, 0.6, and 0.1 for the 3 levels of demand in Table 1. Expressing professional judgments over a range of values as probabilities should be more satisfying than simply using a single best-estimate value. It is certainly a sounder basis for design.

To use the probabilities, we now compute the "expected value" of utility for each alternative in the payoff matrix. The expected value for any alternative is the sum, for all states, of the probability of that state times the utility of that alternative if that state occurs. For example, the expected value of the expressway is $(0.3 \times 1.7) + (0.6 \times 1.9) + (0.1 \times 2.0) = 1.9$. We then compare the alternatives on the basis of their expected utilities and choose the action that has the highest expected value of utility.

In the preceding example, the alternatives considered were immediate actions regarding particular highway alternatives. In general, however, the decision-maker also has the option of deferring implementation of an action in order to acquire more information about the problem. For example, if there is a great deal of uncertainty about demand, it might be more efficient in the long run to delay construction of a new highway for a period in order to collect sufficient information to reduce this uncertainty. Information can be collected by several alternative ways such as traffic counts or origin-destination surveys. Thus, the more general problem has 2 basic sets of alternatives: immediate actions such as highways, or actions that involve collecting additional data first and then making a choice among immediate actions.

Statistical decision theory is particularly appropriate for this more general problem. Data collection programs such as origin-destination surveys or traffic counts can be evaluated not only in terms of cost but also in terms of their role in reducing uncertainty. Then, the decision as to which kinds of data collection programs to conduct can be based on a careful economic calculation. In such a calculation, the costs of deferring action and of data collection are balanced against the "costs" of uncertainty if action were taken immediately. Johnson (9) has done pioneering work in applying statistical decision theory to transportation data collection.

An even more general formulation is that of a sequential decision process. There are significant time lags in implementation of transportation systems alternatives. It takes at least 7 years to plan, design, and construct a new highway. A comprehensive transit and expressway plan for 1985 is not implemented instantaneously, but as a series of stages. Meanwhile, the world continues to change. Transportation planning takes place in a context of continuous change in demand, in technology, and in goals.

Transportation planners need to deal with strategies; each alternative strategy is composed of a sequence of actions staged over time. For example, consider a 20-year comprehensive metropolitan plan. Such a transportation plan might be divided into five 4-year stages. Each stage might consist of several actions such as particular highway links, transit extensions, data collection activities, and community decision points. We can expect that by the end of the first 4-year period things will have changed.

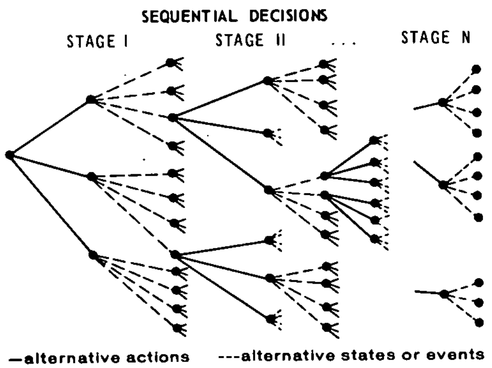

Figure 1. Simple decision model extended to multiple stages via decision tree.

Demand patterns will have changed; new technologies will have been developed, or problems or advantages in existing technologies will have been uncovered; goals and aspirations will have changed; data collection activities will have produced new information. We will have learned more. Because conditions will have changed, the strategy consisting of a sequence of stages should be reviewed and possibly revised at the end of the first stage. If change has been relatively minor, the actions to be implemented in the following stages of the strategy may stay the same; more likely, however, the later stages of the plan will be revised because of the changing world. To have an effective continuous planning process, we need to conceive of a transportation system plan as a sequence of staged actions; at the conclusion of each stage, we must open the door again to review and analyze the succeeding stages based on new information and the results of the preceding stages.

A formal basis for this continuous planning process is provided by the sequential decision model. Figure 1 shows the simple decision model extended to multiple stages via a decision tree. At each stage, the set of actions includes not only immediate actions, e.g., highways, but also information-collection actions, e.g., traffic survey. The optimal strategy, or sequence of actions, is determined by a procedure very similar in outline to that of the simple single-stage decision model. For every possible sequence of actions and combination of events, a utility, e.g., total discounted annual cost, is determined, and the probability of various events is established objectively or subjectively. Then, the net expected utility for each sequence of actions in the face of uncertainty is computed by summing the probabilities times the utilities. The best action is the one that has the greatest net expected utility.

In principle, this calculation has a straightforward logic, but, in practice, it is complicated by a number of factors. [Relatively tractable techniques exist for standard statistical processes such as often occur in standard sampling approaches (8).] First, there is generally a large number of combinations of actions and events. Second, the probabilities at different stages of the decision tree are different, because information is acquired at different stages, and the information depends on which actions were taken at earlier stages. Third, the utilities at future periods are different from the utilities at the initial stage. Fourth, and perhaps most significant, to evaluate the utility at any point in the decision tree may require running a complex simulation model, such as the urban transportation package. Clearly, this is impractical for several hundred points in the tree. Therefore, to apply the sequential decision process model to transportation planning requires that special techniques be developed and adapted to the transportation problem. Research has begun on such techniques (10). The objective of this research is to develop practical techniques for treating transportation planning as a sequential decision process in the face of uncertainty.

One of the advantages of this sequential decision process formulation is that it places in perspective the role of experimentation in the transportation planning process. A variety of information-gathering experiments is possible. For example, demonstration programs such as in public transit or high-speed rail transportation are experiments to get information about demand as well as technology performance. It is essential to analyze such experiments explicitly (11); they are as important a part of the set of transportation planning options as the construction of new highways or new transit lines or other physical facilities. The sequential decision process model of transportation planning emphasizes this perspective by including explicitly such information-gathering activities, as well as physical actions, in the context of staged strategies.

HIERARCHICAL STRUCTURE

We now turn to an extension of the statistical decision theory model to represent the analysis process through the concept of hierarchical structure (12). Figure 2(a) shows a hypothetical highway route location problem. The objective is to locate a highway between 2 termini roughly 15 to 40 miles apart. In a typical process, the engineer will not immediately start developing a detailed design for a single highway location between 2 termini. Most often, there will be a series of steps in the analysis process, successively narrowing down the range of alternatives under consideration.

In the example, we have assumed that there are 3 such steps in the location process. The first step involves bands of interest or approximate areas of highway location, such as "generally on the north of the valley" or "the easterly side of the ridge." The engineer will begin the location process by developing several possible bands of interest based on general surveys of the terrain. Then, he makes a judgment about which band of interest should be studied in more detail and shifts his focus to location bands. A location band is an approximate location for a highway, perhaps within a range of several hundred feet. In the example, the engineer generated 2 bands of interest, A and B, and then decided to work with band of interest B; within that he generated 2 alternative location bands, C and D, which he evaluated. Finally, he selected location band D, and developed a single detailed location, E, within that location band.

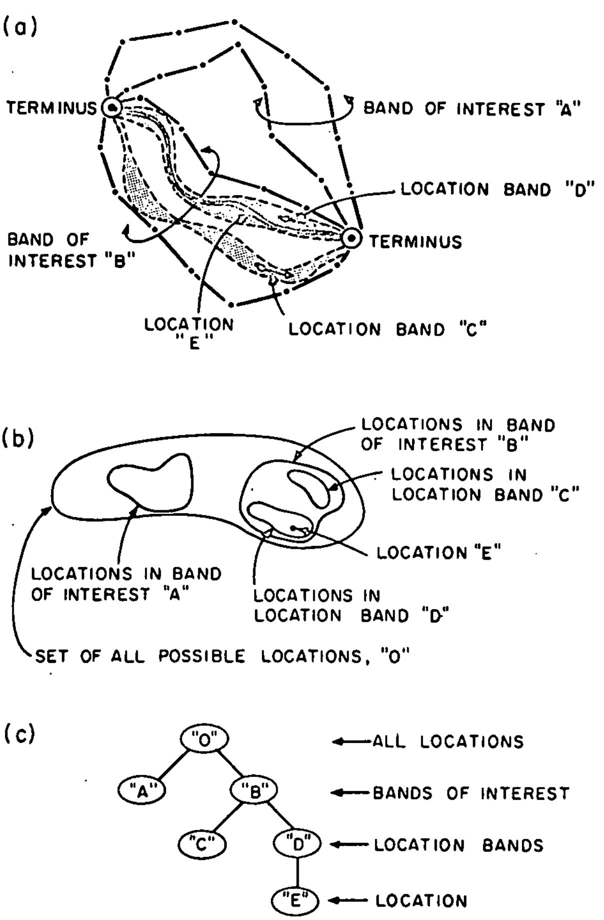

Figure 2. A history of a location process.

This process of progressively narrowing the space of alternative locations can be modeled explicitly. Consider the set of all possible locations between these 2 termini, as shown in Figure 2(b). What is a location band? It is simply a symbolic designation for an even larger set of specific locations, and it also represents a number of location bands. Thus, in the process of solving a particular location problem, we progressively narrow the set of possible locations. First, we look at large sets, bands of interest; then at smaller sets, location bands; and then at locations, the basic elements of the set.

To visualize this, consider a particular stage in the location process. Prior to this stage, we have generated 5 actions; 2 bands of interest, 2 location bands, and 1 single location. The relationships of these actions as sets is shown in Figure 2(c). At this point, there are a number of possible things we might do next. We can generate either (a) a location in location band D, (b) a location in location band C, (c) a location not in any of the previously generated location bands, (d) a location band within band of interest B, (e) a location band within band of interest A, (f) a location band not in either of the previously

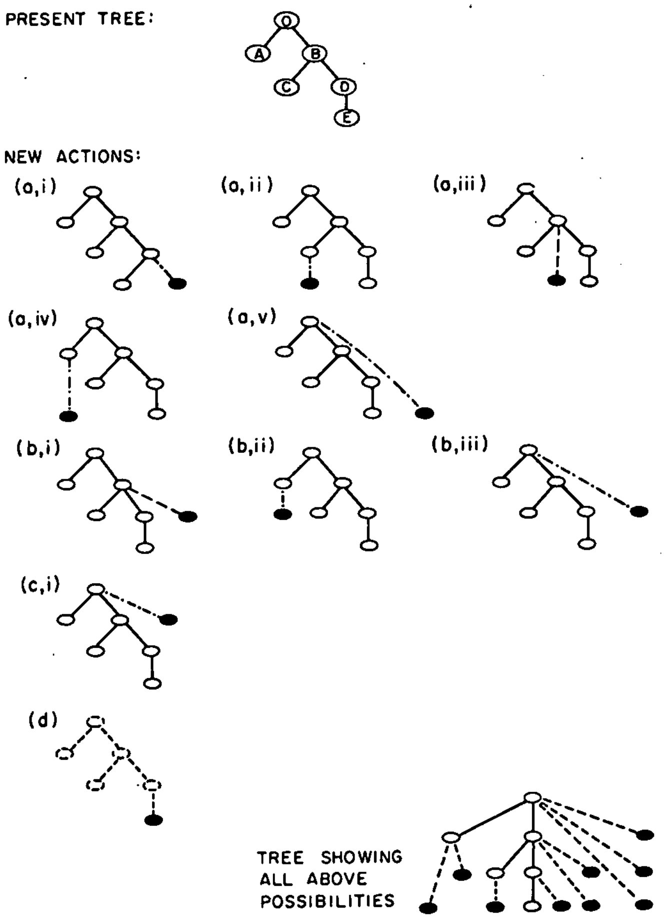

Figure 3. Possible new actions.

generated bands of interest, or (g) another band of interest; or, we can terminate the location process. These possibilities are indicated by the black dots shown in Figure 3. The problem is to know which of these is the best thing to do next in a location process. The hierarchical structure model provides a rational basis for the analysis of which of these possibilities is best.

The basic issue is the value of information versus the cost of acquiring it. To develop and evaluate a single detailed location design is relatively expensive; to develop and evaluate a band of interest is less expensive; and to develop and evaluate a location band costs somewhere in between. On the other hand, only specific, detailed locations are solutions to the location problem. The only value that bands of interest or location bands have is to serve as sort of intermediate way stations in the location process. By examining a particular band of interest or location band one gets some idea about specific locations represented by that band of interest or location band without spending all the resources required to develop and evaluate a detailed location. Thus, in the example, band of interest A has, so far, been rejected in favor of B without the cost of examining a detailed location in that band of interest.

The essential issue is to balance the costs of engineering against the value of information. One can spend a lot of money and get a lot of information through developing a detailed location, or one can spend relatively little money and get somewhat less information through developing and evaluating a band of interest. These kinds of tradeoffs can be modeled using the approach of a sequential decision problem.

The hierarchical structure model provides a rational procedure for guiding a design process such as route location. Several activities are possible, for example, (a) generating and evaluating locations, location bands, or bands of interest or (b) terminating the location process. Each activity is characterized by a cost or resources consumed and by its contribution to the engineer's information about the location problem. (More precisely, at any stage a set of actions, such as locations or location bands, has previously been examined, and over each the engineer has a prior probability distribution. Each activity is characterized by a cost and a conditional probability. There is a utility function over locations only.) The engineer's judgments are expressed as subjective probabilities. The logic of the sequential decision problem, modified to reflect the hierarchical structure of the location problem, provides a basis for calculating the best thing to do next in a location process (12). The hierarchical structure model is general, applying to problems other than route location.

In expressing the trade-offs between information value and information cost, the model also sheds some light on suboptimization. Note that we have not talked about finding the best location out of all possible locations; we have implicitly assumed that the location problem is not an optimization problem in the usual sense of finding the best of all possible. For example, we pick a particular band of interest, evaluate it, and then perhaps decide not to study it any further. The best of all possible locations may very well be in that band of interest. Once having rejected that band of interest, we have lost any chance of even finding that best location. However, given the limited resources of the engineering process and the information that the engineer has expressed in his judgment about the band of interest, we may be making a "reasonable" decision by rejecting that band. This is suboptimizing; we have not picked the best of all locations. Such suboptimization is in fact optimal, however, in the broader context of limited engineering resources and the costs of information. Discarding that band of interest is in fact an optimum strategy. This view of suboptimization has wide ramifications for the structure of engineering processes in general.

SEARCH TECHNIQUES

In our discussion of decision theory, we assumed that all the alternatives were given, and that we knew for each the utility associated with that alternative and a particular state (Table 1). Several questions arise: How did we know what utility was associated with each action-state combination? How did we get the alternatives in the first place? We will return to answer the first question later; here our discussion is focused on the problem of search or how to get the alternatives in the first place.

We define search as the process through which one or more alternatives are produced. [Ferguson (13) discusses the issues at the network planning level.] The process of search may be highly formal, as when mathematical models are used, or highly intuitive, as when an engineer or planner sits down and sketches a possible regional transportation system; or it may be some combination of these. The spectrum of search techniques ranges from mathematical models to intuitive design procedures. The most powerful search techniques now available are those of mathematical optimization, such as linear programming. These techniques do have limitations. First of all, there is the computational difficulty, i.e., the time required for computing solutions. Second, there is the very real limitation of having to force complex sets of goals into the format of a linear objective function and set of constraints. Third, there is the problem of forcing our understanding of a very complex set of phenomena into the linear or partially linear forms required by linear programming and other mathematical programming techniques. Often, however, these limitations are not so grievous, and the returns more than justify the limitations. Thus, we can find many useful mathematical programming formulations that can be used to generate possible alternative solutions to a transportation problem (14, 15, 16).

Less restrictive as an approach is direct search. Direct search techniques include "hill-climbing" approaches, which operate as follows: Arbitrarily or randomly select an initial possible solution to the problem as a base point, explore various small changes to this solution and compare, determine the best of the small changes, and shift the base point to that best solution. Repeat the cycle but explore small changes from the new base point. Continue the process until finally small changes do not produce any improvement. More complex simulation models can be used for testing the solution with direct search techniques than with mathematical programming. For example, instead of the optimal flow formulation, the descriptive approach of traffic assignment can be used. Direct search techniques, unlike mathematical programming, do not guarantee that an optimum solution will be found; but they should prove useful in finding at least local optima if not global optima (17).

One can go further in loosening up the structure of the problem and formulate a variety of heuristic search techniques. By heuristic, we mean simply that these techniques are likely to produce good solutions, but there is no guarantee that they will produce an optimum solution, or even produce good solutions all of the time. For transportation planning, heuristic techniques may be derived by asking questions such as this: If an engineer were looking at a network, how would he try to develop small changes that might be potential improvements to that network? We can propose a number of approaches of this form, program them for the computer, and then use them to try to get better transportation networks via heuristic procedures. This will probably be the most fruitful area for practical search techniques in the near future (18, 19, 20, 21, 22, 23). For example, at present the use of a mathematical programming formulation requires an approach to predicting flows in networks different from the more behavioral approach of traffic assignment (24, 25). Instead of trying to force the network analysis problem into linear programming form, we could use traffic assignment procedures (and thus have a more realistic analysis of the network alternatives) and design heuristics based on the kind of procedures an intelligent engineer might use to modify the network to get a better network. Thus, the heuristic procedures, programmed as a set of computer routines, together with a traffic assignment model might be a reasonably efficient way of searching out alternative transportation networks.

As a fourth major class of techniques, we should mention procedures for guiding the engineer's intuition about the nature of desirable alternatives. One extremely insightful model for guiding intuition was developed by Alexander (26) in the context of architectural design problems, but it is applicable to many different kinds of problems, including transportation planning. This technique is particularly insightful because it does not replace the transportation planner's crucial role in inventing and creating new solutions; it just tries to guide him in the essential issues.

The basic approach is this. First, list all the objectives and constraints that the particular solution has to meet. Second, examine this list of requirements; and for every possible pair of requirements, identify whether that pair is particularly difficult to resolve. For example, if we are dealing with the design of highway interchanges, we may find that the requirement for sufficient vertical clearance for underpasses really conflicts quite strongly with the requirements for minimum earthwork costs (27). On the other hand, requirements for vertical clearance may not conflict at all with lateral clearance requirements; however, lateral clearance does conflict heavily with lane widths or median widths.

Based on this simple analysis of the requirements that the solution must meet, a model of the problem can be built. Each of the requirements corresponds to a node of a linear graph. Where there is a significant conflict or interaction between 2 requirements, we establish a link between the corresponding nodes in the linear graph; where there is no significant conflict, we do not put a link between the 2 requirements. Thus, the structure of a design problem, which may have hundreds of requirements, can be mapped in this way. Then, this structure can be analyzed, using certain procedures. The result of this analysis is the specification of a sequence in which the designer should try to address the requirements; this sequence results from the systematic decomposition of the overall problem into subproblems, using the information in the linear graph. The designer searches for a solution to the problem, juggling these requirements and their interactions. The value of the approach is that the sequencing of the requirements makes the designer's approach more effective. This approach has been applied in an experimental way to search in 2 transportation problems, highway interchange design and route location (28). McHarg (29) in work done later used a similar technique of overlaying diagrams in order to search out a route location. However, there was no systematic analysis of problem structure in McHarg's approach; his technique seems wholly arbitrary.

The problem of search is in the development of good alternatives. Approaches available range from the completely intuitive design to mathematical models. Each type of search technique has its assets and its limitations. We can look forward to the proliferation of a wide variety of search procedures, each of which is best for certain circumstances, but none of which is best for all problems in transportation planning.

EVALUATION AND CHOICE

Let us now turn to the first question we asked: How do we get the utility associated with each combination of an alternative and state? To get the measure of the worth of a certain action, we must first predict its consequences and evaluate those consequences. This evaluation can look at the alternative by itself as well as compare the alternatives with others. In standard transportation planning and highway location studies, the basis for the evaluation of alternatives is nominally that of economic analysis, the standard benefit-cost analysis, or variations on this theme. However, these economic analysis techniques have extremely severe limitations.

The essential issue is this: Any change in the transportation system impacts differentially on different groups. Some groups benefit, some groups lose. If we build a highway through a city to serve automobile-owning suburban commuters, we displace homes and jobs, and reduce transit ridership, thus causing increased fares and lower service for nonautomobile-owning transit users. It is particularly important not to hide these differential impacts, but to trace them out explicitly. If we try to place a dollar value on all the benefits and costs and to compute some aggregate total, such as net benefits or costs, or benefit-cost ratio, we ignore how each of these different groups will be affected. The real issue is not how much total net benefit is increased or decreased, but how each particular group is affected. Any politician recognizes this fact of life: no system can be implemented in reality unless no group is disrupted. For, if some group is negatively affected, then we can expect politically effective reactions. Thus, in the systematic analysis of transportation alternatives, we must explicitly trace out the incidence of these differential impacts.

Techniques are under development to assist in differential impact analysis (30, 31). These include the concept of a goal-fabric as well as the development of computer software systems.

CONCLUSIONS

This has been a very brief survey of a wide variety of relatively subtle issues. We started out with the statistical decision theory approach to treating uncertainty. We extended the simple model to that of sequential decision processes and pointed out its relevance to the problem of hierarchical structure. Then, we discussed search, the generation of alternatives, and finally, very briefly, the subtleties of evaluation and choice among alternatives. Our main objective has been not to present a text on these techniques but simply to point to some of the directions of current work in decision theories that may be useful in transportation (4, 32).

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Discussion

Wilson Campbell

What you are talking about is a procedure that is not done in a few minutes, or hours, or even years; it is a continuing and comprehensive process. I do not see that it is greatly different from the techniques being used today.

Marvin Manheim

True. But let us honestly recognize (a) that we never actually solve the urban transportation problem, (b) that actually the way things get done is as a series of sequential decisions, (c) that we deal with a multiplicity of objectives in a fairly complex way and do not act as though they are all dollar-valued in the market, and (d) that we do not really deal with the problem as a single-level problem but we develop some preliminary alternatives and some final alternatives. Let us recognize this continuous planning process for what it really is.

Dan Haney

Even though we would desire to keep the various objectives and goals separate so that the impact on the different alternatives of each may be measured, we have to know the overall objective function if we are to make major decisions on a systematic basis. This objective function must be used by many people in an organization for designing and evaluating plans; it must cover not only user consequences but nonuser consequences as well. Let us derive it as best we can, and then use the techniques of sensitivity analysis to evaluate what would have been the choice if, for example, the weighting of reduction in unemployment were different in relationship to user costs.

Marvin Manheim

We have to develop a much more flexible, much more subtle approach; sensitivity analysis is one very important tool. The idea is that we should not define some objectives, then find some alternatives and pick the best alternatives in line with the objectives. Rather it is to use widely different statements of objectives as ways of clarifying the issues and finding the alternatives that abide by these objectives, and then to go back into the political process to get the choices made. One very simple experiment I would like to try is to provide an on-line network analysis capability including a visual display, and let the neighborhood groups who are concerned with the highway location vary the line to see what happens in terms of impacts on other groups in the community. Thus, the neighborhood groups would see what it is that either they or the people in the other town are going to pay and to whom and in what form. The essential issue is not analysis by taking a clear-cut statement of objective and solving the problem; rather it is analysis by interacting in the political process to clarify alternatives and objectives, which will lead to decisions in the political process.

Wilson Campbell

Granted goals are likely to change, but we need some target or direction to aim for at a higher level. The target will change and that is why these planning studies are continuing. There are changes in the social and economic attitudes, and presumably these studies are flexible enough to change their goals accordingly.

Marvin Manheim

I believe that you should not come out with reports that say "these are the alternative systems, and this is the recommended system to be completed by 1985 or 1990." Rather the reports should indicate that A is the best alternative to be carried out over the next 5 years, and, if this is done, then probably we will do B over the following 5 years and so on. We would like to have more explicitly addressed the continuing nature of the transportation plan with a statement as to the conditions under which we will choose the alternatives at the next stage.

Community Consequences and Urban Highway Location Decisions

FLOYD I. THIEL, U.S. Department of Transportation

•THE LOCATION of urban highways affects both the motorists and the community. The development of methods to determine what the economic and social effects on the community are has lagged, perhaps because it is difficult to obtain information about these effects and to reduce it to a form suitable for use. Despite many studies, knowledge about consequences that highway improvements have on communities still amounts to considerably less than what is needed for objective evaluation. Studies have usually presented narrow, limited findings, such as the number of jobs, businesses, and homes removed from the right-of-way, or they have provided projected benefits or damages that have seemed unrealistic. In most cases, expected effects have been described in qualitative terms or in such length that comparisons of decision-making or review of recommended decisions are difficult and time consuming.

At least part of the difficulty may be that intricacies of route location considerations are carried too far beyond the point justified by either the nature of the data or the time that a person or group can devote to considering or reviewing the location decision. Indicating by a simple plus or minus whether alternative route locations have positive or negative effects on selected characteristics is an easier way to portray in a summary report the superiority of one location over another. Information of this type should be adequate for situations where a decision has already been made to build a highway improvement and the only question remaining is where to locate the improvement. For example, the decision to build a link in the Interstate System may have been made by Congress or on the basis of user-benefit analysis. Instead of a comparison of precisely how many dollars may be gained or lost by a particular location for a highway, one route is ranked against another so that the items relevant to the route location can be summarized for quick comprehension.

A LIST FOR RANKING

Such an approach could involve a list of characteristics such as that issued by the U.S. Bureau of Public Roads in 1964 and given in Table 1. Table 1 also gives the rankings of the 2 alternate route locations shown in Figure 1.

Several of the characteristics overlap, however, this should present no problems because only pluses and minuses are used to show which location ranks higher for each item. In fact, this overlap generally seems desirable because much of it occurs on matters that deserve emphasis. Thus, there is some overlap among aesthetics, residential character and location, and property values; this simply provides a healthy emphasis. A plus and minus can be used for a characteristic on which the alternate locations are considered to have about an equal effect.

The list of characteristics and rankings for them are intended to help decision-makers comprehend easily how technicians rank alternate route locations. The list should not be a substitute for analysis because each of the characteristics must be analyzed to indicate, for example, why one location was ranked plus for residential character, perhaps because this location left a stable neighborhood undisturbed.

IMPORTANCE OF POINT OF VIEW

In this simplified example, route location A ranks higher than route location B on characteristics such as national defense, economic activity, highway cost, and highway user savings. For recreation, aesthetics, safety, religious institutions, conservation,

TABLE 1

RANKING OF ALTERNATE ROUTE LOCATIONS BASED ON THEIR EFFECTS ON SELECTED CHARACTERISTICS

Characteristic	Alternate A	Alternate B
National defense	+	–
Economic activity	+	–
Employment	+	–
Recreation	–	+
Fire protection	+, –	+, –
Aesthetics	–	+
Public utilities	+, –	+, –
Safety	–	+
Residential character and location	+, –	+, –
Religious institutions and practices	–	+
Rights and freedoms of individuals	–	+
Conduct and financing of government	+, –	+, –
Conservation	–	+
Property values	+, –	+, –
Replacement housing	+	–
Education and disruption of school district operations	–	+
Specific numbers of families and businesses displaced	+	–
Operation of highway facilities and other transportation facilities during construction and following completion	+, –	+, –
Engineering, right-of-way, and construction costs for proposed highway facilities and related transportation facilities[a]	+	–
Maintenance of highway facilities and other transportation facilities[a]	+	–
Use of highway and other transportation facilities, and user costs[a]	+	–

[a]Also analyzed, at least in part, in the user benefit-cost analysis.

and education, location B outranks location A. It is quite conceivable that in such a situation an evaluator with a local point of view would favor location B. It is longer and more costly to build, but it might be expected to provide more nonuser benefits than location A.

The detailed analysis of each characteristic on the list will permit the analyst to take account of points of view, a matter of special importance in evaluating community benefits. Thus, an educational point of view might be more locally oriented than a national defense point of view.

SOME IMPACT PRINCIPLES

As an aid in ranking alternate highway route locations and in reviewing these rankings, especially pertinent information can be summarized in the form of a list of general principles or findings based on an analysis of highway impact studies. Such a list of general principles may be useful regardless of whether a simple plus-minus ranking system, a numerical rating plan or some other system is used. A few items that might

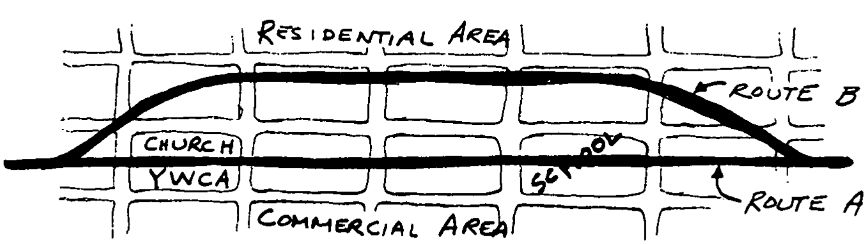

Figure 1. Location of alternate routes.

be developed into a list of general principles useful in highway location decisions are as follows (1):

1. Industrial and commercial properties have apparently benefited more than residential land from having a highway nearby.
2. Adverse effects of highways may be mitigated or eliminated by well-landscaped highways located outside or on the border of neighborhoods or school districts.
3. New highways have apparently hastened economic changes that were previously under way; this appears to be more characteristic of gains (or potential gains) than losses.
4. Local tax roll losses due to right-of-way acquisition have typically been offset by new development or by intensifying existing development.
5. Interchange areas have experienced a disproportionately large amount of economic activity.
6. Residents relocated from right-of-way areas have typically improved their living accommodations and increased their living costs.

Problems may be encountered in preparing a list of principles. It may be difficult to reach agreement on which findings are firmly enough established to be considered principles. This is because some finds or principles are based partly on nonquantifiable information. Also, several different groups participate in some way in highway location decisions—staff workers who make the initial location recommendation, members of the public, and officials or legislators who make the final decision (2, 3). Almost any set of principles will seem trite to some and controversial to others.

This problem can be partly overcome by documenting the items on the list. For some of those using such a list, fairly full documentation could be provided, perhaps with some analysis as well as references to completed studies. For users without the time or inclination to follow the full documentation, it may suffice to provide summary references to pertinent findings such as the following:

> Principle
>
> Industrial and commercial properties have apparently benefited more than residential land from having a highway nearby.
>
> Sources
>
> Bureau of Public Roads analysis of California, Georgia, and Texas studies shows median annual percentage gains along major highways of 17 for industrial, 11 for commercial, and 9 for residential. Bureau of Public Roads analysis of severance cases from 40 states shows median value gains between acquisition and remainder sale of 45 percent for commercial and industrial and 25 percent for residential parcels. Also see: Michigan Proximity Study, No. 203.

SUMMARY

Bringing relevant economic data to bear on highway location matters may be aided by means of a simple plus-minus ranking of selected characteristics relevant to route selection. Such a ranking, or that by some other system providing numerical ratings, will be assisted if highway study findings can be distilled into a list of principles that is substantive enough to be meaningful but short enough to be manageable.

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Socioeconomic Factors and the Highway Decision Process

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•THE PURPOSE of this paper is to stimulate discussion about the socioeconomic factors associated with decisions in highway location and design. Perhaps the best way to start is to list some of the factors that have been issues in many location and design decisions in California.

- Recreational and park areas
- Historical and aesthetic values
- Property values including impact on tax rolls
- Public and quasi-public facilities
- Total transportation plans
- Community master plans
- City street and county road traffic
- Land uses
- Noise levels
- Air pollution levels
- Trade, wholesale, and retail
- Employment
- Area stability
- Persons displaced
- Population levels
- Population composition
- Housing availability
- Open space
- Parking availability
- Intercommunity relationships

This list is by no means complete. Many of the factors must be divided further for proper consideration; for instance, land use should be divided into specific uses, such as residential and commercial.

Despite an increasing awareness that highways affect these factors, our ability to predict the effect or direction of change has actually reached only a low level of expertness. We can only crudely approximate the real relationship between the highway and the rest of the environment. Intensive interest in clarifying this relationship reaches back only a dozen years or so, and published results of studies still number in the few hundreds. To make matters more difficult, few of these studies formulate specific rules, because most were designed to shed light on particular problems at particular places. Therefore, we are and probably will be for a number of years in a trial-and-error period. Even so, highway decision-makers must deal daily with socioeconomic factors, basing their decisions on available information. This information must be organized and treated rationally in order to maintain public acceptance of the decision process.

It would seem rational to translate potential effect into monetary terms wherever it is possible to do so, and it is possible to do so with most of the factors. I am not at all sure, however, that such an exercise is always relevant to the decision process. Take the factor of land use, for example. If a route is located through a single-family residential area zoned for multiple use, an acceleration of the change to multiple use can be predicted. Demand can be estimated, a time for the conversion to multiple use can be figured and compared to existing trends, and then the discounted value of the change to the area can be calculated. But demand is not created by the presence of the highway; it is only focused and located from some place else in the region. If this is true, what is the value of the calculations?

It is important to the community involved to know that a more rapid conversion to multiple use can be expected because this affects tax base, school enrollments, and public services required. If the route or design is acceptable, the fact and possible timing of potential change is much more important than is the possible monetary value of such a change. And if the route or design is acceptable, there is, in my opinion, no reason to go further. There are situations, however, when a community asks to have a proposed route moved from the location of greatest net benefit to a location that would encourage a land use change such as that just described. In a case of this kind it does seem proper to weigh the discounted increase in land values against the potential decrease in net benefit to the motorist by reason of the relocation.

Clearly, community desires must be taken into consideration, and the highway should be fitted to these desires if losses in motorists' benefits do not exceed gains to the community. There is inevitably some trade-off of gains necessary between motorists and community in order to permit achievement of the motorists' objective of improvements in highway facilities.

It would seem appropriate then to attempt to express socioeconomic effects in monetary terms only when the motorist is being asked by the community to incur higher costs or to enjoy fewer benefits than he would if the route or design were selected by means of a conventional highway engineering economy study. The comparison would seem to be properly made only between the increment of cost, or loss in benefits, and the gain to the community.

At the present time, there are several practical restraints to full consideration of all pertinent socioeconomic factors in nearly any route location situation. Expertise is limited, little applicable research has been done, and adequate financial support or personnel are just not available. These restraints require that consideration be limited to those factors that are likely to become key issues in the process. Currently a major problem is to identify these issues early enough in the process and to organize and prosecute a study effort that can assist with solution.

For this reason efforts are now being made to find bases for determining community attitudes and values. For instance, knowing whether a community will resist or seek change often makes possible the initial selecting of alternatives that will act as a buffer to, or will encourage, change in the community. In this way, potential controversial issues can be limited.

If it is not economically feasible to provide alternatives that will reinforce community values, then, at the least, study can be started on indicated key issues. Factual information adequately analyzed can often deter community leaders from adopting positions from which they may later be reluctant to retreat. Notification to the community that route location and socioeconomic studies will be started usually brings reaction that can indicate fruitful directions for study emphasis.

In the initial stages of route study, the community may indicate a concern, through its technical staff, its city council, its newspapers, or its legislative representatives, about its assessed value base or the potential for smog problems or the stability of uses in the corridor through which the route is proposed to be located. Often, at this point, minimal study of the key issue can influence community attitudes. Assessed value losses along several potential lines can be calculated, estimates of salvageable improvements can be made and offset against assessment losses, potential land use changes can be predicted, and value changes can be indicated also as offsets. Frequently, merely calculating assessed value losses and comparing them to average annual community increases can reduce fear of loss.

Similarly, past research findings can be interpolated in light of local conditions to provide general indications of effect for other socioeconomic factors. Certain factors reflect very direct relationships to the highway. Park areas or historical sites are either taken by the route location or they are not. The cost of avoiding them can be calculated as can the cost of replacing the park or relocating an historic building. For adjacent sites the cost of a wider right-of-way or extra landscaping may be pertinent. The value of parks or historic sites is irrelevant to the economy study process. If they have sufficient value to the community, the highway decision-maker will have a choice of building on an alternate route with fewer benefits or, if that is unacceptable, of not building at all. So the costs of the other alternatives are the items of importance.

Other factors of concern to the community may be important either because they lie within the right-of-way of a proposed route or because they are indirectly affected or because they are not affected. The number of persons displaced and the houses they occupy is obviously a matter of concern. The cost of the improvements is estimated as a matter of course as a part of the economy study process. Replacement housing for the persons displaced can become a major issue. Normally, it can be shown that, given reasonable lead time for the acquisition process, vacancies occurring in the remainder of the community and new construction will fill the housing gap. More difficult replacement problems can usually be solved by stretching out the acquisition process, and the cost of this solution can be calculated in terms of user benefits deferred, if necessary.

A particular route location may be disputed because it will encourage conversion to undesirable land uses—undesirable, that is, to the adjacent residents or because potential uses do not fit the community's general plan. Conversion is usually to a more valuable use and gains can be estimated, although access restriction in rural areas can halt conversions to more valuable uses in which case losses can be estimated. Usually there are gains, however, and even though they may be significant, if they are not desired by the community, the value of the attitude or plan can only be expressed in terms of added costs or lower net benefits because of rerouting or redesign.

Similarly a community may wish a more expensive routing or special access provision to serve specialized land uses or to achieve a community objective such as reducing pressures for land conversion. Economic gains, if any, can be calculated but, and especially in the latter case, gain may not be apparent except in terms of satisfying a community desire. The loss in benefits to the motorist, in these instances, must be subjectively weighed. Certainly protracted negotiations for location will cause deferment of user benefits, and this should be considered as part of the economy process.

Although a number of approaches to dealing with socioeconomic factors have been suggested in this presentation, the concepts are still generally in the process of development. In the past several years much experimentation has been done by the California Division of Highways and by private research consultants in California. The consultants have generally taken the approach of assigning subjective weights or rankings to factors that must be considered in the route location process. In one approach, for example, 30 factors were listed including the normal components of a highway engineering economy study and those socioeconomic factors considered by the consultant to be important. Each factor was assigned a weight of 1 to 5. Construction cost was weighted 2, and aesthetics, 4. Each route alternative was then ranked on the basis of an evaluation of its comparative relationships to the factor under consideration. The highest construction cost was ranked 1 and the lowest, among 4 alternatives, was ranked 4. Weight times rank produced a point score, and the highest score theoretically indicated the best route.

It is difficult to agree with either the subjective evaluation approach or with the assignment-of-points approach that currently seems to be in vogue. The weak points of subjective evaluation do not need to be amplified. Assignment of points tends to obscure the vital significance of many of the elements whose importance can only be realized when the expression is in terms of dollars or when strong narration and documented research indicate the alternatives and consequences.

It has been said that highways are one of the few permanent features of the landscape and that other man-made features will probably change several times during the life of the highway. Certainly with our increasing proclivity to encourage obsolescence we may find that this is an accurate statement. If it is true that a highway serves as a relatively unchanging framework for other activities, its location and design are of the highest importance. And if, in fact, other factors of concern are, by comparison, more temporary in nature, the thesis should hold that basic effects should be measured in terms of lower or deferred net benefits to the motorist as a result of avoiding or achieving effect.

This then is the viewpoint that, it is hoped, will stimulate some discussion. It is briefly summarized as follows:

1. Basic community attitudes toward change must be identified as early in the route location process as is possible.
2. It is not practical, and may not be necessary, to identify, study, and measure every potential socioeconomic effect or community value but only those key issues that may cause adjustment in location or design of the best choice selected on a rational basis.

3. Subjective evaluations of the relative importance of socioeconomic factors and point-grading systems are nearly valueless and may be inimical to rational decision.

4. It is not proper to weigh socioeconomic factors in highway engineering economy studies. Socioeconomic costs or gains should be identified and, if possible, quantified in money terms or fully evaluated and described as to potential effect only when necessary to aid in a decision to accept lower net benefits.

5. The decrease in, or deferment of, net benefits by reason of community-requested location or design adjustment must be carefully calculated. Trade-off of gains by both the motorist and the community should be expected.

This viewpoint begs at least one major issue: Should not highways be located to achieve the greatest net gain? The question—gain to whom, the community, region, state, or nation?—is impossible to answer in today's environment; therefore, this issue remains.

Dealing with socioeconomic factors by using a problem-solving approach can be like standing too close to the forest. Important, long-range aspects of the larger problem may be overlooked. It is hoped that this does not occur. Continuous research into what appear to be important aspects of highway impact is conducted as a matter of course. The relationships between community attitudes, economic conditions, and observed change are a matter of great concern as is also the place of the highway in the change pattern.

At this point in the development of our experience, extreme care must be taken that we do not move too rapidly away from the side of sound economics. Careful and individual attention must be given to socioeconomic factors of importance to the community, but caution must be observed in formulating general rules. For this reason standardization of procedures should await the future developments that will increase our information base. Meanwhile, the highway decision process is being improved as this base grows.

Discussion

Marvin Manheim

It sounds as though you have a very effective process of comparative analysis among and within communities. This is certainly a very important thing to do. Have you been able to go back and see to what extent your predictions or anticipations were valid, and, if not, why you were wrong?

Bamford Frankland

No, to answer simply. One reason is that the consequences seldom follow quickly. However, one exception was our analysis for a single-family residential area in Glendale zoned for multiple-family residences. We predicted that, when the route adoptions were announced, existing land uses would be converted to higher uses. This happened exactly, and several years before actual construction. But for other kinds of consequences that take so long to materialize, an after-analysis is difficult.

Dan Haney

Would it be feasible to get a community to develop its own weighting scheme, one that could be used repeatedly in the community where more than one highway is going to be put through it and one that could be used throughout the entire design process rather than just in the process of route selection?

Bamford Frankland

We place very little credence in opinion surveys. Let me give you an example. When we first started studying the economic effects of freeway bypasses, we asked the affected businessmen how the freeway had affected them. Some said that business was great, never better; others said that business was lousy. We produced a study on this basis. We also went to the State Board of Equalizations, where income and sales tax records are maintained, and checked on that community. We found that those who said business was great were doing poorly and those who said business was lousy were doing great. This illustrates one problem of opinion surveys.

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