Applications of Economic Analysis to Highway Systems and Programs

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SEVERAL PROBLEMS are continuing to confront highway administrators, and it is desirable that some tool be available to assist them in making proper decisions. Among these many problems are the ones resulting from:

1. Additions to the highway system;
2. Transfers from one system classification to another; and
3. Selection of alternate projects and route locations.

The questions arise, "Can economic analysis be utilized to assist highway administrators in making the decisions confronting them?" and "Can the application of economic analysis develop a rather simple method of determining relative priorities which can be used for selecting additions to the highway system, changes in system classification, and the selection of proper alternate routes or locations?"

As early as 1937 the Oregon State Highway Department published a technical bulletin (1) which was a complete treatise on this subject. The problem at that time was no different from the problem today. It is extremely important that some means be available to evaluate properly changes in the highway system, whether they be additions to the system, transfers from one system classification to another, or for the selection of proper routes for relocation and improvement. It was determined that there were three main factors which should be considered in this type of analysis: costs, revenues, and benefits. It was felt that the proper correlation of these factors would give a sound basis for the engineers' decisions.

The three factors utilized in the analysis were all resolved to an annual value so that they could be related on a common basis. The problem in using these factors was a need for finding some means of combining them to develop a composite measure. The first step in this combination was the development of the ratio of annual revenue and cost which was termed "solvency quotient." The solvency quotient provided a measure as to whether the project was economically sound or not. If the solvency quotient is less than unity, the project cannot be financed from revenue derived from the traffic using the facility unless there exists another source of revenue. If, on the other hand, the solvency quotient exceeds unity, then additional money is available for expansion or improvement of the highway system.

The application of the solvency quotient to systems requires the computation of a solvency quotient for the existing system as well as the contemplated system. If the existing system is not solvent within itself, it must obtain support from another area in order to make expansions or improvements economically sound. On the other hand, if the existing system is solvent and thus has a surplus of revenue, then it may be meritorious to expand the system or improve it. The use of the solvency quotient alone does not take into consideration the savings which may be accruing to the motor vehicle users through the improvement of highway routes or the establishment of new routes; therefore, the solvency quotient alone will not provide the complete answer necessary for administrative decisions. The savings to the motor vehicle user (benefits) can be combined with the annual costs to provide a ratio commonly called "benefit quotient."

The next step in the development of a composite measure is the proper combination of the solvency and benefit quotients. Clearly, these two values cannot be added directly as a scalar value. One cannot add horses and cows and arrive at a result in composite units. Neither does the multiplication yield results which have much logic to defend them. It therefore appears that the component quotients could be combined by a process of vector or geometric addition which would have a certain degree of logical significance. The procedure of vector addition presented in the Oregon study (1) is quite complicated and will not be outlined herein. This vector addition of solvency and benefit quotients provides a measure which can be used for the purposes outlined above.

McCullough and Beakey (1) brought out that the selection of highway improvements is not a problem susceptible to exact mathematical solution, and that the final selection must be tempered by knowledge of individual conditions and needs. The most that can be expected from mathematical measurement is the development of a somewhat crude measuring stick or method which will indicate interrelations of the factors considered.

In the development or the use of the solvency quotient or the benefit quotient, it must be kept in mind that the revenue developed by a highway is based on tax rates which are normally based on arbitrary decisions of the proper level of taxation by the legislatures. Similarly, the level of design and the resulting highway costs may be based on an arbitrary decision of the engineers. The adjustment of either one of these items taking into account economic considerations could conceivably give answers entirely different; therefore, unless the level of taxation and design standards are developed to provide the maximum economic returns, considerable caution must be exercised in using these measurements.

The objective of the foregoing procedure was to develop a mathematical evaluation whereby the earning capacity and the benefits from the project could be combined and evaluated in relation to the cost, thus providing the measure of a composite desirability of the project. The procedure, though well documented, was very complex, and its complexity and the long period of time required to carry out the analysis discouraged wide spread usage. As a result, those portions of the procedure dealing only with benefits and costs were extracted to put into everyday use and the resulting ratio of these two items, the benefit quotient, gained widespread popularity. On the other hand, the portion of the analysis dealing with the solvency quotient has become almost unknown except on a systemwide basis. The question arises as to why the composite quotient was not used to any large extent. Was it due only to the complexities of the computation, or was it due to a possible misunderstanding of the intent in meaning of the quotient because of the complex method by which it was put together. As near as can be determined, the composite quotient was lost in the normal succession of personnel, and the portion of the computation for the benefit quotient only has been retained. Not only has this become the popular method of analysis within the State of Oregon, it has also been recommended by the Committee on Planning and Design Policy, of the Association of State Highway Officials (2).

A measure to be used as a tool in selecting highway improvements must be somewhat easy to compute, but more important it must be of such a nature that it is easily understood, not only by the engineer using the tool but the layman who often will need more of an explanation and more justification for the priority than the engineer does. The composite benefit quotient was apparently too complex to meet these needs. The question then arises, how can or how should the benefit analysis be utilized in making system studies or developing programs for highway improvements?

Experience has indicated that there are certain inherent deficiencies in the benefit quotient; therefore, they will not in themselves provide this index for priority. The present benefit analysis reflects primarily a savings to the motor vehicle users through improved alignment resulting in fuel and time savings. These are direct benefits. On the other hand there are indirect benefits such as ease and comfort of driving congestion-free facilities that are not adequately measured in a benefit analysis. These factors should be given consideration in programming future developments. The existing method of computing the benefit quotient does not give any indication as to whether or not the proposal is solvent. The benefits could greatly exceed the costs, yet it is conceivable that such an improvement would not be solvent because there would not be sufficient excess revenue to provide for this improvement. It has been indicated in the AASHO Report that the present method is not suitable for use on an area-wide or statewide basis, because the results cannot be compared if they are based on dissimilar routes, traffic patterns, terrain, or design standards. The present method apparently does not provide a measure of need in addition to a measure of benefits. It provides an aid in selecting the best alternate route for improvement only; therefore, there remains the problem of finding some measure of need which, when used in conjunction with a benefit analysis, will assist in the assignment of priorities.

REFERENCES

1. McCullough, C.B., and Beakey, John, "The Economics of Highway Planning." Oregon State Highway Department Technical Bulletin No. 7 (1938).
2. American Association of State Highway Officials, "Road User Benefit Analyses for Highway Improvements. Pt. 1 - Passenger Cars in Rural Area." Informational Report by Committee on Planning and Design Policies (1952).

Discussion

Campbell. — Concerning vector analysis you have said that when one has quantities of unrelated and non-compatible units to measure and place a value upon and to add together he cannot combine them into a total of homogeneous units by the ordinary mathematical procedures of arithmetic addition, but that he can resort to vector analysis. But is it not true that as soon as one arbitrarily sets the scalar values for each vector and artibrarily sets the angle between the vectors that he arbitrarily does establish a mathematical relation between the two supposedly different kinds of units which we said in the beginning are not compatible?

Is there any relationship between solvency and benefit? Can you simplify for us the logic of adapting vector analysis to this problem? Would you say that my statements with respect to vector analysis are correct?

Blensly. — I think you are correct. I hope I did not mislead. I do not think it was intended that there was any implication that vector addition was the answer. It was just felt that it was possibly a logical way of doing it. There was a little logic to it; in it was some means of combining the two, and you couldn't add them directly; it didn't make very good sense to multiply them; vector addition seems to be a little more logical mathematically.

It may not be correct, because one is still trying to add horses and cows to get an answer, but it is probably better than direct addition or direct multiplication or any direct method of combining.

Campbell. — Let me pursue some further this subject of combining the solvency and benefit quotients in order to obtain a resultant quotient useful in priority rating. These quotients can be combined, properly or improperly in several ways. One way would be that of computing the net gain or loss shown by each quotient (subtracting unity from the quotient) and then adding algebraically for each project its net gain or loss in solvency to its net gain or loss in benefit. This would give a composite number representing total gain or loss. If the solvency component is regarded as of unequal weight with the user benefit, it can be weighted before combining.

I do not recommend this method because I do not know how to interpret the resultant composite number. For use in priority determination I would set the solvency quotient opposite the benefit quotient for each project in tabular form. This will show the negative and positive values (unity plus or unity minus). Beyond this, judgment of surrounding circumstance is necessary I believe to rank the projects in priority.

St. Clair. — I do not think that user tax revenues or earnings can be added to highway benefits either directly or by vectors. Furthermore, I do not think that government revenues can be classed in the category of benefits. Benefits to the government should be of the same sort as benefits appearing in the private sector of the economy. They include, for example, savings in transportation cost, including time costs, in the use of governmental vehicles, aid in the national defense, and aid in the carrying of the mails.

User-tax payments have their most direct relation to user benefits in the following manner. They reduce the effect of the benefits on the user who pays them. If the user tax were exactly equal to the benefits, they would net out to zero. If this were the case there would be no separate benefits left over to be transferred to other sectors of the economy, to the consumer in the case of a commercial vehicle and to the land in the case of improvement in automobile transportation. In any complete treatment of benefits and costs the payment of the tax must be reckoned in as a negative term in the equation.

This does not say that solvency calculations have no legitimate standing. They should in the first instance be considered as an independent calculation, made for the purpose of determining whether the particular road improvement pays for itself or needs subsidy from other parts of the system.

There is, I think, another way in which the solvency calculation can come into the analysis of benefits. The fact that the users are willing to pay the tax needed to support the facility is positive evidence that they receive a benefit at least equal to the tax payment. This is very plainly to be seen on a toll facility, and the toll authority can maximize its revenues by a delicate adjustment of the tolls on different classes of vehicles (this would not of course maximize the benefit received by the public from the toll road). In the case of user taxes the evidence is not so direct, but the point can be established by a study of the earnings of a road or of a road system, over a period of years.

Campbell. — The subject of length of project has been raised more than once, and we have seen that if the study area is confined, for example to the length of a bridge — and a bridge is usually a very expensive thing to build — that the bridge project will in a good many instances not have a benefit quotient as great as or greater than unity. This can easily happen if one does not study the economic consequences deriving from the total change in traffic pattern affected by the project.

Isn't it better then that we consider as the study area of a project, whether short or long, the whole length of trips between origins and destinations of all the traffic that used that particular bridge or that particular project, rather than considering only that length (with vehicle-miles) which lies nicely between the immediate ends of the new construction project? Does not a piece of highway anywhere on a trip affect the convenience and economy of the total trip, and affect the choice of route? In other words, will we not find a higher B/C ratio in our analysis if we spread the benefits and costs over the entire trip length, or at least for enough to include total length of local trips (say 5 miles or so each way from center) whose benefits from the project as related to trip length are proportionately greater than for long distance trips?

Blensly. — I don't know that I have got the answer for you. I do know that you do not have to confine it to the length of a bridge. We have situations where we make a benefit analysis on a fairly long piece of highway, where there may be a situation where the new road may cross the existing road two or three times. Now, we could take any one of these several portions of the new road which are severed by the existing highway and run a separate analysis on each of them as separate entities or in a series of different combinations of the several parts, or of the whole project as one integrated whole.

In many cases, the alternate route may be such that you could have several pairs of alternates; you will get different answers with each one.

I personally feel that the proper procedure is to take the over-all project from origin to destination of trips assigned to it for study, rather than a small section in the middle.

Winfrey. — I think you can make a reasonable approach to determination of proper project length by analyzing the problem on an incremental basis. In other words, you start from some point, be it the middle or either end, then keep adding increments of length, and taking different lengths of construction, analyze each of them. Take 2, 4, 6, 8, and 10 miles and so forth on an incremental basis, and soon you will find that it may not be economical at all to build 4 miles, but it is economical to build 10 miles, because of the greater use of the facility that you may get out of that additional length with its additional attraction to traffic, and at the same time its possible lower unit cost per mile.

I think we also can analyze bridges and get ratios greater than one, because you have there the problem of either to do without or to do with, and if there is no bridge there at all, where is the value of the bridge? What will it mean? What will people pay for a bridge?

I think you can quickly prove that the bridge is highly desirable for the general economy and for the general welfare.

Blensly. — I might use an illustration of a point where I feel that the benefit analysis falls down for a priority system of accounts.

We had a certain case of analyzing alternate routes between two points, and it was one that could logically be considered in these two elements, a northern improvement, or a southern improvement.

In one of the particular alternates, the northern improvement provided what we felt was needed to relieve congestion in the outskirts of an urban area, and it would have helped the motorists considerably. The highway was old and needed improvement, but there would be no substantial time saving nor distance saving afforded by the improvement. That is, there was a little time saving; you would increase the speed during the peak hour, but the southern half would save about 2 ½ miles in some 10 or 12 miles. It would afford a substantial mileage savings, when you considered the over-all project. It had a high benefit quotient.

The northern half, which we felt was the portion that was actually needed, had a very low benefit quotient, something less than one; whereas the southern half had the much higher mathematical rating.

There was the question: How do you use this rating for priority purposes then, if you feel in your own mind that, other things considered, the northern half is the important one, and the southern half you will not need for twenty years? How do you evaluate these factors? What procedure do you use to take judgment into consideration?

St. Clair. — I would like to return to the use of the economic analysis in priorities. In fact, I would like to reopen, really, the subject of the relation between comparing a heavy traffic route and a country road with respect to their benefit-cost analyses.

Well, if you took them in the raw, so to speak, you would never build any country roads, and I believe Moskowitz pointed out that if you do not have the origins of traffic, you would not have any traffic or need any roads. But the question I will pose grows out of what we all agree to be the logical conflict that seems to be present. It is quite obvious that regardless of anything in the way of political decision, you do need the light traffic roads.

You do not necessarily need them improved to a high quality, but you need them, and you might decide from a social point of view that there was a greater priority at some time in a program of light traffic roads.

How then, in face of this logic, would you set up an economic analysis on a system basis that would solve this problem mathematically, so to speak, rather than judgmatically?

Grant. — I think this is discussed in a paper by Professor Lang, concerning the use of digital computers.

St. Clair. — What I mean is that sufficiency ratings actually take that consideration into account. To be specific, sufficiency ratings do not always suggest that you improve the heaviest traffic road, but that you improve on the basis of the total program. Maybe the economic analysis is not fitted to cope with that problem, but programming simply is not all politics; it is common sense, for one thing.

Gardner. — With respect to a low volume traffic road, is it necessary to improve that low traffic volume road, or should we maintain it in kind as it now stands, and let it, shall we say, perpetuate itself?

Secondly, can we apply benefit-cost analyses to priorities? In a paper which I am preparing, congestion delay is computed for all the highways on the whole system by reason of capacity and other items.

The congestion delay is a tremendously large factor in the benefit-cost analysis, and in the broad picture, if we rate all of our highways on just this item, we are almost getting 100 percent confirmation that the highest congestion is going to be the highest benefit.

When we relieve that high congestion, we are getting the highest benefit. I might be anticipating one of the papers. It would be impossible, I confess, to do such a job without the electronic data processing system. But that is what Pennsylvania's approach will probably be to this priority problem. The benefit that derived from decreasing the congestion divided by the cost of the project will give what I have termed a "modified benefit-cost ratio" and sequential, descending values of that benefit-cost ratio will provide priority ratings.

Of course, after it has been decided that a certain project recieves top priority, it will be analyzed for alternate routes. It will be looked into as to whether it will stay on the existing location or be changed in basic location, or in what respects we will do something about it.

But that is a supplemental problem arising after determining the priority.

Moskowitz. — Mr. St. Clair, I see nothing wrong with the thought that you presented, but you are going to have this problem: there are going to be an awful lot of roads that do not have any congestion on them which you still want to improve.

Suppose we did this in California. I guess the worst congestion in California is on the Bay Shore Freeway, which was built about five years ago. What should we do, make it 16 lanes?

In other words, suppose it came out that we should improve this Freeway first, when actually, it is one of the projects that we have just finished improving. On the other hand, you are going to find that there are some country roads that are on some local system, but I think that we have only got one highway system, and that includes all the roads that are public roads. I do not think there should be any relation between the amount of money that a road gets and what system it happens to be on. I think that the amount of money that a particular segment of road ought to get should be based on first, solvency, and second, how much money it gets should be based on traffic and engineering reasons, rather than what system it happens to be on.

I am beginning to question the whole theory of different design standards for different systems.

Johnson. — I would like to say, Mr. Moskowitz, that I for one agree with you that there is one system, that the automobile does not recognize differences between interstate, primary, secondary, urban, rural, and local roads, and we approach the problem that way in Connecticut.

Also, in this problem of design, we feel that recognition must now be given to land use, to prevent in the future some of the problems that we are now faced with in the drainage program that is astounding dollar-wise, due to the fact that land development has taken place and made useless the existing drainage facilities.

So the design department of the Connecticut Highway Division is presently determining a factor of land use potential, so that they might install appropriate drainage in the initial improvements, to take care of the drainage at the time the land does develop.

Burch. — I think in the last 10 or 15 minutes we have opened up a Pandora's box. We have been talking about state highways. Now if we acquiesce to the concepts expressed by Mr. Gardner and by Mr. Moskowitz — that there probably should be nothing such as highway systems — that a road is a road — I am afraid we could not live with that.

North Carolina is one of the few states where the state has all of the roads (the counties and townships have nothing to do with them). The state has 70,000 miles of road, varying from little pigtrack trails up to the expressway-freeway type. The people just won't let you consider all those as being the same, the differences being the differences between land services—not land use, but land service performed.

In the case of local roads where land use and geography are paramount, we can admit that there is no traffic or practically none, but yet the road must be there ready to serve.

The other consideration is the human voter reaction. If you don't give those roads a reasonable level of traffic service, then the people who live on or near them, few though they be, will say, "We are becoming or have become second class citizens," and that won't do, either.

Newcomb. — May I suggest that the problem is a problem only if you consider highways as in a vacuum. In other words, people do not travel over highways to burn gasoline and time; they go because the value of the goods at the end of the trip is greater than the value of the goods at the starting point.

A ton of lettuce, grown in Norfolk or North Carolina, is valueless on the farm, but that lettuce in a Pittsburgh market has a high value, so we see that these highways are here not alone to save money in the form of less expenditure for gas or tires, but to add value, add space value. When you put the total economy into your formula, then Blensly's problem becomes quite soluble. The southern route may add much less to the economy of the community than the northern route, though it does add more to the saving of gas and rubber. Let's start looking at the impact of the highway on the total economy; it might make poor formulas, I think it makes good sense.

Blensly. — I think such a concept would require a revision of what is called "benefit analysis." Our present procedures are very inadequate.

Newcomb. — I think so, and I hope that we can get a revision of our thinking to put the total economy into our formula.

Lang. — I would certainly agree 100 percent with what Mr. Newcomb said, and it is my impression (in connection with this matter of minor roads where there is little or no traffic) that we become confused and say, "well, because there is no traffic on these, an economic analysis of their value to us does not make any sense."

I think this assumption is quite incorrect. What we are doing is failing to take account of all of the economic consequences of not building the road or of building the road. If we did take account of all the economic consequences, we would find an economic analysis is just as applicable to this type of road as it is to a freeway.

Winfrey. — Mr. Blensly, you asked a question a moment ago about whether you should build a certain projct now or some 20 years in the future, in speaking about the priority between a northern or southern improvement. Am I correct in that?

Blensly. — The southern improvement shows the high benefit quotient and is the one that you do not need for possibly 10 or 20 years, while the northern improvement shows, I believe, a very low benefit quotient, yet it is felt that there is a need there, maybe because of congestion, or for other considerations.

Winfrey. — It seems rather an unusual result to get such a high economic value out of something which is not needed, so I would first suggest reviewing the analysis and see why that happens, or, if it does happen. If you want to know how much you should build today for a benefit which does not come about for some time in the future, then you have the simple problem of comparing values and cost and benefits at a common time value.

If a piece of today's construction will not be used for 20 years, then in 20 years its equivalent cost is the present cost compounded at the proper interest rate for the 20-yr period.

Likewise, if you are considering today a benefit which is not going to materialize for 20 years, as indicated a moment ago, then you have to discount it from 20 years hence down to today, by defining its present worth value.

That is a standard type of application we make with the compound interest theory, in order to get things at a common point in time, and it is the only way that you can compare it. You cannot at all compare a dollar today with a dollar 10 years from today, even assuming a stable economy, without bringing them to the same time point, which means compounding one or "present worthing" the other.

Blensly. — I think possibly you misunderstood me. I was not implying that it would not be used today; what I was implying was that the traffic was such that there would not be sufficient traffic to require it for another 20 years.

In other words, the existing facility could handle the traffic for maybe another 20 years, and at that time, there would be congestion and you would need the other facility.

This example shows the fallacy of our existing method of computing benefit analyses, in that it is based almost entirely on savings in time and distance, or the combination of the two.

Here is a substantial savings in distance. If you have any traffic at all — and you will have some trips — it is a benefit to that traffic. If it does not cost much — in this instance, it does go through virgin territory and is rather cheap construction — you can build it cheaply, and you will have a good benefit-cost ratio.

Moskowitz. — I hate to monopolize so much time, but I have a good example to illustrate Mr. Blensly's point.

In Arizona twelve years ago, US 66 was an old 18-ft wide oil cake, and some of it was not even paved, and it dipped in and out of all the drainage channels.

Even then, it was carrying two or three thousand cars a day. People drove 60 and 70 mph, and our present methods of just taking time and distance would not have shown much benefit in converting that route to modern standards.

I am not talking about a 4-lane freeway now; I am just talking about building what they called their standard road at that time, which would have been 36 ft wide for two lanes, including the shoulder.

On the other hand, there was a proposed route from Kingman to Winkelman, which for the few people that would have used it would have saved over 100 miles, one of the most fantastic cases you will run into anywhere. Serving a very few hundred cars a day, it would cost around a hundred million dollars to build this road; yet, the rate of return method or any other method of analysis would show that you should build this shortcut, and that you should build it before you should improve the road which served several thousand cars a day.

Here is where we have to get into the solvency aspect of the problem. Is it right to spend so much highway revenue on what would be an extremely "insolvent" project so that somebody can reap some high benefits along this shortcut that saves a hundred miles?

In other words, this shortcut is quite similar in character to the one that Mr. Blensly thinks can be put off for 20 years. When he says that, of course, he is applying an economic evaluation that has not yet been formalized.

Grant. — My comments are in further answer to Mr. St. Clair, and to point out that everybody really has been answering him — particularly Professor Lang, who phrased it concisely, that is "we must take account of all economic consequences in our analysis." The rest have all been saying the same thing, which is that if the formal analysis for a basis of decision gives one conclusion, and your intuition gives a completely different conclusion, either your intuition is wrong, or you need to improve, to sharpen up, your techniques of formal analysis.