Research in Economic Analysis at M.I.T.

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● RESEARCH in the economic analysis of highway improvements currently under way in the Department of Civil and Sanitary Engineering at M.I.T. is the outgrowth of studies originally directed at some of the strictly technical problems involved in current highway design. This development has been a strictly logical one, inasmuch as economic considerations must inevitably play a large part in any complex engineering work.

About three years ago the photogrammetry laboratory under the direction of Prof. C.L. Miller began a series of studies aimed at the integration of modern photogrammetric and electronic computing equipment into an efficient system for the location and geometric design of highways. These inquiries led to the development of the so-called Digital Terrain Model (DTM) system and a number of associated instruction programs for an IBM 650 electronic computer. Basically, the DTM system involves the collection of topographic data in digital rather than analog or map form. These data, when combined properly with a mathematical description of a trial highway alignment, can be operated upon by a computer so as to produce complete information on the geometry of the alignment and the associated earthwork quantities.

The most significant characteristic of this system lies in the fact that the topographic data are all referenced to a generalized coordinate system rather than to some particular alignment under study. This permits the engineer to analyze a large number of alignments extremely rapidly and with only a small additional expenditure over that required to analyze but one alignment. As a result of this analysis the engineer has, moreover, a complete set of geometrical information upon which to base quantity estimates for such things as pavement, drainage structures, and fencing, as well as earthwork. Yet, these items when costed out do not tell the whole economic story by any means.

A consideration of the advantages of the DTM system for the determination of these particular components of construction cost led to the realization that the current reluctance on the part of practicing highway engineers to undertake really thorough economic studies was due in large measure to the relative inability to handle the large amounts of data involved. These "data engineering" problems seemed, in fact, to call for the same sort of approach that was taken in the development of the DTM system. Thus, it was decided to broaden activities to include such other parts of the total problem of the economic analysis of highway improvements as might be amenable to the data engineering approach.

One outgrowth of this effort has been the development of a method (still in the testing stage) of estimating the land costs associated with alternatives in alignment. This method involves making an approximate assessment of land costs, probably directly from aerial photographs, for the entire section of terrain through which alternative alignments for a highway might be expected to pass. The area of interest is marked off into zones on a map overlay and the cost per sq ft or per acre shown on each zone. The map overlay is then sectioned off by rectangular coordinates and the data on the location, size, and cost of each zone are punched on cards in a fashion similar to that in which data are handled for the DTM system. These data, together with the geometric description of right-of-way limits as determined by the DTM programs, are then fed into a computer with the EA-2 instruction program. The computer outputs land cost for that alignment by station.

It will be recognized that this technique is not sufficiently accurate for use at the stage where detailed attention to individual parcels or improvements becomes necessary. It is, rather, strictly intended for use in the reconnaissance or preliminary location phases of highway design. Where the locating engineer is interested, however, in analyzing a large number of alternative alignments in order most nearly to optimize his final location from an economic standpoint, this gives him a rapid and inexpensive way to determine land costs. The objective here is the same as that of the DTM system of computing geometry and earthwork; namely, to put within reach of the practicing engineer a means whereby he can do a thorough job of highway design with a minimum of time and expense.

The second effort in the direction of simplifying the over-all problem of making economic analyses of highway improvements actually antedates this somewhat simpler land cost problem. This is a technique for computing vehicle operating costs and travel time requirements for alternative highway alignments.

The technique of computing vehicle costs is somewhat different from those previously mentioned, inasmuch as it works directly with annual costs rather than with first or capital costs. The heart of the technique is a computer program which will simulate the operating performance of any sample vehicle over an alignment as specified by the locating engineer. Using the vehicle speeds and energy requirements thus determined, the computer is able to output the various vehicle operating cost factors. It is also able to output total travel time for the alignment in question, which can then be costed out by the locating engineer at the figure which he deems appropriate. The sum total of these costs for the sample vehicle or vehicles can then be extended to cover the entire vehicle population on the basis of traffic estimates made for the highway under study.

An experimental instruction program, the EA-1 Vehicle Operating Cost Program, has been written to perform the type of computations outlined above. It should be emphasized, however, that while this program has been coded and debugged, it is definitely nothing more than an experimental effort at the present time. A large number of difficult problems, some of which will be mentioned, still remain to be solved. In particular, major revisions in program logic will probably be necessary before we can claim to have a practicable technique whereby the locating engineer can determine the effect of alternatives in alignment on this most critical cost component.

Despite the fact that the work is still in a somewhat imperfect state, it is of interest to follow through the logic of this EA-1 program. Basically the program works with three sets of input data. The first of these describes the horizontal and vertical alignment of the highway under study, as well as the maximum speeds at which an operator can be expected to drive his vehicle over various sections of that alignment. The alignment data can be taken directly from the output of the DTM geometric programs, while the speed restriction data must be compiled separately by the locating engineer.

A second set of input data defines the sample vehicle. These data include such things as vehicle weight, engine horsepower characteristics, gear ratios, air and rolling resistance parameters, fuel and oil consumption parameters, and parameters to describe tire wear and maintenance cost. These data also include the maximum acceleration and deceleration rates which the driver can be expected to use. The third set of input information is of an administrative nature, including such things as the station at which computations are to begin and end, the initial speed of the vehicle as it enters the section of alignment under study, and the interval at which speeds and costs are to be computed and punched out.

The program is then designed to output vehicle speed at each computing station, cumulative running time including stops, cumulative fuel consumption, oil consumption, tire wear, and maintenance cost. In addition, it is possible to amend the program output so as to include such things as fuel efficiency in miles per gallon, average running speed, or energy consumed in braking.

Figure 1 is a logical flow diagram showing in simplified form the general sequence of computational steps through which the computer goes at each computation station.

Present thinking is that computational runs in both the forward and reverse directions would be made for each of three classes of vehicles (automobiles, single unit trucks, and combination trucks) over each alternative alignment under study. The somewhat different driving habits for each of these vehicle classes would be simulated through

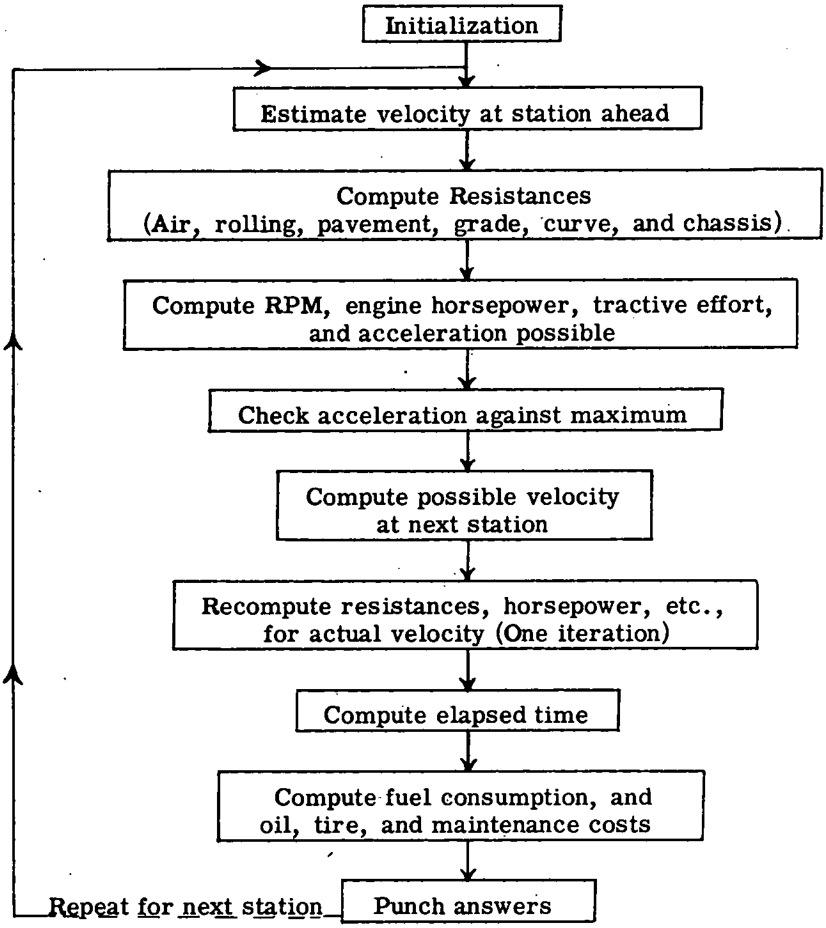

Figure 1. Flow diagram.

the maximum speed restrictions and acceleration and deceleration rates imposed by the locating engineer. These values would be representative of average driver performance, and would not necessarily correspond to either posted or design speeds. The input parameters describing each sample vehicle would be determined in advance on the basis of the composition of the existing vehicle fleet.

Current research efforts in connection with this computer program and its use are centered around three major problem areas. The first of these is concerned with the simplification and modification of existing program logic so as to produce acceptable answers at a smaller expense in computer time. The present program is thought to be too slow to enjoy widespread use by practicing engineering offices. The second problem area concerns the selection of sample vehicles which will be truly representative of the very large and diverse fleet of vehicles which can be expected to use any highway over even as little as a year's time. The third problem is that of testing computed results to determine how closely they would conform with actual vehicle performance. In each of these problem areas the research group has enlisted the assistance of various members of the staff of the Bureau of Public Roads, and the prospects for an early solution to many of the present difficulties seem good.

The EA-1 program as originally conceived was designed principally to handle the problem of alternatives in route location of high-type, intercity highways. It has been recognized, however, that this is only one type of problem — though perhaps the most important type at the present time — which such a computer program might be able to handle. Among other possibilities are the following problems: the analysis of at-grade versus grade-separated intersections; the determination of optimum interchange spacing; the determination of limiting grades for design standards; design of passing lanes on upgrades; or determination for tax-allocation purposes of the benefits accruing to various classes of vehicles.

There is, unfortunately, one major difficulty involved in handling many of these problems. This stems from the fact that the ability of even an improved instruction program to produce answers which will be accurate for widely varying types of alignment and for a wide range of vehicles may be too limited. This does not, however, rule out the possibility of preparing additional instruction programs designed specifically to handle some or all of the design situations mentioned above. It is also thought of prime importance that some effort be made to take account, either in the existing program or in some future program, of the effect of traffic congestion on vehicle performance. To date we have been unable to develop any promising ideas on this aspect of the over-all problem.

Regardless of the deficiencies in the present EA-1 program and of the difficulties involved in its improvement, we cannot help but feel that the sort of information which it can furnish the locating engineer would permit him to do an incomparably better job of economic analysis than is currently within his reach. The important thing in this connection is that it is a long way from the solution of the conceptual problems associated with the economic analysis of highway improvements to the implementation at a practical engineering level of the complete economic decision-making process.

Thus, the objective is the development of systems and methods of analysis which will permit the engineer to put into practice on a day-to-day basis the principles of engineering economics which others in attendance at this conference are working so hard to develop for highway engineering problems.

Discussion

Blensly. — My concept of the present method of economic analysis and its use is generally at the very preliminary stage of the discussion of a route or an alternate route, possibly before we even have a definite line; maybe in the reconnaissance stage.

It seems to me you are developing a procedure which will provide an economic analysis but at the time you are just getting around to comparing design features. At that time, one already has to have his design made, so of what benefit is your economic analysis when you have gone so far that you can't go back?

Lang. — It is true that I may want to consider vehicle operating costs, in the reconnaissance of location stage where you are not describing in any great accuracy the vehicle alignment. I question whether any state highway department or anyone else is actually making accurate computations of vehicle operating costs at this stage.

We are not trying to produce in this technique something to replace reconnaissance techniques, but rather a means of evaluating alternate design possibilities to determine cost components entering into economic analysis. It is hoped that this technique will be usable for both the preliminary and the final design stage, and in a large measure in the preliminary design stage, where you do actually establish curves, for example, both horizontal and vertical, and you do try out various curves for fit, and economy. In other words you have specified your alignment.

Let me refer again to the DTM techniques to help place this new technique in perspective. One of the principal things that the DTM system for determining the geometrics of alignment tries to overcome is this: with existing techniques of analyzing data it was expensive to analyze more than one or two alignments in detail, and the engineer was not getting anywhere near what might be considered an optimum conclusion, because the initial choice of an alignment is largely on a guesswork basis, and there is every reason to believe that if the engineer developed and analyzed 6 trial alignments, rather than two, he would on the average be bound to find one of those extra four that would be better than the two first ones that he tried. But he does not do it now, because it is too expensive.

As far as the geometric computations and the earthwork computations are concerned, with the DTM system, the engineer can analyze 6 or 12 or maybe even 20 alignments for what it costs him to analyze 2 by the old techniques.

Now this seems far-fetched, but as the Ohio Department and some of the other departments who have looked into this system have vouched for, this is literally the case, because what the DTM system does is to eliminate the need for taking the basic topographical data more than once, which in the old system had to be done.

Well, we are trying to do the same thing with this vehicle operating cost program, which is to make the actual job of determining vehicle operating costs so easy for the engineer that he will analyze 6 or 8 or 10 alignments in this fashion. Once you have the basic data for this type of a system, it becomes very cheap to analyze about as many alignments as you wish.

This system might have limited usefulness where you are trying to determine whether or not or where to locate the components of an over-all network. This is a different sort of problem, but even though you are working with an entire highway network, you still have to have some idea of vehicle operating cost. This system may give you the means of determining these so rapidly that you won't shy away from it, and this will permit you to fill in one more cog, at least, in the over-all economic analysis.

But of course it should be recognized that when you have got capital costs and vehicle operating costs, you still haven't got all the associated costs. Actually what we hope to do is to see whether or not we can determine some of the other cost components in the total economic cost picture, feeling that the experience gained in what we have done so far may be useful in attacking some of the other problems.

But we are interested in the implementation of economic analysis at the day-to-day level.

Berry. — I would assume that this method would apply particularly to mountainous terrain, or in areas where there is quite a high percentage of trucks, because it is in the truck that you get a differential in time due to grade; whereas, with a high percentage of passenger cars the operating cost and the travel time to not, perhaps, change as much in alignment for grade.

I would assume, also, that you would build into this a feedback so that as traffic volume increases it would have its effect in travel time and that would be priced along with the operating costs, but it looks like it certainly has possibilities if you are able to overcome some of the difficulties brought out by Mr. Blensly.

Lang. — Well, I hope someone will give us some ideas as to how to take account of congestion and its effect on the actual operation of the vehicle.

Our feeling is that one of the biggest shortcomings of the present technique is that we are unable to take any account of congestion, but we have given it some thought. This is one of the problems that will have to be overcome before this whole system will reach its maximum usefulness.

Rothrock. — Mr. Lang, we are using the digital terrain model in Ohio in several jobs. We like it especially in rough terrain. In some of the flatter parts of the country we do not think that it is particularly useful.

This program that you are working on is simply vehicle operating costs and time. Are you going to extend the program to include the computation of the benefit-cost ratio or probable rate of return?

Lang. — No. We definitely have no intention whatsoever of trying to compute benefit-cost ratios or rates of return directly. To attempt to systematize this area or this part of the economic analysis would so obscure the refinements and the difficult problems and judgment decisions that are inherent in this final process of the over-all economic analysis that it would be much more of a detriment than a help, and in any case, the actual mechanics of these computations are so simple that there does not seem to be any particular justification for putting them on a computer.

Rothrock. —Then your technique is used to produce comparative data useful to the engineer in evolving analysis and design and for making decisions.

Lang. —That is right. We are not even trying to compute final costs. We are outputing them, and then it is up to the engineer to assign some proper unit cost to this.

Burch. —In reply to the question about the effects of congestion, it may be of interest to you to know that North Carolina State College we have a research project under way now, on a mathematical model, using a 650 computer and simulating the actual movements of vehicles and their interrelationship on a highway.

This is not an intersection study; there has been a lot done on that in cities, already; this is a typical rural highway.

Rothrock. —In your technique of computing the motor vehicle cost, or cost of operation over a given length, if you want to compare this with the present corridor, or operation on the present corridor [Ed. Note: This could be used to formulate for the present indexes for adequacy ratings for geometrics.] then you must put in the geometric data for the present highway (and any other highways which are in the corridor) also, which has to be determined?

Lang. —That is correct, yes.

Rothrock. —And what you come out with is simply a unit cost per vehicle.

Baker. —I have gotten the opinion that these economic analyses are not as accurate as they might be, not so much because we do not know curvature and so on, but because we do not have certain basic information such as fuel consumption under given situations. Isn't it true that we need a great deal of research in certain areas before you can make maximum use of the techniques you are developing?

Lang. —We really do not have good unit cost figures, nor do we have good information on the nature (mathematical nature is what we are specifically interested in) of the cost functions that we are working with.

But there is every reason to believe that as more data are accumulated and more sophisticated statistical analyses of that data are carried out, we will begin to get unit cost figures and basic characteristics of cost functions which will permit us to do a good job.

It is admittedly crude now, but you have got to admit that it is still better than nothing, and nothing is substantially what we are working with now.