# A Comprehensive Method of Scientific Programming

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By utilizing studies, accumulated data, and the newer techniques now available, the highway administrator may program construction on a scientific basis invulnerable to political and other pressures while maintaining flexibility over both the short term and the long term programs.

The Planning and Traffic Division of the Michigan State Highway Department has reviewed and studied methods of highway classification, priority ratings, sufficiency ratings, highway capacity ratings, highway needs, benefit quotients, and other factors for several years past. The material is all available, and in most instances is maintained on a current basis through continuing surveys and studies.

With this mass of factual information available, a study was inaugurated to evolve a method of scientific programming. During the course of the study it became apparent that no system or method of scientific programming existed which would enable the administrator first to present a sound program, and second, to bolster his program with unimpeachable facts.

It was determined that some of the methods previously used were neither logically nor mathematically sound, especially in the field of sufficiency ratings, since arbitrary weighing of the elements could produce any predetermined or desired results. Abuse of this factor, particularly to satisfy political commitments, has been a major cause of unscientific programming.

Eventually, our study produced a method which we believe to be superior, since it avoids the objections raised against other methods and approaches the ideal sought by highway administrators. The method utilizes only observed data, reported by trained engineers, and capacity limiting factors provided by the Bureau of Public Roads. The formula devised for establishing construction priorities is tamper-proof. Mechanical equipment provides speed and accuracy in tabulating the data, but is not essential to operation of the method.

Flexibility is provided to the extent that programs can be determined by card sorting, complete with estimated costs, on any one of several bases, including: by trunkline routes; by federal aid systems; by counties or highway districts; by rural or urban or combination identification; and others.

Finally, the method provides the administrator almost immediate programming on a factual and scientific basis up to the limit of funds available for any construction period plus additional scheduling on the same basis for any year in the future for which data is available.

● HIGHWAY administrators have long sought a wholly objective method for programming, divorced from whim and human error, and capable of incontrovertible substantiation from any attack. The tools are at hand; the techniques established by countless studies are available to all.

The Bureau of Public Roads was looking far ahead when, in 1936, it established Highway Planning Surveys in all of the states. The studies which have produced a wealth of factual information for the benefit of the highway administrators, are largely due to the original Planning Surveys and to the efforts of thousands of dedicated men who pursued the quest for the kind of planning which will produce better highways on the locations where the traveling public most needs them.

The highway administrator who has taken advantage of the opportunities opened up in the original Planning Surveys can, by simple request or order, provide himself in brief time with all of the data necessary for construction programming on a completely factual and scientific basis. And he can buttress his choice by unassailable facts and figures, against which political pressures and the attacks of special interests cannot prevail. Every highway administrator is, to some degree and at some time, subject to those pressures and attacks. Human nature being what it is, the condition is universal.

In the same vein, every administrator seeks the method which will stand up against the pressures, the method which will confound critics and which will by its very mathematical infallibility satisfy and gain the support of the highway users of his state. Such a method exists; it is in the public domain; it is a matter of simple mechanics which any highway administrator can employ. It is neither expensive nor complicated.

The method of scientific programming is a straight-line evolution and development of the studies in which all of us have participated, in some degree, over the past 20 years. There is no arbitrary point of beginning in the study by the Planning and Traffic Division of the Michigan State Highway Department, which led to the scientific programming method which I will explain in some detail, because, as previously noted, our method is merely the logical development of the many specific studies previously made.

Like other governmental highway agencies, we have been through many years of studies and reviews of such factors as highway classification, priority ratings, sufficiency ratings, capacity ratings, highway needs, benefit quotients and others. Some of you will remember that our advanced study on highway classification was presented in a paper before this body in 1949. The method is now used by many states. Again, as in your own experience, our continuing studies produced a mass of data relating to benefit cost analysis, priorities, sufficiency and capacity, because great stress has been placed on these factors in the highway complex.

During these recent years, some interesting methods of programming have been developed from this mass of data. Sufficiency ratings, particularly, which caught and held the public fancy as well as the close attention of highway administrators, have been studied minutely and with the greatest hope that they would provide the answer to the universal need for scientific programming.

Our conclusion has been that sufficiency ratings are neither adequate nor dependable criteria for programming. Sufficiency ratings include arbitrary factors which are subject to human error; the weighting of various factors can predetermine results. The system can much too easily be prostituted to desires, and manipulated by anyone who so chooses—for reasons political or otherwise.

In our own experience, sufficiency ratings gave top priority to a section of trunkline highway which was obviously not even of secondary importance. Every factor in this instance was determined by experts, unbiased, completely objective. Yet the result was so patently preposterous that it cast immediate doubt as to the validity of any ratings based upon sufficiency factors. Further study confirmed the conclusion that sufficiency ratings were faulty and imperfect at best; at worst, they were too easily subject to manipulation to meet any predetermined result. Our study for a more perfect method continued. Several systems which at some time showed promise, were finally rejected.

The method ultimately chosen evolved as a result of previous failures. It is, in essence, a mathematical consolidation of available information assembled on a series of three IBM cards.

Card number one contains identification and analysis of the existing roadway.

A card is punched for each subsection of our trunkline highway system.

Subsections are units used to indicate certain portions of a control section; they have been defined through five criteria, including geometric section, traffic volume change, surface condition, surface type, and lane width. A subsection might conceivably be as short as one-half mile, or extend several miles in length. Thus a newly improved 10-mile length of roadway is a subsection, while a contiguous one-half mile length of poor road would also be a subsection.

As a preface to listing the information coded on the IBM cards, let me explain that all information having to do with the physical condition of the roadway and structures was gathered in the field by a highly competent staff of engineers.

Since our programming method depends upon factual data, we built our code cards from field reports, not from records. And since it is essential that all data be accurate, we assigned only engineers trained for field reporting to the task of gathering the information.

On card one, several boxes in the upper right corner identify the general area: the Highway Department's administrative district, our control section number including county identification, the state or federal route number; the type of route, whether business route, or bypass; and system under which the route is classified—as federal primary, secondary, interstate, non-federal, and so forth.

The subsection is identified in the two columns at the extreme left on the card, followed by specific location whether rural or urban, population group if the latter, and distance to hundredths of a mile from point of beginning to start of the subsection.

Physical description of the subsection is next in line, including overall length: the type of base, sub-base, and surface; and the year in which the base was built followed by the year in which the last surface was laid.

Analysis of the roadway in the subsequent columns includes condition of surface and base; alignment, showing percent of the total length of the subsection where the required 1500 feet of sight distance is not available followed by the $A$ factor obtained from a graph of values derived from O. K. Norman's Table 11, page 58, "BPR Capacity Manual," 1950, in which the percent of restricted sight distance is plotted against the percent of travel carried under ideal conditions.

Note: At 60 percent restricted sight distance the three-lane approaches the capacity of a two-lane pavement.

Lane analysis, including number and type, and width in feet; and the $W$ factor (same BPR reference) representing the percent of capacity of an ideal 12-foot lane width.

The $T$ factor or percentage of passenger vehicles in the total volume will reduce the capacity as the ratio of trucks increases. The thirtieth high hour volume to the nearest 10 vehicles is derived from the state-wide traffic volume survey.

Capacity columns include basic capacity per hour to nearest hundred for each geometric type of roadway, followed by the practical capacity per hour to the nearest hundred as computed by the formula:

$$C_p = C_i \times A \times W \times T$$

where:

$C_p$ is practical operating capacity.

$C_i$ is basic capacity for 12-foot lane on level tangent section—no trucks.

$A$ is percent decrease due to sight restrictions.

$W$ is percent decrease due to reduction of lane width.

$T$ is percent decrease due to truck traffic.

The priority number or rating is then obtained as the ratio of practical capacity to the thirtieth high hour volume, with the quotient rounded off to three decimal places.

$$P = \frac{C_p}{C_{30}}$$

where:

$P$ is the priority number.

$C_p$ is practical operating capacity.

$C_{30}$ is thirtieth high hour volume.

It is readily apparent that the resulting quotient is a number which indicates by its value either lack of capacity in that subsection if the figure is less than 1.000, or that unused capacity exists if the quotient is greater than 1.000. A value of exactly 1.000 would indicate that the roadway subsection is operating at practical capacity, and that no additional traffic can safely use that portion of roadway without some kind of improvement.

Note that condition of the surface has not been used in the mathematical formula but is tabulated as a separate item and can be mapped as such. Also accident experience and roadside friction while important items that influence the need for improvement cannot be assigned accurate mathematical values having any relationship to those used in the formula. A simple map showing location of accident frequency together with roadside usage will be more valuable as a guide when compared with the priority map.

Densely built up commercial and industrial roadsides in rural areas were treated as urban areas when assigning lane capacities in the formula. In this manner, rural roadside friction is taken into account except in isolated cases.

Studies are in progress to place mathematical values on surface condition, accident experience, and roadside friction comparable to the mathematical values used in the formula.

The second card, for the same subsection, covers structures and rail crossings. Location and identification information from the first card is carried over; the structures are identified as to type, that is, whether a bridge over a stream, a highway or railroad separation, or a rail grade crossing; the dimensions of the structures; the age and safe loading weight and deficiency cause, if any; the average daily traffic volume and percentage of commercial vehicles included in the traffic stream; and for rail grade crossings, the information includes type of crossing protection, number of trains per day, number of main and side tracks. This card is for the purpose of determining inadequate structures only and carries the same priority number as its containing road section.

The third card contains location and identification information carried over from the number one and two cards, plus cost estimates for improvement of inadequate subsections to desirable standards including inadequate structures. It also includes columns for projecting traffic to any future year, with priority rating also projected to that year.

To recap briefly, our programming method begins with a subsection of trunkline roadway. For this subsection we code two cards which describe the physical condition of the roadway and structures, together with traffic volume and any factors which limit capacity; and on the third card we describe and estimate the cost of improvement to desired standards.

The priority number for the subsection is the wholly realistic expression of the deficiency or adequacy of the existing physical condition against the design ideal, resulting in a numerical figure which may be compared with the priority number for all other subsections of our trunkline system.

By machine-sorting the cards, we can run a tape which will give us an unassailable record of construction priorities by subsections, beginning with the most necessary construction. Obviously, however, we cannot program on the basis of a wide geographical distribution of short sections of highway. Should we do so, we would be perpetuating the kind of programming which highway administrators have decried, and which the motoring public condemns—scattergun construction which never completes a route.

To provide realistic and defensible programming, therefore, we have established what we tentatively denote as "programming sections," that is, a length of trunkline route between two cities or major intersections where adequate terminal connections can be made. A programming section may be 20 miles in length, or upwards; in rare instances it might be less, as in the case of a single section necessary to complete a route or to fill a bad gap in an otherwise improved route.

Having designated programming sections, we then identify the subsections within those sections and average the priorities on a per mile basis. The resulting priority for the programming section is then available for comparison with the priorities for all other programming sections; the list beginning with the first priority then becomes the programming schedule. Should any two or more programming sections show identical numerical values or priorities, that route carrying highest traffic volume would move ahead of the route or routes carrying lesser traffic.

The advantage of coding all of the information previously enumerated onto punched cards is obvious. Punched cards can be sorted by machine in a fraction of the time required for manual tabulation. Further, sorting can be by any one of a wide variety of types, to provide tape records of any information desired. For instance, we can sort all of our subsection cards for an entire trunkline route; or we can sort by rural or urban location; by federal system; by road condition; by counties or administrative districts; or by business route or bypass, in addition to the priority sort.

Tabulation by programming section priorities will provide immediately a cost estimate from card three. The tape also shows a cumulative total of cost. As soon as we determine the exact amount of funds available in each federal and state category, we have only to run our priority tapes with cumulative costs to determine how much construction we can program in each of those categories.

Our programming by route, location, and cost is a mechanical operation, without any consideration except the equation which determines the priority—actual capacity determined according to the formula laid down by the Bureau of Public Roads against the desired or ideal capacity.

In addition, this system and method permits the utmost flexibility in that such new information as changes in traffic volume and road condition either by use or improvement, changes in system designation and so forth can be transferred to the subsection cards either periodically or as rapidly as it is received. The cards can be brought up to date at any time on the basis of information and data at hand.

Use of the forecast traffic increase factor also provides a valuable function for the punched cards.

We have forecast our traffic increase for each of the 10 years, 1956–1965, and for 1970 and 1975.

By applying the increase factor on card number three, for any given year, we can provide a tape showing, for instance, all subsections which will be operating at or above capacity in that year. Or, we can show the deficiency over any trunkline route, or part of a trunkline route, in any of the future years for which we have a forecast of traffic increase.

Any changes in the cost structure can be quickly transferred to the cards, thus reflecting a realistic figure for estimated costs. But for as long as factual figures are used in the information which goes on the cards, there is no method by which priorities can be manipulated. Only by falsifying factual information could any tampering be effective. And with our routine methods for checking all information before it is transferred to the cards, the likelihood of error is very remote.

I commented earlier that all of the information which we code on the punch cards is available to highway administrators. The time and expense involved in coding and punching cards is negligible. Maintaining up-to-date information is also a trifling cost factor.

Coupled with the simplicity and economy with which this system can be installed by any state highway department, is the solid assurance it provides for the highway administrator. To the best of our knowledge it is completely scientific, wholly factual; it is tamperproof. It provides the bulwark which administrators have been seeking against political pressures and against the maneuvers of special interest groups.

Properly installed, it takes the guesswork out of highway construction programming.

Properly used, it is a valuable tool in the planned approach to our highway problems.