NUMERICAL RATINGS FOR HIGHWAY SECTIONS AS A BASIS FOR CONSTRUCTION PROGRAMS

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SYNOPSIS

A method of assigning numerical ratings to highway sections, taking cognizance of structural adequacy, safeness, and service, as a basis for reconstruction priorities, is offered. The ratings provide a means for arraying in one sequence all the sections of a given system, when the sections vary in traffic importance and in adequacy compared to present design standards. The method is based on deductive reasoning to the extent permitted by existing knowledge, but assumptions based on judgment and trial have been made to bridge the gaps in the deductive process.

The elements comprising the basic qualities are analyzed and weights are assigned to each. Formulas are given for computing values in some elements. A method is proposed for accounting for traffic volume priority.

The method has been applied to 3800 miles of the Arizona State Highway System and 1000 miles of the Arizona Forest Highway System, and has been accepted as a practical and valuable aid in the preparation and substantiating of construction programs.

There is never enough money to correct all the deficiencies in a highway system, such as a state highway system, in one budget period. Even if there were, it would not be physically or economically feasible to do so. It is therefore necessary to program improvements on sections of the system, and the first improvement should be programmed where the need is greatest.

When the deficiencies consisted of unimproved roads, the programming of improvements was relatively simple and could be done on a geographic pattern. Later, some of the original surfacing wore out, and renewal of worn-out surfaces provided an automatic program. During the last 15 years it has become apparent that renewal and replacement are desirable for reasons other than structural deterioration; roads have become obsolete in service rendered, and in safeness of operation. The various sections of any system differ from each other in all of these, and they also differ in importance as measured by traffic volume.

If the need for improvement or renewal, which is a combination of all of the above factors, can be reduced to a single number, the comparison of sections one against the other will be greatly simplified. In a sense, everyone charged with the preparation of a construction program does rate the existing facilities, and up to about a dozen sections can be arranged qualitatively in order of priority. Numerical ratings on a fixed datum provide a convenient form of memorandum for setting these down, and going on to consider the relative position in the list of each of other hundreds of sections in the system. In an extensive system, it is often necessary to combine the observations and requests of several engineers into one program. Numerical ratings provide a common denominator for effecting this combination. Finally, and very important, a quantitative listing of all the sections of a system is a powerful means of substantiating a program against sectional or otherwise biased pressure for fund dispersal.

This report suggests a method for assigning such numerical ratings to all the sections of a given system. It is empiric in that it is better than arbitrary and less than mathematically rational. In the autumn of 1946 it was used to assign ratings to all sections of the Arizona State Highway System. The lists proved to be practical and useful for the purposes enumerated in the preceding paragraph.

Planning the growth and continuance of a system of highways involves four steps, which are:

1. Determination of the extent and location of the system, on the bases of traffic demands and geographic, political and economic factors of the area to be served,
   (a) and of the sources and amounts of funds necessary for this purpose.
2. Allocation of available funds to
   (a) operation,
   (b) maintenance-of-way,
   (c) replacement of worn and obsolete highways,
   (d) extension of the system.
3. Establishment of design standards for the various sections of the system.
4. Periodic (e.g. annual) programming of construction within the amounts set up in step 2, (c) and (d).

This discussion, and the numerical rating system proposed, are concerned with programming the amount allocated in step 2 (c). It is presumed that depreciation and obsolescence are to be offset by renewal of units, or sections, of road at a rate equivalent to the depreciation of the whole system.

The numerical rating for each section multiplied by the length of the section is a convenient although by no means exact quantitative measurement of value remaining in service, which can be arrived at quickly and periodically in the light of present standards without being negated by changing conditions such as prices, construction methods and administrative policy. The total of this value divided by the mileage in the system produces an average rating for the whole system. The comparison from year to year of the system rating will provide a check on whether depreciation is in fact being provided for.

It is realized that the numerical rating as developed below has no absolute significance. As stated by Alfred M. Freudenthal, in "Reflections on Standard Specifications for Structural Design," PROCEEDINGS, ASCE, February 1947:

> "There is no particular virtue in mathematical functions or in numbers as such. If they are not really representative, they can be even more misleading than verbal statements, because, psychologically, the number or formula is bound to give the impression of accuracy. Much engineering knowledge is still description, although its presentation is mathematical.... The significance attributed to information expressed by numbers or mathematical functions is an indication of the level of scientific organization of experience. At the level of descriptive science, experience is purely qualitative, and, therefore, not measurable. Most knowledge has not advanced beyond this stage. A higher level is reached when methods of measuring assumedly relevant, recurrent phenomena have been developed and when the resulting figures and relations are used to devise a quantitative, although empiric, classification of experience. Numerical data still have no absolute significance; they are useful only as far as they are suitable to delimit certain classes of phenomena."

The relative weights assigned the various components of sufficiency could not be determined by wholly deductive reasoning. Assuming that it was desirable to arrange sections of highway in sequence of need for improvement or renewal, the gaps in mathematically rational treatment of the problem were bridged by empirical methods based on judgment and on trial and error. This report describes in detail the method finally used, after trying and discarding several sets of relative weights, in assigning priority sequence to all the sections of the Arizona State Highway System. The results were very satisfactory in that State, but it is realized and readers should understand that in systems having different idiosyncrasies, different weights will probably be necessary for the various elements, and in fact other elements not included in this description may well be introduced. The method is offered as a background for developing methods for use in other States and not as a fixed procedure.

METHOD

The objective of the ratings is to arrange sections of the highway system in sequence of relative need for improvement. This could be done by assigning the highest numbers to the sections of greatest need, and this logic was attempted. However, it was found that this resulted in negative numbers, equivalent to expressing temperature as "how cold" instead of "how hot." The method adopted was to assign sufficiency ratings, with the most sufficient roads having the highest ratings.

The first step was defining the elements of sufficiency which were to be evaluated, and assigning each element its proper importance, or weight. The next step was to develop a method of computing or assigning a value to each element for the section of road being rated. The third step was adjusting the rating according to the importance of the road. The steps are discussed separately below.

ELEMENTS OF SUFFICIENCY

The elements used, and the weight finally assigned to each, are shown in Figure 1.

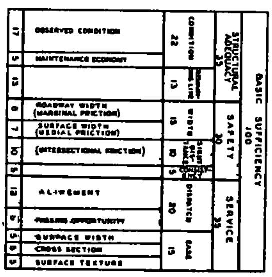

Figure 1

Whole Sufficiency

For convenience, the number 100 was used for the whole sufficiency. Three main qualities to be provided by a road are Structural Adequacy, Safety, and Service. These classifications are general enough to cover all aspects of sufficiency of a highway and each is as important as the other. The 100 points allowed for the whole sufficiency were therefore divided into approximate thirds (35, 30, 35).

Each main classification was then divided into sub-classifications and weights were assigned to the latter. The further this subdividing is carried out, the more uniform will be the treatment of the several road sections, and the simpler is the task of the engineer in assigning values to each element. However, if the subdivisions are too small, the leeway within each is insufficient for recording contrast between sections. That is, if only 5 points are allowed for one element, road sections which are 10% different in value of that element will both receive the same rating.

Structural Adequacy

Structural Adequacy was divided into Condition and Remaining Life. Since it is known that every road depreciates and will eventually have to be replaced, some element of the rating must decrease as the road becomes older. On the other hand, it is conceivable and even probable that for many years the maintenance cost as well as the apparent or measurable condition, and the safety and service, of a given section will remain level. To provide for these facts, an element of "anticipated remaining life," the value of which is computed solely on present age and actuarial data for the surface type and traffic volume group of the section being considered, was introduced as a subdivision of Structural Adequacy. This item was assigned 13 of the 35 points, on the reasoning that significantly more than half (18) of the structural points should be used to evaluate each section on its own merits, as opposed to its average or actuarial merits.

"Condition" of a road structure is a difficult thing to measure. Relative maintenance costs reflect relative structural condition of various sections, other things being equal. However, they probably do not vary as greatly as the condition of the road, simply because it is not possible to perform sufficient maintenance to rectify the condition of many sections; starting with roads of excellent condition and minimum maintenance costs, maintenance will increase as condition becomes worse, up to a point where no more maintenance can be physically applied, but beyond that point there is plenty of room for road sections to be progressively poorer. In Arizona it is not possible to determine the maintenance costs of specific road sections, because of inadequate cost accounting, and it is likely that this is true also in other states.

For these reasons, although the importance of maintenance costs is recognized, and it is realized that annual maintenance can equal the annual cost of a new capital investment, the item of maintenance costs was assigned but 5 of the 22 condition points, and the balance is reserved for variations in observed condition. The term "observed" is used in its broad sense. It does not mean merely looking at the surface, but implies the continuing knowledge of the behavior of surface and subgrade, which materials and maintenance engineers possess.

Safety

The objective and rational way of assigning safety ratings would be simply on the basis of the accident rate of each section, expressed say in terms of accidents per million vehicle miles. The trouble with this method is, first of all, the experience on all but the very heaviest traveled roads is too slight, with the result that the rate is dependent on pure chance. That is, one section may have one accident in its history, and another section, two. This is not enough experience to justify any conclusions as to the relative safety of the roads. Second of all, accident reporting and tabulating is not accurate enough to know what has taken place on short road sections.

There is little conclusive literature on the relation between roadway standards and accident rates. When there is, the method here proposed for rating safety can probably be improved.

Congestion and friction between opposing or intersecting traffic streams, and between stationary and moving traffic, are doubtless among the most important contributing factors. In Arizona the great majority of roads carry 2500 or less vehicles per day, and these items do not govern. For rating the safeness of this type of rural road, the subjective outlook was applied, by answering the rhetorical question, "What makes me feel safe"? The answer is (1) If a road is wide enough, an alert driver can nearly always avert accidents notwithstanding the behavior of other vehicles, failure of his own, or other faults of the road; (2) Other conditions being equal, the farther he can see, the greater his safety, and (3) the road must not offer abrupt changes, such as sharp curves between long tangents, narrow bridges in wide roads, and vertical dips. These are in descending order of importance and they were assigned values of 15, 10, and 5, out of the 30 points available. The 15 points for width were further divided into equal weights (8 and 7) for roadway width and surface width, on the basis that although the whole road may be roomy enough to avoid collision, a narrow surface on such a road confines opposing traffic streams and creates a hazard.

To use trite phraseology, the three causes of accidents are Marginal friction, Medial friction and Intersectional friction. On low volume rural roads these correspond exactly to roadway width (shoulders), surface width, and sight distance. On high volume roads, and where there is considerable roadside development, the terms "width" and "sight distance" are superseded by the more general terms, and values computed accordingly.

It may be noticed that alinement is not considered in the evaluation of safeness except as implicit in controlling sight distance.

Service

Service to the road user comprises the dispatch and ease with which a given trip can be made. The 35 points were divided 20 for dispatch and 15 for ease. It may well be argued that economy of operation is an equal factor in the service a road should provide. However, dispatch and economy are interdependent, and part of "ease" as defined below also contributes to economy.

The difference in operating costs over various roads is not significant unless the time or distance is excessive on one of them. The principle of the numerical ratings is to provide and evaluate variation between sections. It would be contrary to this principle to introduce a factor whose value would be nearly equal for all sections. Variation in economy is taken care of by variations in dispatch and surface texture.

Dispatch on most rural roads is simply a function of alinement and passing opportunity, and on lower volume roads, more of alinement. The 20 points is therefore divided into unequal portions of 12 and 8, respectively.

On heavy volume roads, dispatch is a function of freedom from congestion, which is dependent upon many other features of design besides alinement. On this type of road, alinement was ignored and evaluation of the 12 points allotted was based on the normal operating speed on the existing road.

"Ease" was considered to be dependent upon traveled lane width, regularity of cross-section (absence of sway), and surface texture, which three items cover most of the reasons for tension or absence thereof in operating a motor vehicle, other than the reasons allied with safety and dispatch.

It may appear, particularly to those whose principal concern is the priority of widening from 2 lanes to 4 lanes, that freedom from congestion is not given enough weight. It was found in Arizona that congested roads which could be remedied by increasing the number of lanes automatically are lacking in all of the items comprising the 30 points for safety, and in surface width which is 5 points of the service component, as well as in the 20 points allotted to dispatch. In other words, conditions leading to congestion are reflected in elements amounting to 55 of the possible 100 points. Furthermore, in step 3, described below, the basic rating is adjusted on the basis of traffic volume and this operates to enhance the priority of such sections. The preponderance of all mileage needing reconstruction is two-lane standard, and one of the problems this rating method attempts to solve is the sequence of priority between medium or low-volume roads which are wholly inadequate in structure and alinement on the one hand, and high volume roads which are inadequate in dispatch on the other hand. The funds are in each case, rural state highway funds, and as long as the road is in the system, the highway department has the obligation of making it standard.

One important factor which is not included in this rating method is directness of line; routes which are completely out of direction are not satisfactorily rated. For example, in Arizona the existing road from Phoenix to Prescott is 114 miles long and portions have very high ratings, while other portions are tortuous, obsolete, and worn out. This route was rated section by section and about 18 miles came out with very low ratings, enough to be in the first priority of improvement, and the balance had fairly high ratings. A new route is proposed between the same points which saves 24 miles of distance, but the ratings do not lend themselves to demonstrating when this work should be undertaken, or even that it should be undertaken at all. (This is discussed further under the heading "Application to Programming.")

It will be noted in Figure 1 that there is interlocking or overlapping of the minor elements; e.g., a high value for sight distance would automatically result in a high value for alinement, and surface width appears in two places. The viewpoint taken is (1) that if good alinement is necessary to produce good sight distance, the analysis results in a proportionate weight for alinement which more correctly reflects its total influence on the overall rating, and (2) that although good sight distance insures good alinement, good alinement is possible without good sight distance, and so forth. From this viewpoint it would be incorrect to combine the related factors, especially when attempting to derive their correct relative weights. This was found to be no inconvenience in rating the 3800 miles in Arizona.

EVALUATING THE ELEMENTS FOR EACH ROAD SECTION

After deciding what elements were to be rated and the relative importance of each, the next step was to devise uniform methods, or formulas, for evaluating each element, for each road section being rated.

These formulas depend on the principle of comparing each road section with the present standard for that section. The comparison is made for each element of sufficiency set forth above.

It is necessary to provide a table of standards, and to know the traffic volume classification of each section of the system. In Arizona there are 15 sets of standards, five different traffic volume groups and 3 kinds of topography in each group. (Certain standards are equal in several of the 15 sets.)

Observed Condition, weight 17 points, was rated on a plain qualitative basis, as follows:

Excellent	16-17 points
Good	12-15 points
Fair	8-11 points
Poor	0-7 points

Maintenance Economy, weight 5 points.

Each section was assigned a value from 0 to 5 from judgment and conference with the maintenance engineers. In general, this rating was more or less an extension of "observed condition." In some cases, however, there was a difference. Gravel roads were rated very low in maintenance

TABLE 1

TABLE USED FOR DETERMINING "ESTIMATED REMAINING LIFE" RATING

Yr Built	Age	Mixed Bituminous R4 Type Survivor Curve 15 Yr Average Life Total Life	Yrs to Go	Points	PC Concrete R4 Type Survivor Curve 25 Yr Average Life Total Life	Yrs to Go	Points	Bit Surf Tr Medium Traffic Vol L1 Type Survivor Curve 5 Yr Average Life Yrs to Go	Points	Bit Surf Tr Low Traffic Vol L1 Type Survivor Curve 8 Yr Average Life Total Life	Yrs to Go	Points
1946	0	15	15	13	25	25	13	5	5	8	8	8
1945	1	15	14	13	25	24	13		4	8 2	7 2	7
1944	2	15	13	13	25	23	13	3 4	3	8 4	6 4	6
1943	3	15 1	12 1	12	25	22	13		3	8 8	5 8	6
1942	4	15 1	11 1	11	25	21	13	2 55	3	9 2	5 2	5
1941	5	15 2	10 2	10	25	20	13		2	9 8	4 8	5
1940	6	15 3	9 3	9	25	19	13	2 0	2	10 4	4 4	4
1939	7	15 4	8 4	8	25	18	13		2	11 1	4 1	4
1938	8	15 5	7 5	7	25	17	13	1 5	1	11 7	3 7	4
1937	9	15 5	6 5	6	25	16	13		1			3
1936	10	15 7	5 7	6	25	15	13	1 0	1	13 2	3 2	3
1935	11	15 9	4 9	5	25	14	13		1			3
1934	12	16 2	4 2	4	25	13	13	0	0	14 8	2 8	3
1933	13	16 4	3 4	3	25 2	12 2	12					2
1932	14	16 7	2 7	3	25 4	11 4	11			16 2	2 2	2
1931	15	17 2	2 2	2	25 6	10 6	11					2
1930	16	17 7	1 7	2	25 7	9 7	10			18 0	2 0	2
1929	17	18 3	1 3	1	26 0	9 0	9					2
1928	18	19 0	1 0	1	26 3	8 3	8				1 0	1
1927	19	19 7	0 7	1	26 6	7 6	8					0
1926	20	20 5	0 5	0	26 8	6 8	7					0
1925	21	21 2	0 2	0	27 1	6 1	6					
1924	22	22	0 0	0	27 4	5 4	5					
1923	23				27 8	4 8	5					
1922	24				28 2	4 2	4					
1921	25				28 7	3 7	4					
1920	26				29 2	3 2	3					
1919	27				29 8	2 8	3					
1918	28				30 4	2 4	2					
1917	29				31 1	2 1	2					
1916	30				31 8	1 8	2					
1915	31				32 5	1 5	2					

economy although their condition might be very good. Surface treated roads may have an observed condition of excellent, but because of high maintenance costs, may have a very low maintenance rating.

If precise cost accounting were in effect, the unit cost of each section could be used directly for the maintenance rating. The application could be by subtraction of one rating point for each increment of unit cost above a determined minimum. If this method were used, it would seem proper to assign the maintenance item much more than 5 points of the 22 for structural adequacy. For reasons stated under the heading "Elements of Sufficiency," the item of observed condition cannot be eliminated or supplanted entirely by "maintenance economy," but it could be reduced to perhaps 8 points, which would leave some latitude for expressing differences between sections and at the same time would increase the weight of the non-controvertible cost-of-maintenance to 14 points.

Estimated Remaining Life, weight 13 points.

One point was allowed for each year of life remaining; the years remaining were determined from survivor curves of the patterns suggested in Bulletin 125 of the Iowa Engineering Experiment Station. For convenience, these were reduced to tabular form for the types and traffic volumes encountered in Arizona. The table used is reproduced here as Table 1.

When the years remaining attained 13, the maximum value for this element, all younger surfaces were rated at 13 points. The reasoning is that if less than one point per year is used, the spread between the various sections will be reduced and the purpose of introducing this rating element is counteracted; furthermore, the ratings are to be executed periodically and there is not much point in trying to peer into the future more than 13 years; the object of the "life" element in the whole rating is accomplished if retirement is begun to be anticipated that far in advance.

Roadway Width, 8 points.

The deviation from standard was measured in the field, and the proportion which the actual was of the standard, was multiplied by 8 to obtain this value. Since surface width is accounted for separately, roadway width is really shoulder width. In Arizona on many roads there is no physical distinction between the surface and the shoulders. Shoulder width of the actual road is therefore computed by subtracting the standard width of surface from the actual roadway width. The fraction that this is of the standard shoulder width is multiplied by 8 to give the rating. In the form of an equation,

$$R = 8 \times \frac{W_{RA} - W_{SS}}{W_{RS} - W_{SS}} \quad (1)$$

Where R is the rating in roadway width,
W_{RA} is the actual roadway width,
W_{SS} is the standard surface width (can be less than actual), and
W_{RS} is the standard roadway width.

Surface Width, 7 points.

It was assumed that a width 7 feet less than standard is wholly inadequate, and rates zero. The rating is 7 minus the deficiency in width expressed in feet. If the standard is 22 feet and the actual is 20 feet, the deficiency is 2 and the rating 7 - 2, or 5. This may be expressed as follows:

$$R = 7 + W_{SA} - W_{SS} \quad (2)$$

Where R is the rating in surface width, and
W_{SA} is the actual surface width in feet,

In this or any other rating computation, if the dimension or quality of the actual road exceeds the standard, the rating is of course the total weight assigned the element, and never greater.

The remaining elements, namely stopping sight distance (or intersectional friction), consistency, alinement, passing opportunity, cross section, and surface texture, were rated by inspection in the Arizona survey. Surface width as an item of service was rated by subtracting the deficiency in feet from 5. In the case of roads where dispatch was governed more by roadside interference, or heavy traffic volume, than by curvature, this element was rated in proportion to the average attained speed in the section, compared with the standard design speed.

It is feasible to apply judgment, or "inspection" ratings to all the elements, particularly where one engineer conducts the entire survey. Doing it in this fashion, i.e., using tables or formulas for remaining life and width elements but using judgment for all the other items, two engineers driving together were able to assign ratings to about 200 miles of road per day of driving. It is necessary to drive as fast as the road can be driven in order to make true observations of the effect of restricted sight distance, alinement, and the other factors other than structural adequacy. Driving slowly as when inspecting the surface, these items are likely to cause an entirely different reaction on the observer. Stops were made to measure widths which due to various reasons, often differ from plan widths. Sight distances were not measured.

It would be preferable to apply formulas wherever possible, for the sake of uniformity and to preclude bias, as well as to insure that several engineers will arrive at the same results for equal conditions. Formulas for sight distance, alinement, and passing opportunity have been worked out and are appended at the end of this report. These have been tested in the office, taking data from plans, and appear to be satisfactory but they are somewhat tedious and consequently expensive, particularly if the sight distances are measured in the field as they should be.

ADJUSTMENT FOR TRAFFIC VOLUME

The basic sufficiency, derived above, is simply a numerical expression of a comparison of each road section with the standards for that section. Since these standards depend to a large extent upon the traffic volume, the basic sufficiency does recognize to a degree, the traffic on each section.

However, important roads which deviate from one standard should be given priority over less important roads which deviate from another standard by the same amount. Or, put another way, to attain an equal position on the priority list, important roads need not deviate from standard as far as minor roads. A system of adjusting the basic rating to accomplish this effect was devised, which reduces the ratings of high volume roads, and increases the ratings of low volume roads.

Dividing the basic rating by the traffic volume, or subtracting the basic sufficiency from 100 to obtain the deficiency, and then multiplying by the traffic volume, would give higher priority to heavy volume roads; in fact, it would give such a large advantage to the latter, that none but the heaviest traveled roads would ever appear on the list. The State highway system is in the nature of things bound to embrace a wide range in volume, and a considerable portion of the mileage must therefore be low volume roads, with any normal frequency distribution. Suppose that one road has a sufficiency of 90, or a "deficiency" of 10 points, and carries 10,000 vehicles per day; this would make a volume-deficiency factor of 100,000. Now suppose another road on the same system has a sufficiency of 50, or a deficiency of 50 points and carries 500 vehicles per day; the factor would be 25,000. It would be absurd to improve the first road up to a sufficiency of 97.5 before improving the second.

The method devised eliminates this objection. No adjustment is made when the traffic volume on the section is equal to the average traffic volume of the system being tabulated. When the volume on the section exceeds the system average, the sufficiency is lowered; the amount of lowering is proportional to the logarithm of the traffic volume. Using the logarithmic function has the effect of keeping the adjustments within practical values, i.e. all adjusted ratings still come out between 0 and 100. It also has some logical significance, as the adjustment between sections carrying 100 and 500 per day (the 500 being 5 times as important as the 100) is the same as the adjustment between 200 and 1000, 1000 and 5000, or any other pair where one section has 5 times the volume of the other.

Furthermore, no adjustment is necessary nor desirable if the basic rating is either 0 or 100. Any section, if on the system at all and no matter how low in importance, which has a basic sufficiency of 0 should be at the top of the priority list, and any section which meets standards in all respects (basic sufficiency 100) does not need any adjustment regardless of traffic volume.

A three-variable equation which accomplishes the results stated in the preceding two paragraphs, and is plotted as a family of curves for any given system, was derived as follows:

If B is the basic rating,
R is the adjusted rating,
R_S is the adjusted rating where traffic volume is the average traffic volume on the system,
y is the adjustment,
T is the traffic volume on the section, and
T_S is the average traffic volume of the system;

then when $T = T_S$, no adjustment is made, and

$$R_S = B \text{ (Fig. 2)} \tag{3}$$

For basic sufficiency, B, of 0 or 100, the adjusted sufficiency would still be 0 or 100. For any value of T, therefore, y is made equal to 0 for B = 0 and for B = 100, and is made greatest at B = 50 (Fig. 3). A

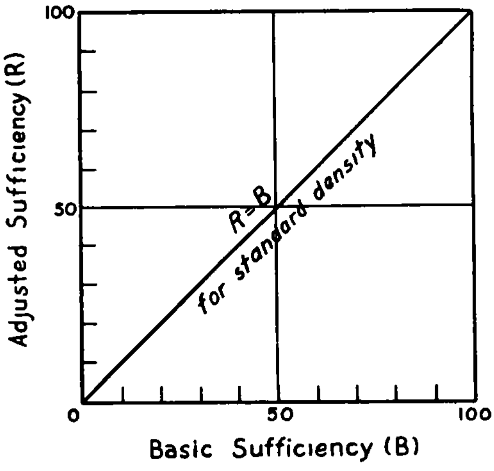

Figure 2

parabola accomplishes this and gives satisfactory results. By trial it was established that for T of 1 vehicle per day, a maximum y of 50 is reasonable (this means that when the basic sufficiency, or the final rating of a road section carrying T_S vehicles

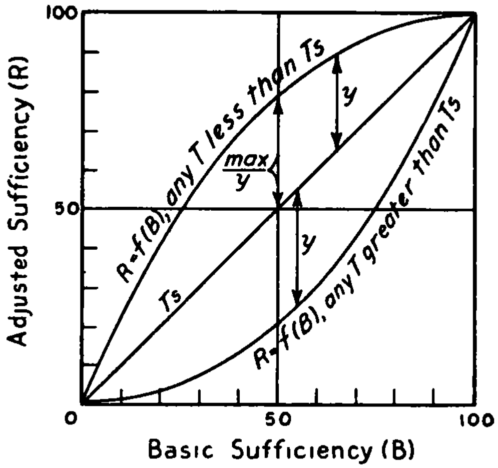

Figure 3

per day is 50, the adjusted sufficiency of the same road carrying 1 vehicle per per day would be 100). The equation of this parabola when T = 1 is

$$y = \frac{100\ B - B^2}{50} \quad \text{(Fig. 4)} \tag{4}$$

For a given value of B, y varies as the logarithm of T, or

$$y = K \log \frac{T}{T_S} = K (\log T - \log T_S) \tag{5}$$

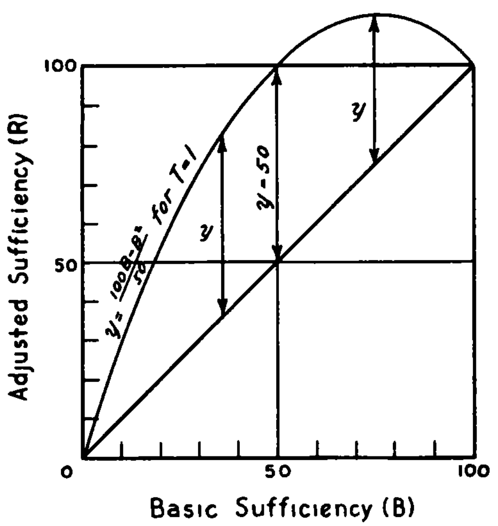

Figure 4

Equating (4) and (5),

$$K = \frac{B^2 - 100B}{50 \log T_S} \tag{6}$$

The adjusted rating, R, is the rating for standard volume plus y, and from (3), R_S = B and R = B + y. Substituting from (5) and (6),

$$R = B + K (\log T - \log T_S) \tag{7}$$

$$= B + \frac{B^2 - 100B}{50 \log T_S} (\log T - \log T_S).$$

Figure 5 shows several intercepts of this equation for various values of T, where T_S = 1000 vehicles per day. This chart was used for determining the adjusted ratings for the Arizona Federal-aid System.

It will be noted that for all practical values of T, R falls within the range 0 to 100; also that values of y are reasonable for all values of B. The difference in R between volumes of 5,000 and 10,000 is small, which is as it should be since both are of first importance; or at least the difference in importance is no greater than that between volumes of 500 and 1000.

EXECUTION

In Arizona a form for recording data in the field was designed and mimeographed on card stock, 5 by 8 in. The form used is shown in Figure 6.

Each route was divided into consecutive sections which were identified by route and route mile, the limits of which were determined by convenience (existing project termini), and homogeneity. Since existing designated projects control existing records and, frequently, changes in type or construction standards, they would be natural units to use for each rating section. However, it was found that one or more of the basic elements often changed in value within a project, and obviously a new rating had to be made when this occurred. Because of this, the route mile was the only practical means of identification of sections. Breaks were also necessary where the standards changed.

The sections varied from a fraction of

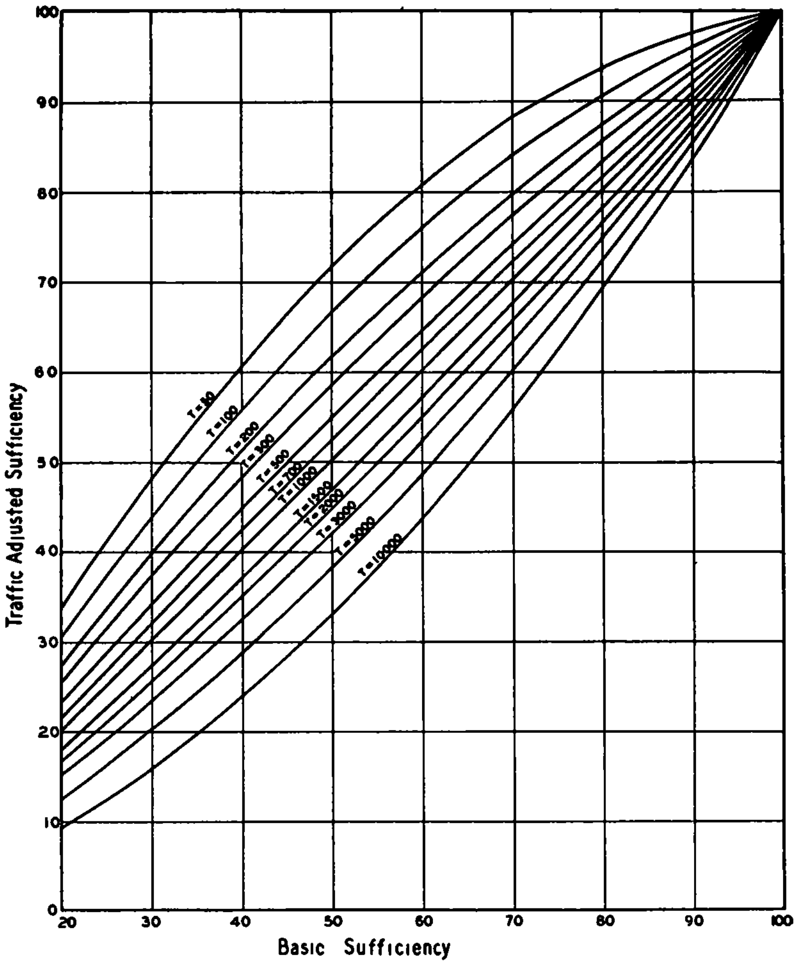

Figure 5

a mile to about 15 miles, and averaged about 5 miles in length; they cannot be too short or the values for items like alinement become meaningless, and on the other hand if they are too long, local deficiencies are diluted, and conversely "good" mileage might be contaminated by a short stretch of deficient road.

The information on the cards was transferred to business machine accounting cards (punched cards), and various lists were then made up. The first list of course was a list in ascending order of adjusted sufficiency ratings. Within each rating, the sections were arranged in ascending order of safety rating. Another list was made in the form of a route log giving the sufficiency of each section of a route in geographic sequence. A frequency curve showing the number of miles having various ratings was prepared, and the average rating (weighted by mileage) of the system was computed.

A limited number of copies of the lists are available to interested readers, at the Arizona Highway Department, Phoenix, Arizona.

APPLICATION TO PROGRAMMING

It is possible to use the top part of the list of ascending ratings as a construction program, going down in the list just as far as the available money will go, with the following modifications:

First, as stated in the introduction, the money for construction must be divided

Route	Dist.	Route Mile	FAP	Yr. Built	Avg. Daily Traffic	Length	Basic Sufficiency	Traffic Adjusted	County
		To							

STRUCTURAL ADEQUACY	Standard	Actual	Par	Rating
Observed Condition			17	
Estimated Life			13	
Maintenance Economy			5	
STRUCTURAL ADEQUACY				

SAFETY	Standard	Actual	Par	Rating
Roadway Width (Marginal friction)			8	
Surface Width (Medial friction)			7	
Stop sight distance (Intersect. frict.)			10	
Consistency			5	
SAFETY				

SERVICE	Standard	Actual	Par	Rating
Alignment (Safe speed)			12	
Passing Opportunity			8	
Surface Width			5	
Rideability			10	
SERVICE				

Location	Class	Estimated cost of constructing to standard
	Topog.	R/W
		Grading
		Drainage
		Surface
		Bridges
		Other
		Total

Date	Odom
	To
By	From
Serial	Dist.

Figure 6

into "renewal" and "new routes." The new routes will not appear on the rating list.

Second, section termini for construction will necessarily be determined in the route survey or design stage. For example, a stretch of 15 miles is rated as follows:

Mile	0.00 to 5.60	65
	5.60 to 6.00	45
	6.00 to 15.00	55

The 0.40 mile of 45 points will be in the top priority, the 9.0 miles of 55 will be about 5 years from the top, and the rest will be more than 5 years away. For a practical construction program mile 5.60 to 15.00 should all be improved at one time.

Third, sections of high priority, but which will be eliminated from the system by major relocation, naturally will not be programmed. Major relocations are in some ways the same thing as new routes. In any event, the numerical ratings of existing highways will not help much in programming their construction. The necessity for, and the timing of, such construction should be based on individual, comprehensive studies for each case, coupled with continuous accounting methods which will show the current financial condition of the whole system.

Although it is recommended that the ratings be made annually, the program based on the ratings should be a five-year program. Each year, a new five-year program can be set up; thus the annual program becomes merely a segment of the running continuous program, and the modifications of the rating list to the construction program are smoothed out, particularly in the determining of practical termini for projects.

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APPENDIX

Evaluation formulas for sight distance and alinement.

Stopping Sight Distance (weight 10 points)

The relative sufficiency of a section containing restricted sight distance would seem to be proportional to the length restricted, and how restricted. That is, suppose the standard minimum sight distance is 1000 ft. Then a half mile wherein the sight distance is 800 feet would be more sufficient than a half mile wherein the sight distance is, continuously, 500 feet. But perhaps a half mile at 800 feet would be as great a deficit as 1/10 mi. wherein the sight distance is 400 feet. Some experimenting with the many variables involved was done, and the following formula seemed practical:

$$R_S = \frac{L - 2.5\ N\ S_m}{L} \times 10 \qquad (8)$$
$$= 10 - \frac{25\ N\ S_m}{L}$$

where S_m is the standard minimum sight distance
L is the length of section
N is the number of restricted places
R_s is the rating

This may be interpreted physically as meaning that a sharp vertical curve would necessitate grade adjustment for a distance of 2.5 times the minimum required sight distance, in order to attain that minimum. A typical case would be a section 2 miles long, where the standard calls for 800 feet, and there are three places where 500 feet is the maximum distance that can be seen. In this case,

$$R_s = 10 - \frac{25 \times 3 \times 800}{2 \times 5280} = 4$$

It is very possible that the formula can result in a value of less than zero. In this case zero should be used.

Alinement (weight 12 points)

A method of combining the intensity and frequency of deficiencies from standard is offered. The travelable speed of a curve varies roughly as the square root of the radius, or inversely as the square root of the degree of curve. For a single excessive curve, then, the relative sufficiency (r_c) for the length involved would be $r_c = \sqrt{D_s/D_a}$, where D_s is the standard maximum degree of curvature and D_a is the actual degree of curvature. To find the rating for a section of road with this curve included, it would appear proper to multiply the rating r_c by the length which is deficient, multiply the remainder of the section by 1, and divide the sum by the total length of the section to obtain a weighted rating. Actually, this results in too high a rating for a section with numerous short excessive curves. To provide for reduction of the rating due to number of deficiencies and to simplify calculation, it is proposed to assign a constant length for each excessive curve, equal to one mile divided by the standard degree. This also provides for the fact that an excessive curve spoils more than its own length, and penalizes those sections with faulty alinement design. Thus where the standard maximum curvature is 3 deg., one excessive curve is considered to affect 0.33 mile; where it is 10 deg., one excessive curve is considered to affect 0.10 mile, etc.

Let L = length of section in miles
D_s = standard maximum degree of curvature
D_a = actual degree of curvature for each substandard curve
N = number of substandard curves
$r_c = \sqrt{D_s/D_a}$, proportion of standard (intensity) for each curve

Then the length substandard by the above definition is $1/D_s$ for each excessive curve, or N/D_s for the sum of all excessive curves.

The length standard would be $L - N/D_s$.

The weighted average A for the section is the length standard multiplied by 100 percent plus the sum of the lengths substandard multiplied by r_c, all divided by the length of the section.

$$A = \frac{1.00\left(L - \frac{N}{D_s}\right) + \sum r_c \times \frac{1}{D_s}}{L} \qquad (9)$$
$$= 1 - \frac{N - \sum r_c}{LD_s}$$

For example, the following section built in rolling country in 1931 where 3 deg. is the present standard is cited:

Length of section 3.54 miles.

Excessive Curves		$r_c = \sqrt{\frac{3}{D_a}}$
No.	D_a(deg.)	
1	6	.71
1	4	.87
1	6	.71
1	6	.71
1	6	.71
1	6	.71
1	5	.77
1	6	.71
1	4	.87
1	6	.71
1	6	.71
11		$\sum r_c$ = 8.19

$$A = 1 - \frac{(11-8.19)}{3.54 \times 3} = 0.74$$

The alinement rating (out of 12) is 12A, or in this case, 9.

Several sections of substandard alinement have been rated by this formula and the results are consistent with the facts. It seems almost impossible to arrive at a rating less than 0, although if this happened, 0 would be used.

Passing Opportunity (weight 8 points)

A knowledge of the traffic density during the peak hours of the year, of the section being rated, is necessary to assign a fair value to this element. If this is low enough so that passings are rarely necessary to avoid delay, then passing sight distance is not required frequently. If, however, the traffic density lies between this limit and the upper limit, where unlimited sight distance is of no avail, then the rating can be computed as the proportion of 8 that the unrestricted mileage is of the total mileage. If passing opportunity is restricted during 30 or more hours a year by the traffic density, instead of by restricted sight distance, the rating should be zero.