Priorities Determination and Programming In Tennessee

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● A COMPREHENSIVE STUDY of highway needs in Tennessee was completed in November 1955, under the direction of the Automotive Safety Foundation. The report, "Highway Transportation in Tennessee," presented alternative long range programs for the several systems of roads and streets.

The Tennessee Department of Highways and Public Works decided that the first step in putting into operation the study's proposals relative to the state highway system, was the formulation of an initial 5-year short-range program to remedy the system's most critical deficiencies. A second step should be the formulation of criteria, techniques, and procedures necessary to establish a continuing construction program to meet future deficiencies as they accrue. Pursuant to this decision, the department and the Automotive Safety Foundation entered into a cooperative research project to accomplish these two tasks.

Work on the first of these tasks has been completed and this paper describes the development of the priority rating method and procedures found to be best adapted for the formulation of the initial 5-year program.

ORGANIZATION OF THE FIELD OF STUDY

It was agreed that the initial program would be based upon data collected and developed during the highway needs study with attention concentrated on the sections found critically deficient. Such sections accounted for about one-half of the rural state highway mileage and about one-third of the system mileage on city streets. It was clear that correction of these deficiencies (estimated to cost $505 million on the rural highways and $268 million on their urban extensions) would utilize more than the estimated income of the department for the projected 5-year program period.

The problem of formulating improvement programs was complicated by the mass and variety of the conditions involved. Not only was there a great volume of the "needed-now" situations, but different sections of road were judged critically deficient for many reasons. On rural state highways alone, there were 3,284 miles which had serious structural defects, 3,000 odd miles were appraised deficient with respect to geometric design or alignment, 554 miles lacked sufficient capacity, and many sections had a combination of these deficiencies. In addition, some sections were "accident prone" while others, even though they have serious physical deficiencies, did not seem to produce accidents. Finally, some deficient roads penalized thousands of vehicles a day and others, only a few hundred.

There were different degrees of urgency among these sections even though they were all critically deficient. If the sections were to be examined and tested individually to establish the relative urgency of their condition, the first requirement was to develop a procedure for dividing them into comparable groups to narrow the field of judgment. Moreover, a practical construction program must provide an adequate amount of work on the state highway system throughout the state and on the several subdivisions of the system with due consideration for the various types of federal aid and state funds applicable to their improvement.

To accomplish area distribution, the various funds available were apportioned among the department's four field divisions in proportion to the total needs in each division as determined by the needs study. To provide distribution to the several parts of the state system, it was determined that within each field division a rating procedure would be applied separately to the critical needs of the rural and urban portions of the federal aid primary system and of the rural and urban state highways not included in that system. Programs were then developed for each of these highway subdivisions providing for an equal rate of improvement throughout the system.

INTERSTATE SYSTEM

In the early stages of this study, the rural and urban sections of the National System of Interstate and Defense Highways on the existing state system were also considered as subdivisions of the state highway system and deficiencies on them were determined in relation to the high standards prescribed for interstate routes and then were apportioned and rated in the same manner as deficiencies on other federal aid and state highway sections. However, after the programming study had been under way for some time, the Federal Aid Highway Act of 1956 was passed and soon thereafter the state and the Bureau of Public Roads agreed upon routes for interstate highways which, with few exceptions, were on new locations, generally some distance from the existing routes.

It was evident that a sensible and logical program for interstate projects on these new locations could not be formulated solely by reference to the conditions on existing parallel state highways. Even though the condition of such parallel routes is a consideration in programming interstate projects, factors not pertinent to urgency must be taken into account.

Accordingly, it was decided that former interstate routes would be regarded as rural federal aid highways and would be rated as such. Furthermore, no attempt would be made to rate present deficiencies on existing state highways in Tennessee's four major cities until the interstate urban freeway program had definitely taken shape.

This decision was based on the premise that the greatest congestion exists in Memphis, Nashville, Chattanooga and Knoxville where interstate routes are to be built to freeway standards. The locations of freeways in these cities have been fixed and consulting firms are now at work on detailed surveys. Initially, interstate funds will be devoted to completing all urban and rural surveys and plans as quickly as possible and to acquisition of rights-of-way in the larger cities. Earliest construction will take place, for the most part, on those sections for which right-of-way can be acquired most readily and which, when completed, will represent usable and complete improvements within themselves.

The scheduling of interstate freeway construction in the four major cities will vitally affect the scheduling of work on other state highways in these cities. For example, it would be unwise to schedule major construction on a surface highway for the same time a nearby freeway is to be built, since the present street must remain open to carry traffic while the freeway is being completed. The freeways will be the principal traffic arteries of these cities and it is apparent that the construction as well as the operation of other major streets be correlated with theirs. In programming, however, several improvement projects to correct critically deficient sections in these cities were included when their location was such that there would be no conflict with construction on the freeways and no severe impairment of traffic service.

With the deficiency items of the study grouped according to the field divisions and the subdivisions it was necessary to develop procedures for further narrowing the area of judgment within each of these groups. To this end, rating methods were devised for application to the needs as they existed in each of the highway subdivisions.

Careful study was devoted to the selection of indices and procedures for determining the relative urgency of the deficiencies. Sufficiency rating formulas adopted by other states were examined and members of the study staff visited three states, California, Oregon and Colorado, to see the operation and results of rating and programming procedures.

TENNESSEE'S RATING REQUIREMENTS

The purposes of the Tennessee study project did not require a rating for every section of the state highway system. What was required was a screening process which would array the total number of deficient sections within each highway subdivision into a reasonable number of priority groups—in this case, five groups comprising, successively, conditions of greatest to less urgency with each group representing approximately one-fifth of the total cost of correcting all of the critically deficient sections.

The process selected derives from the experience of Tennessee people and agencies in their progress from the early wagon roads to present day transportation arteries.

Tennessee's highway problem at the beginning of the modern highway era was to build a system of roads for going any where at any time. The next phase of the problem was to provide the facilities for expeditious and comfortable travel. Obviously, freedom from hazard was an important characteristic of such travel.

The three major objectives which motivated this historic process—dependability or structural condition, facility of movement, and safety—were chosen as the major criteria in formulating the program to correct the critical deficiencies on the state's present primary system. All these criteria are included in some form in sufficiency rating procedures; what is particularly noteworthy are the methods adopted for measuring facility of movement on rural roads and urban streets.

These criteria could not be applied in the same form to rural and urban conditions. However, their basic significance in relation to efficient traffic accommodation, was used with reasonable effectiveness as a guide in determining priorities in both kinds of areas.

Rural Priority Rating Procedures

The process of segregating the critically deficient sections on the rural state highway system into five priority groups, was accomplished in two stages: (1) the individual sections in each highway subdivision of each field division were analyzed and rated; (2) the sections were then arrayed in order of their rated urgency and arranged into five groups.

Selection of the sections for correction and the determination of their sequence in the construction program required the judgment of the highway engineer and administrator.

RATING CRITERIA

Each of the three rating criteria chosen for this programming study—dependability, facility of movement and safety—retains its own identity throughout the rating process; each is weighed with the others, but is not lost in a single index figure.

Dependability or Structural Condition

Dependability is measured by structural condition. The existing condition of the roadbed and road surface of every section of the rural state highway system was reported as a part of the highway needs study. Four elements of the roadway structure were reported: subgrade, drainage, base, and surface. The original field survey indicated the condition relating to each of these elements as good, substandard occasionally, substandard substantially, or substandard continuously.

The reported conditions of these elements were incorporated in an index by means of a scoring system which was to give each its due weight as a component of structural condition. This scoring system is illustrated in Table 1.

By these point values, a section where subgrade, drainage and base, and subbase were occasionally substandard, and the surface was substantially substandard, would be scored 50 points; if maintenance costs were excessive, the score would be 55 points.

These point values were selected as the result of a considerable process of trial and fitting. They were derived empirically to arrive at a set of indices representative of known conditions and which, at the same time, arrayed those conditions in usable order. They also avoid the tendency for a number of sections with varying deficient elements to fall into the same group.

TABLE 1

STRUCTURAL CONDITION INDEX

	Point Values[a]			
	Subgrade	Drainage	Base and Subbase	Surface
Good	0	0	0	0
Substandard occasionally	2	2	6	10
Substandard substantially	8	8	24	40
Substandard continuously	10	10	30	50

[a] For excessive maintenance, add 5 points

Considering the use of this rating scheme in retrospect, the possibility of something other than purely technical approach to structural condition may be considered. Some states rate only surface condition or "ridability." From the point of view of the motorist, the "ridability" of the road is probably the most important factor. He has little or no knowledge of the technicalities of subgrade quality, drainage, or base adequacy. He does not care which of these is causing the bad riding condition.

A rating system could be devised and aimed to measure the effects which represent a deficiency from the viewpoint of the motoring public and not the causes which produce those effects. Such a rating scheme would have to include some means for the field engineer to note the structural causes separately and to indicate that, although the present riding quality is good, the need for corrective measures rates the section high.

When the structural condition of all the critically deficient sections of a highway subdivision in one of the four divisions had been rated, their rating scores were arrayed in the descending order of their magnitude. They were then divided into ten groups, each comprised of sections with similar condition ratings. These groups were given a numerical designation ranging from 9 to 0, as indicated by the first digit of the rating scores of its included sections. Those with rating scores of 90 or over were in group 9; those with scores 80 to 89, in group 8; and those with scores 0 to 9, in group 0, etc. These digits are the indices of structural condition for the contained sections and are given the first, or left-hand place in the final 3-place index of the section's urgency.

Facility of Movement

Facility of movement was chosen as an index to measure the degree to which the existing road and traffic conditions permit vehicle drivers to travel safely at reasonable operating speeds, in comfort and without undue mental or physical strain. Modern design standards are intended to provide such operating speeds and conditions within the traffic volumes for which they are planned. The amount by which an existing road fails to provide the standard operating speeds is a measure of its deficiency in providing facility of movement.

Aside from poor surface condition, which is an element of the structural condition criterion, and regulatory speed limits, which are outside the field of this study, the factors that are impediments to the attainment of standard operating speeds are excessive traffic, too steep grades, bad alignment, lack of passing sight distance, narrow pavements and narrow shoulders. Other procedures have attempted to rate several of these roadway factors by assigning arbitrary point values to each one. Most of them, however, do not give adequate weight to the adverse effect of traffic congestion.

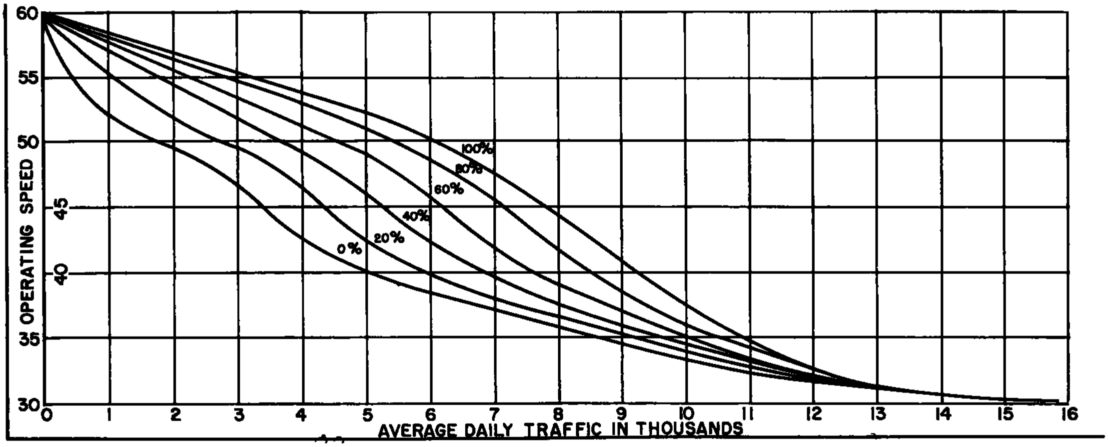

Figure 1. Effect of traffic volume and available passing sight distance on operating speed with average design speed of 60 mph. (Computed on the basis of no grades exceeding 3 percent, 12-ft lanes, 12 percent design hour, 5 percent dual-tired commercial vehicles in the design hour, and a truck equivalent of 2.)

At the request of the Tennessee Highway Department, O. K. Normann, Chairman of the Highway Research Board's Committee on Highway Capacity, developed for the first time a set of basic curves which show the operating speeds that can be obtained in the design hour under various existing conditions. This discussion is confined to the application of these devices to the Tennessee programming study.

The curves and correction factor table stem from three basic items: design speed, operating speed, and design hour traffic.

Design Speed. Used for purposes of highway design, design speed is the highest continuous speed at which individual vehicles can travel when conditions of weather and traffic are favorable and the design features of the highway are the governing conditions for safety. Design standards for a primary highway with design speed of 70 mph, tolerate no horizontal curves which require a lower rate of travel.

Operating Speed. This is the highest over-all speed, exclusive of stops, at which a driver can travel on a given highway under prevailing conditions without at any time exceeding the design speed. Therefore, in hours of very light traffic, operating speed equals design speed. As traffic increases, operating speed falls off because of the interference of other vehicles and reaches its lowest point in the hour of maximum traffic.

Design Hour Traffic. Design hour traffic is that volume of traffic (in Tennessee the 30th highest hour, or 12 percent of average daily traffic) which guides the design of highway features. In this study, design hour traffic was considered the maximum hourly traffic, which is the maximum hour except for the few hours in the year when the hourly traffic exceeds the design hour.

The design speeds and corresponding operating speeds in the design hour, adopted as design standards for the needs study were used as par values in facility of movement in hours of light traffic and of heavy traffic.

The Normann curves are based on what is called "actual average design speed," and they show, for various highway and traffic conditions in the design hour, the "actual operating speed."

Actual Average Design Speed. The calculated average speed at which a vehicle could traverse a given highway section under favorable conditions of weather and traffic when the existing horizontal alignment of the highway is the governing condition for safety is the actual average design speed. It was obtained by noting the length of subsections where too sharp horizontal curvature cut speed below the standard design rate and then averaging the speeds for the whole length of the section. Thus, for a section where sharp curvature cuts speed to 40 mph for a third of its length but where 70 mph is practical for the rest of its length, the actual average design speed would be 60 mph.

Average design speeds were computed for every rural highway section as a part of the Tennessee study. Considered in relation to standard design speed, they are indications of the degree of deficiency in operating speed at low traffic volume.

Actual Operating Speed. This is the operating speed that is estimated to prevail under the actual conditions of highway and traffic existing on a specific section. Actual operating speed in the design hour is read off the pertinent Normann curve and is a reference point for determining deficient facility of movement in hours of maximum traffic volume.

Seven sets of curves were constructed for 2-lane highways for actual average design speeds of 70, 60, 55, 50, 45, 40 and 35 mph. For each average design speed, actual operating speed in the design hour for any volume of traffic can be read off curves

TABLE 2

NEEDS STUDY SPEED STANDARDS

	Average Daily Traffic								
	Less than 1,000			1,000-3,000			3,000 and more		
Terrain	Flat	Rolling	Mountainous	Flat	Rolling	Mountainous	Flat	Rolling	Mountainous
Design speed	60	50	40	70	60	50	70	70	60
Operating speed in design hour	45-50	40-45	35-40	45-50	45-50	40-45	50-55	45-50	45-50

representing all percentages of available passing sight distance. The curves in each case are computed on the basis of no grades exceeding 3 percent, 12-ft lanes, 3- to 4-ft shoulders, 12 percent design hour traffic, with 5 percent dual-tired vehicles in the design hour representing a truck equivalent of two passenger cars in flat terrain.

All of the five latter highway and traffic conditions which are taken as fixed quantities in the computation of the curves, actually are highly variable. It was necessary to make adjustments that would reflect these variations.

Inasmuch as facility of movement is a function of traffic, means were found to compensate for these variations in traffic terms. Accomplishment of this purpose was aided by the existence of a wealth of factual information demonstrating the effect of variation of these conditions on highway capacity and movement. Most of these data had been produced through research and observation.

The first step in the procedure of appraising a section for facility of movement, was the selection of the proper set of curves indicated by the section's actual average design speed as determined by the highway needs study. Next, adjustment factors for whatever variant conditions might exist were applied to the section's average daily traffic. This produced a weighted traffic volume figure which, when used with the selected curve, gave the actual operating speed on that section.

Rating the section for facility of movement was then a mechanical process. Deficiency of movement in hours of low traffic and of maximum traffic was obtained by subtracting actual average design speed from standard design speed and actual operating speed from standard operating speed. The average of the two differences (plus differences were disregarded) was taken as a measure of the over-all deficiency throughout the range of hourly volumes. This figure was multiplied by the section's average daily traffic to give recognition to the amount of traffic affected. The resulting figure indicated the section's weighted deficiency in facility of movement.

Rated sections of a highway subdivision in a single geographic division, were arrayed in descending order and were then arranged in 10 groups each representing a like range in the weighted index and comprising approximately the same number of sections. The sections in these groups were given index numbers 9 to 0, indicating their degree of, or freedom from, deficiency. This digit was entered second in and became a part of the section's 3-place priority index.

The index of facility of movement has distinct advantages over an index of the relationship between practical capacity and existing traffic volume, usually expressed as a ratio in which all values greater than one indicate the degree to which existing traffic exceeds practical capacity. But even on very heavily traveled routes, traffic will exceed capacity only during a few hours of the day. During the remaining hours there is no capacity problem, but operating speed may be seriously reduced by a combination of lower volumes and deficient geometrics and alignment. Adequate capacity is only one of the several features that traffic is entitled to expect in its use of a highway. Traffic is vehicles in motion, and the rate, freedom and convenience of its movement at all times are factors of basic importance in measuring highway adequacy. To a very large degree these factors are reflected in the computation of the facility of movement index.

Safety

Accidents are the true measure of lack of safety. If all accidents were reported and if the reports pin-pointed the location of each accident, then accident occurrence would provide a reliable index of highway hazard.

However, no state has accident records which approach this degree of completeness and accuracy. Fatal accidents usually are reported with details as to time, place and other major facts. It is estimated that on rural state highways there are over 100 non-fatal accidents for each accident in which a fatality occurs, but in only one state do the records show a ratio of as high as 75 to 1, and in the remaining states ratios vary from 60 down to 13 to 1. In Tennessee in 1955, the ratio of non-fatal to fatal accidents on rural state highways was 23 to 1, according to the best available records.

There are differences in the completeness of accident reporting in the different parts of Tennessee as there are between the several states. The range of these differences is indicated by the 1955 ratio of non-fatal to fatal accidents on rural state highways as reported in Tennessee's four field divisions (Table 3).

TABLE 3

	Non-Fatal	Fatal	Ratio
Division I (Knoxville)	3,560	155	23
Division II (Chattanooga)	1,863	88	21
Division III (Nashville)	3,498	122	29
Division IV (Memphis)	2,219	115	12
All four divisions	11,148	480	23

These data make it obvious that there was very incomplete reporting of non-fatal accidents throughout the state. However, except for Division IV, there is a certain degree of consistency in the ratios and the reported accidents probably reflect the relative distribution of accident occurrence with a tolerable degree of accuracy.

All accident records for 1955 were located in the road sections where they occurred and the number of accidents per mile was computed for each section. For the most part, accident occurrence on the rural state system ranged from no accidents per mile to 10 accidents per mile in 1955. Thus, the rating scale for the safety factor was practically ready-made by the data.

Selection of the rate per mile rather than the rate per 100 million vehicle miles of travel was premised on the fact that the latter method distorts the seriousness of the hazards on both high and low volume roads. This fact can be illustrated briefly from a study of accident rates made in Ohio in 1955.

Examination of data for the 39 high accident sections on the rural state highways show the following inconsistencies between per mile and per 100 million vehicle mile rates. One section 1.8 miles long carrying an average of 15,600 vehicles per day had 90 accidents; on a per mile basis it rated 3rd among all sections, but in terms of rate per 100 million vehicle miles it ranked 128th. Another section 2.5 miles long and with an average daily traffic load of 12,500 vehicles had 72 accidents; its 28.9 accidents per mile made it 7th on the list, but its rate of 6.3 accidents per 100 million vehicle miles put it down in the 258th place. Among lower volume sections, one with a length of 1.68 miles and 5,600 average daily traffic, had 33 accidents; its per mile rate put it in 16th place, but in terms of volume it was 120th.

It was believed that the per mile method relates accident occurrence more directly to the roadway itself, whereas the rate per volume reflects the character of accident occurrence as a by-product of traffic movement. Therefore, this method focuses attention on those sections having a large number of accidents and points to the need for elimination of possible hazards.

The numerical rate for safety was used as the third digit in the section's 3-place index figure.

DETERMINATION OF URGENCY

Completion of the rating procedure was followed by the determination of priorities among the rated sections. In carrying out this operation, it was necessary to give particular attention to two special types of circumstances. Where, in the course of stage construction, a temporary gravel or similar surface had been laid on a roadbed of approved design, the section was given a score of 5-0-0 as a means of identifying its status as a stage construction project. Also, in the case of planned new construction on a new route not now existing, the projected section was given a special 0-0-0 rating to indicate its special status.

The process of determining the relative urgency of the other sections demonstrated the advantages of the 3-digit form of the rating index. The digits 0 to 9 were used to designate increasing degrees of deficiency in structural condition, facility of movement and safety, and the rating digits of these factors were arranged in the order named from left to right to form the total index of deficiency for each section.

The order in which the factors were represented in the rating index indicates the order in which they were used in determining the sections' relative priority. As the process of determining priorities shows, individual adequate consideration was given to each of the factors. Throughout the procedure, careful consideration was given to instances where the other factors were associated as causes or effects with the controlling factor in each stage of the process.

The final operation in the process of urgency determination consisted of arranging all the rated sections of each highway subdivision in the order of their urgency. This was done by making five successive arrays of the sections in each subdivision, the order of the array in each instance being determined by a different combination of the rated factors.

The first array consisted of those sections with deficiency ratings for structural condition of 9, 8 and 7 arranged in that order. Each of these groups of like appraised structural deficiency was further arrayed according to the amount of the rating of the sections for facility of movement and, then, of their rating for safety. The sections so arranged were set aside as constituting the situations of highest urgency.

The second array consisted of the remaining sections with deficiency ratings for facility of movement of 9, 8 and 7 in that order. Sections in each of these groups of like deficient facility of movement were further arrayed according to the amount of their rating for structural condition and, then, of their safety rating. These sections so arranged, were added to those previously arranged, as constituting the situations of next highest priority.

The third array consisted of the sections remaining with deficiency ratings for safety of 9, 8 and 7 arranged in descending order and then further arrayed according to their structural and facility of movement ratings. So arranged, they were the sections of next priority.

The fourth array consisted of the remaining sections which had a rating for structural condition of 6 and 5 and arrayed according to their facility of movement and then according to their safety ratings. These sections were of still lower priority.

The fifth and final array consisted of arranging all of the remaining sections in order of their rating for facility of movement and then arranging them in order of their structural condition rating and of their rating for safety. These were the sections of lowest priority.

The total array was then divided into five groups which represented successive degrees of urgency, and like estimated total cost of correction.

Priority Rating for Urban State Highways

Determination of priorities among the critically deficient conditions on urban state highway routes was concerned with sections in municipalities of from 1,000 to 35,000 population. State highway routes in municipalities with under 1,000 people were processed along with the rural highways with which they connect. Tennessee has no cities in the population range, 35,000 to 100,000, and, as has been explained, rating on the system's extensions in the four largest cities was postponed until interstate system plans for freeway development in these centers have matured.

The reasons for delimiting the urban problem in this manner are clear. In the smallest places (those under 1,000) the problems are not urban, but continuations of rural problems; in such places the city streets are only "bridges" in the rural state highway system. On the other hand, the largest cities can be considered entities in themselves since the size of their construction needs permits and requires programming over a period of years. Moreover, very often, the improvements needed in these latter places are not definable in terms of existing deficiencies on present state highway routes.

CRITERIA FOR APPRAISING PRIORITIES

The task of selecting factors by which priorities among critically deficient urban sections could be determined, was made difficult by conflicting conditions. There should be some degree of consistency in the criteria applied to all parts of the system, rural and urban, but the availability of data differed in the two kinds of areas and there are basic differences in the characteristics of the service demanded of rural highways and city streets.

Various highway planning engineers have commented on the difficulty of rating urban street systems according to the same criteria used in rural areas. Some of the weaknesses common to such methods are especially apparent in urban ratings. A more objective method is needed and it has been suggested that a congestion index would be useful (1).

The methods for priority determination in this study were chosen after study of experience and opinion in the highway planning field. The choice was shaped by differences in the data available for and the service required of rural and urban highways. These divergencies were reconciled in a way that permitted appraisal of urban sections from viewpoints similar to, though by no means identical with, those used in judging the rural sections.

The factors selected are listed below along with the comparable factors used for rural priority determination.

Urban State Highways	Rural State Highways
1. Condition	1. Structural condition
2. Congestion	2. Facility of movement
3. Route characteristics	3. Safety

Condition

The condition factor used for determining priorities on urban sections does not measure deficiency by such fine gradations as does the structural condition factor used for the rural sections. Although the needs study noted four degrees of condition for each of four elements of the rural roadways, it lacked the data to do more than appraise the whole structure of a city street as a single unit and judge it merely as tolerable or as failing structurally and needing immediate attention. In rating sections, therefore, their condition was designated as either 0, acceptable, or as 9, meaning that they were in critical need of resurfacing or other reconstruction. There was no middle ground between tolerable and critical conditions.

The structural condition of most arterial streets is not up to rural standards; however, on these streets where rate of movement usually is limited by other factors, structural condition is not as important as on rural highways where higher speeds are the rule. This fact was given recognition in the final process of arraying sections for priority determination where congestion, and not condition, was used as the initial control factor in arrangement.

Congestion

Facility of movement was used as the basic factor for determining the service rating of both urban and rural sections. However, facility of movement is a general term which has specific meaning only in relation to the particular conditions to which it is applied. On rural highways it means rapid travel by individual vehicles with wide latitude in their choice of speed. On urban arteries it means free and steady flow of traffic streams with minimum interruption of the movement. Congestion was adopted as the index of an urban section's deficiency in facility of movement in the same manner that restriction of speed was adopted for that purpose on rural sections. The amount of congestion was measured in terms of vehicle-miles of travel inconvenienced by congestion.

The method for identifying the locations where congestion exists and measuring the amount of such congestion was based on traffic observation data. In the past few years, numerous traffic counts had been made on the state highway routes in all of the cities and these provided adequate information about the distribution of travel in relation both to time and to sections.

These data were first used in total to ascertain the state-wide average distribution of Tennessee's urban traffic in the 24 hours of the day. The percent of total daily traffic occurring in each hour was computed and the hours were then arranged in the descending order of the percentages. A table of hourly percentages and accumulated percentages of average daily urban traffic was then constructed (Table 4).

The highest traffic hour accounts for 8.5 percent of the whole day's traffic while the lowest, or 24th, traffic hour accounts for 0.4 percent. The accumulative percentages show what proportion of the total daily traffic movement occurs in all hours accounting

TABLE 4

HOURLY PERCENTAGES OF AVERAGE DAILY TRAFFIC[a]

Hours	Percent in Each Hour	Accumulated Percent	Hours	Percent in Each Hour	Accumulated Percent
1	8 5	8 5	13	4 9	81 0
2	7 5	16.0	14	4.0	85 0
3	7.4	23.3	15	3 9	88.9
4	6 3	29 7	16	3.4	92 3
5	6.2	35 9	17	2 5	94.8
6	6 0	41.9	18	1.3	96.1
7	6.0	47 9	19	1.3	97.4
8	5 9	53 8	20	0.8	98 2
9	5 8	59 6	21	0.5	98.7
10	5 6	65.2	22	0 5	99.2
11	5 5	70.7	23	0.4	99.6
12	5.4	76 1	24	0.4	100 0

[a] Urban areas in Tennessee arrayed in descending order.

for as much as, or more than, a given percent of the day's traffic. For example, the 6th highest hour has 6.0 percent of the day's traffic and the six hours when as much as, or more than, this proportion of the day's traffic is passing, account for 41.9 percent of the total daily traffic movement.

Records of traffic surveys and counts in individual cities provided traffic volume data for all state highway urban routes and included the average daily traffic volume on each section. The capacity per hour of each of these sections had been estimated by the 1955 highway needs study.

Determining the amount of congestion on an urban section was begun by computing the percentage of the section's average daily traffic which is represented by its capacity per hour. Referring this percentage to the table of the hourly distribution of Tennessee's urban traffic, showed how many hours there are when the section's capacity is exceeded and what proportion of its daily traffic passes in those hours. Application of these latter percentages to average daily traffic gives the number of vehicles affected; and when this figure is multiplied by the length of the section, the vehicle-miles of inconvenience due to congestion is obtained.

For example, on a section with average daily traffic of 10,000 and estimated capacity of 600 vehicles per hour, the existing roadway could accommodate 6 percent of the day's traffic in one hour without congestion. Referring this 6 percent figure to the table, shows that, on the average, there are six hours when more than 6 percent of the day's traffic will pass, and that these six hours together account for 41.9 percent of the whole 24-hour movement. That would mean that 4,190 vehicles would be passing during hours of congestion; if the section is one-half mile long, there would be 2,095 vehicle-miles of inconvenienced operation.

The number of vehicle-miles of inconvenience computed for each section was considered the section's score for determining its congestion rating. All of the critically deficient urban sections in municipalities of from 1,000 to 35,000 population in each of the department's field divisions, were then arrayed in the descending order of their scores.

It was intended that the array would be broken at approximately equal intervals of the scoring scale to form 10 groups of varying deficiency status. However, the array revealed such a preponderance of sections in the lower end of the scale that it was evident that this grouping not only would assign few sections to the higher deficiency groups, but would make it difficult to discriminate in rating the sections in the lower brackets.

This difficulty was overcome by breaking the array into groups at progressively wider intervals in the scale as the score for inconvenienced vehicle-miles increased. The method and the resulting groups are shown in Table 5.

Sections in the groups formed in this way were assigned congestion rates 0 to 9 according to the indicated absence or degree of congestion. This procedure resulted in a more equal distribution of sections among the several deficiency rating groups, but it was something more than a mere arbitrary statistical device. It tended to give due weight to the critical significance of even small degrees of congestion in a period when traffic is increasing at the currently established rate.

The digit representing the congestion index was placed second in the deficiency index on the urban sections.

TABLE 5

CODE FOR VEHICLE-MILES INCONVENIENCED

Code	Vehicle-Miles Inconvenienced	Interval
0	None	
1	1 - 99	100
2	100 - 299	200
3	300 - 599	300
4	600 - 999	400
5	1,000 - 1,499	500
6	1,500 - 2,099	600
7	2,100 - 2,799	700
8	2,800 - 3,599	800
9	3,600 and over	

Route Characteristics

The lack of adequate urban accident records made it impossible to rate urban sections for safety by the method used for rural sections. Not only did the existing data indicate that reporting of the number of accidents was far from complete, but individual reports in many cases failed to locate the occurrence with even relative accuracy. A substitute was required and a factor called "route characteristics" was adopted.

TABLE 6

Feature	Deficiency Score
Traffic lanes	
7 foot	50
8 foot	40
9 foot	30
10 foot	20
11 foot	10
Bad curves	10
Offset in alignment	10
Right angle turns	10
Wandering alignment	10
Rural cross-section where urban cross-section is needed	50
Mainline railroad grade crossing	50
Restricted clearance, both horizontal and vertical	50

As a factor in priority determination, route characteristics include a number of dimensional features of the roadway cross-section and certain features of alignment and development. The deficiency scores adopted for these features are shown in Table 6.

The character of this factor as adopted, has a relationship with safety, but the relationship is not sufficiently close or direct to make route characteristics a completely satisfactory substitute. However, the factor as used also reflects conditions related to both facility of movement and adequacy of design and development, and so has real value as an indication of deficiency.

After scoring for route characteristics was completed, the sections in each field division were arranged in the descending order of their scores and divided into 10 groups, each group comprising sections of similar deficiency. The sections in the successive groups were given ratings for route characteristics ranging from 9 to 0, depending on the degree or absence of deficiency. This rating figure was then set in third place in the 3-place index of the sections priority index.

COUNTY	ROUTE	SECTION	SUB-SECTION	TERMINI OF SECTION	LOG MILES From	LOG MILES To	LENGTH	EXISTING LANES Number	EXISTING LANES Width	EXISTING LANES Shoulder Width	EXISTING LANES Surface Type	1955 AVERAGE DAILY TRAFFIC	PERCENT CAPACITY
Knox	1	2	3	Knoxville City Limits To The Grainger Co Line	30 55	36 34	5 79	2	11	4	A	3551	87
Knox	73	11	1	Knoxville City Limits To The Blount Co Line	0 37	5 81	5 44	2	11	4	A	7201	197
Scott	29	1	2	Morgan Co Line To Oneida City Limit	3 60	11 52	7 92	2	11	4	A	1810	101
Cocke	35	6	1	Newport City Limits To The Greene Co Line	2 85	11 67	11 82	2	9	6	B	1310	35

Match Line

RURAL STATE HIGHWAYS

Division 1
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PROPOSED IMPROVEMENTS Design Standard Number	PROPOSED IMPROVEMENTS Description Of Work	COST IN THOUSANDS OF DOLLARS Right-Of-Way	COST IN THOUSANDS OF DOLLARS Construction	COST IN THOUSANDS OF DOLLARS Total	COST IN THOUSANDS OF DOLLARS Vehicle Mile Per Year	PRIORITY Number	PRIORITY Class	PROGRAM YR	REMARKS
17	Widen & Resurface The Existing 2-Lanes And Build 2-New Parallel Lanes To Make 4-12' Lanes Divided With 10' Shoulders	165	1124	1289	0 22	514	3	3	
17	Widen & Resurface The Existing 2-Lanes And Build 2-New Parallel Lanes To Make 4-12' Lanes Divided With 10' Shoulders	225	1611	1836	0 15	158	2	283	Have A Survey But No Plans
12	7 10 Miles Of New Construction To 2-12' Lanes With 10' Shoulders With 2 40 Miles Of Truck Lanes	41	1664	1705	0 33	120	4	4	Section Shortened 0 82 Mi
8	New Construction To 2-12' Lanes With 8' Shoulders	169	1475	1644	0 29	711	1	3	

Figure 2. Priority listing.

COUNTY	ROUTE NO	SECTION NO	DESCRIPTION (Termini, Description Of Proposed Improvements And Design Standard)	PROJECT NO	LOG MILES From	LOG MILES To	LENGTH	PRIORITY CLASS
Knox	1	2	Beginning At The Jct Of FA S Rt No 2505 & Extending To The Grainger Co Line—Widen & Resurface The Existing Lanes & Build 2 Parallel Lanes To Make The Section 4-12' Lanes Divided With 10' Shoulders		30.55	36.34	5.79	3
Knox	73	11	Beginning At The Knoxville City Limits & Extending To The Blount Co Line—Widen & Resurface The Existing Lanes & Build 2 Parallel Lanes To Make The Section 4-12' Lanes Divided With 10' Shoulders		0.37	5.81	5.44	2
Scott	29	1	Beginning At Elgin & Extending To A Point 8.05 Miles South Of Oneida City Limits—7.10 Miles Of New Construction On New Location To 2-12' Lanes With 10' Shoulders Including 2.40 Miles Of Truck Lanes		3.60	11.52	7.92	4
Cocke	35	6	Beginning At The Newport City Limits & Extending To The Greene Co Line—Existing 2-9' Lanes With 6' Shoulders To Be Constructed New To 2-12' Lanes With 8' Shoulders		2.85	14.67	11.82	1

RURAL STATE HIGHWAYS

Division 1
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ESTIMATED COST IN THOUSANDS OF DOLLARS													REMARKS
PROJECT ESTIMATE			1957-58		1958-59		1959-60		1960-61		1961-62		
R/W	Constr	Total	R/W	Constr	R/W	Constr	R/W	Constr	R/W	Constr	R/W	Constr	
165	1124	1289					165	1124					
225	1611	1836			225			1611					
41	1664	1705							41	1664			
169	1475	1644					169	1475					No Survey Or Design Data Available

Figure 3. Program schedule.

DETERMINATION OF PRIORITIES

When the rating process was complete, the urban sections in each field division were put through a procedure of arrays similar to that employed in determining priorities among the rural sections, but with certain differences dictated by the character of the factors used.

It was decided that congestion should control the initial selection for priority determination. Consequently, the first array consisted of sections with congestion ratings of 9, 8, 7, 6, and 5, grouped in that order. Each group was then further arrayed according to its condition rating and, then, according to its route characteristics rating.

Next, all remaining sections rated 9 for condition were arrayed according to their rating for congestion and route characteristics. All these sections were then put aside in this order as those having the highest priority. Since rating for condition was 9 or 0, this array completed processing of all sections in which this factor was deficient.

The next array consisted of all remaining sections with ratings for route characteristics of 9, 8, 7 and 6, arranged in that order. These groups were then further arrayed according to their congestion ratings, and were then added to the sections already arrayed.

The final array consisted of all remaining sections with congestion ratings of 4, 3, 2 and 1. So arranged, they were further arrayed in order of their route characteristic ratings. As with rural sections, urban sections which were planned for construction where there was no existing street, were marked 0-0-0, but sections where only the surface was needed to complete their stage construction were given a special 9-0-0 index. This completed the determination of priorities among the urban sections.

Treatment of Bridges

No satisfactory method was developed to include deficient bridges in the rating procedures for rural or urban roadway sections. Structurally deficient bridges are not related to structurally deficient roadway sections, nor do narrow bridges affect operating speeds seriously over roadway sections of significant length. The hazards of narrow bridges would be reflected in the safety index to the extent they caused accidents in 1955.

Deficient bridges were not entirely ignored. The highway department has had underway for several years a program for widening short span, narrow bridges and is eliminating this hazard. In the programming process described below, small deficient bridges were taken into account in scheduling improvement of roadway sections, and larger bridges seriously deficient structurally were scheduled for early replacement as separate bridge projects.

Priority Lists and Formulation of Program

Throughout the process of priority determination, the rural and urban sections with critical deficiencies were treated separately and this separation was continued through the final operation of forming the programs. Priority lists by routes, were made of the rated rural sections, one for each highway subdivision in each field division. Similar lists of the rated urban sections were made for each field division. Each of these lists served as the basis for setting up a 5-year construction program.

This separate treatment of rural and urban deficiencies and programs was made necessary by the differences between the services demanded of the roadways, the problems involved in construction, and the funds available for highway improvement in the two areas.

The 5-year programs to correct the critical deficiencies on the rural and urban routes of the state highway system were formulated from the priority lists. These lists provided the raw materials from which the programs were built; the materials were carefully selected but they had to be tested to assure a sound and practical program structure.

CHECKING PRIORITY LISTS

As a necessary preliminary to program building, the lists of priorities were taken to the field division offices for checking. There, each list was inspected by the staff engineers most familiar with the conditions involved.

Particular attention was given to instances where stopgap or other construction completed since the needs study appraisal had changed the deficiency status of a section. Also checked were cases where there had been unexpectedly rapid deterioration of surface or other roadway elements. The priority lists were revised accordingly.

In addition, the experience, judgment and special knowledge of the division engineers were called upon to check the practical validity of the results of the priority rating. They sometimes were cognizant of road conditions and traffic usage not included in the needs study data, which had a bearing on the priority rating. They also were familiar with such operational factors as the progress and time requirements of plan preparation and right-of-way procurement which affect the sequence in which projects can be undertaken.

THE PROGRAMMING PROCEDURE

Actual formulation of the construction programs is based on the fiscal realities of the situation. The amount of construction that could be programmed in each field division was limited by the amount of funds that would be available there during the program period. The initial step was the apportionment of estimated funds available during the next five years to the four field divisions according to their proportion of the total needs reported by the highway needs study.

The amount that could be programmed for any highway subdivision in a division depended on the funds which had been allotted to that subdivision from the field division's apportioned share of the department's income. This allotment also had been made on the basis of needs as indicated by the study.

The amount that could be programmed for each year of the 5-year program was determined by the proportion of the total approtioned funds which would be available in that year. Finally, since carrying through the construction of the Tennessee routes of the National System of Interstate and Defense Highways was considered of highest importance, estimated annual expenditures for this purpose were set aside in the field divisions where such routes were located.

Within the limits established by these several apportionments and allotments of available construction funds, the actual formulation of the 5-year programs was accomplished. The program for each highway subdivision was set up for the successive years by selecting sections from the upper ranges of the priority list for that highway subdivision.

Ordinarily, the stage construction situations, carrying an index of 5-0-0 in rural sections and 9-0-0 in urban sections, were given first consideration since completion of such projects would provide full benefits to traffic. Next, the sections indexed 0-0-0, representing projected new routes were considered because these usually represented correction of serious traffic conditions. Where construction would provide significant relief, these sections were selected for the program.

Selection of other sections proceeded, the sections being taken up in the order of their priorities but with careful consideration for several factors which have basic importance in the practical operation of a construction program.

Reference was made constantly to the estimated cost of the proposed project per vehicle-mile of annual traffic which had been computed for each of the critically deficient sections. Sections with excessively high cost per vehicle mile frequently were in difficult terrain with poor alignment and geometrics and carried low traffic volumes. Where there was little prospect that traffic would increase materially after a complete improvement, the complete improvement was deferred beyond the 5-year program. Such sections will serve their low volume traffic by stop-gap improvements, such as resurfacing and minor widening and alignment corrections.

Interference with traffic movement which would result from construction operations on adjacent or parallel routes was studied. Availability of contractor services, forces, and equipment in different areas of the state was considered, and so were such items as the status of surveys, plans and right-of-way.

Programming construction on the urban highway sections was influenced by most of these factors. There were limits to the funds available for projects in municipalities and, where additional or new right-of-way was required, the costs and time required for its procurement usually were greater than on rural sections. The need or the desirability to program work on an urban section at the same time as on the rural sections with which it connected had to be weighed.

All these factors were considered by the program study staff in its initial operations, and they were given further attention and study in several conferences with the engineering and administrative officers of the department. In these meetings, such matters as joint state-city improvement agreements to which department funds had been committed and other practical considerations, were discussed and, where necessary, the programs were revised.

The programs as completed and as adopted by the Tennessee Highway Department, conform with the priorities established in this study, modified only by the limitations of funds available and by the requirements of engineering and construction operation.

This 5-year construction program does not provide for the correction of all the critical deficiencies now existing, the funds available for the program did not permit such complete correction. However, the deficiencies left uncorrected are the least critical.

A process must be devised and adopted which will provide not only for correction of the remaining existing deficiencies, but for identifying and remedying future deficiencies as they occur and for the development of the system with the increasing demands for its services.

As a sequel to the present programming study, the same study staff is engaged in a research project to determine principles, criteria, and data required for a continuing construction program and to formulate the procedures essential for establishing such planning as a routine function of the department. This task has not yet progressed to a point where results can be reported.

REFERENCES

1. Schroeder, Walter R., "A Suggested Congestion Rating for Urban Highways," Institute of Transportation and Traffic Engineering, University of California.