whereas scattered trips tend only to raise the general "contour" level "Peaks" on the chart represent business and industrial centers on which traffic converges. The more I have studied the chart, the more I have felt that important trip movements could not be missed or misinterpreted through its use, though experience is not yet at hand to demonstrate conclusively that it gives a complete and accurate picture of the desired directional traffic flow

The mechanical procedure for producing the chart is, I believe, somewhat complex and perhaps beyond the present abilities of those organizations that do not have available rather extensive tabulating equipment and skilled tabulating personnel However, if it does, indeed, present a simple and accurate picture of the extremely complex trip movements in a large metropolitan area, as regards desired directional flow, the chart is worth the effort required to prepare it and constitutes an important contribution to the analysis and presentation of urban origin and destination data. In any event, California is to be congratulated for their extensive and productive research in the field of trip analysis procedures.

# A RURAL HIGHWAY CONGESTION INDEX AND ITS APPLICATION

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## SYNOPSIS

The manual on highway capacity, recently completed by the Highway Research Board Committee on Highway Capacity, provides highway planners with an invaluable tool in the design of highway improvements. Its release will undoubtedly bring into even sharper focus the basic relationship between traffic volume and highway capacity.

This paper presents a simple method of rating a rural trunk highway system on the basis of its traffic carrying capacity. The congestion index is defined as a mathematical rating of highway capacity derived from the ratio of existing design hour traffic volumes to the practical hourly capacity of a rural highway system.

The development of the congestion index requires the following items of basic data

1. Fairly exact information concerning the relationship of the 30th highest hour in the year to the annual daily average traffic for a highway system.
2. Complete data on continuous restricted sights.
3 Detailed information as to the geometric design features of the complete rural highway system.

The practical application of a congestion index is not yet clearly defined. It is apparent that such an index provides a means of relating rural highway congestion to accident rate It also appears that the index can be valuable as an additional guide in the programming of projects for improvement. Its application in this respect may well be twofold; first, to assist in program development and, second, to assist in establishing priority of improvement within a program The application of the congestion index to design problems is at this stage more apparent. A low congestion rating indicates satisfactory geometric design. If improvements are required on routes of this character, they are dictated by other factors The low congestion index should be valuable in preventing overdesign Those sections of a rural highway system showing a high congestion index must, in their redesign, provide additional traffic carrying capacity. The extent to which a new design must provide such capacity can be accurately measured through the application of the principles involved in the calculation of a congestion index

This paper is a progress report It is evident that a great deal of additional work will be required, both to refine the methods of computation and to clarify the application of such an index.

For many years we have followed with great interest the work of many able research men on the general subject of highway capacity. The keen interest in this work stemmed, of course, from a realization that traffic information in a general way, whether applied to rural highway sections or to urban traffic arteries, was limited in value unless it could be applied to geometric design features. As a matter of fact, lack of such information seriously impaired the value of the mass of general traffic information which had been assembled by highway planning surveys in the several states, as well as by other agencies throughout the nation.

Little need be said here concerning the work of the Highway Research Board Committee on Highway Capacity, under the able chairmanship of Mr. O. K. Normann, in assembling and reporting on the research carried on throughout the years on the subject of highway capacity. In an effort to apply the result of this research, we decided to embark on an investigation which had, as its purpose, an attempt to develop a feasible method of measuring the relative adequacy of any given highway section or sections as traffic carrying facilities. The index, which we ultimately arrived at and which is summarized herein, is defined as a mathematical rating of highway capacity derived from the ratio of existing design hour traffic volumes to the practical hourly capacity of the highway section under consideration.

### SCOPE OF THE STUDY

In the early stages of the study, attention was given to Minnesota's 695 mi. of interstate routes. As the investigation progressed, additional mileage was added until a final study total, involving some 1,265 mi., was reached. The final selection was necessarily governed by the availability of sight distance profiles plotted from the recently completed critical features reinventory in the State of Minnesota

### NECESSARY BASIC DATA IS A STUDY PREREQUISITE

Before embarking on a study of this sort, it was determined that certain items of basic information would be required. They are listed briefly as follows:

1. Fairly exact information concerning the relationship of design hour traffic to annual daily average traffic for each segment of the study mileage. This was derived from fixed type automatic traffic recorder records by grouping those routes of generally similar characteristics and establishing the 30th highest hour to annual daily average relationship from the one or more recorders located on highways of those types. Studies of highway capacity reveal the effect of commercial vehicles on the capacity of a traffic lane. In Minnesota, investigation of the peak hour weekday traffic indicated that in no instance did that traffic, with allowance made for the effect of commercial vehicles, equal the 30th peak hour traffic during the year. Consequently, it was decided to accept the design hour traffic values as determined from the fixed type automatic traffic recorder records without adjustment as the percentage of commercial vehicles during that hour was negligible.

2. Complete data on continuous restricted sights which were obtained from profiles plotted from the Critical Features Survey.

3. Detailed and accurate information as to the geometric design features of study sections. This was obtained from plan sheets, from physical inventory records or from both In many instances, heavy maintenance operations over the years had all but obliterated the design as shown on the original plan. The need for a careful scrutiny of all records dealing with actual roadway features is emphasized.

### GENERAL DETERMINATIONS NECESSARY TO THE CALCULATION OF A CONGESTION INDEX

The mechanics of congestion index calculation required three fundamental determinations.

1. A division of the total study mileage into basic sections.
2 A determination of the design speed for each basic section.
3. A determination of practical hourly capacity for each basic section

The criteria which govern the basic section length are fairly general in character The study section should be rural for its entire length since no attempt is made to calculate a congestion index within urban areas. It is deemed possible, however, to include sections of highway through very small incorporated areas or fringing large incorporated places where the effect of purely local traffic is not appreciable and the highway remains fairly general in its rural characteristics A basic study section should further generally terminate wherever the surface width changes or the shoulder width becomes less than the 6-ft minimum If there is no change in surface width or other controlling features, the terminus of the section should be at major trunk highway intersections or the corporate or urban limits of cities

The design speed of the basic section was calculated using the formula developed by Mr Joseph Barnett of the Bureau of Public Roads and contained in the handbook "Transition Curves for Highways." The American Association of State Highway Officials policy manual was used for sight distance design speed values.

Practical hourly capacities for each study section were based on an analysis of sight distance profiles, as plotted from our Critical Features Survey, and known basic physical characteristics of the study section. These capacities were calculated using relationships found in the various tables contained in the "Highway Capacity Manual," which will be shown later In the calculation of practical hourly capacities we were aware of the effect of the frequent occurrence of narrow bridges on study section capacities It was realized that narrow bridges do definitely affect traffic capacities but, at the time this work was proceeding, no means of measuring the length of this effect were available The recently released "Highway Capacity Manual," however, does provide such information We will necessarily be forced to study the effect of these bridges on the congestion index.

Other factors which affect the practical capacity of a section are found on those portions of highway routes immediately adjacent to the limits of large urban areas. As mentioned in earlier discussion of basic study section lengths, these factors made necessary the elimination of those mileages from the study. Important intersections are also subjected to other influences, such as, turning movements, traffic control devices and diagonal sight restrictions, usually sign boards, which materially affect the degree of congestion In addition, as the limits of large urban areas are approached, local traffic, having very short trip characteristics and entering at frequent access points, increases the hourly volume to the extent that the 30th or design hour on these short approach sections is usually far higher than on the more strictly rural highway sections.

In order that there would be some common denominator for the several study sections into which our basic mileage was ultimately divided, we established an average operating speed of 45 mph This particular speed was chosen because studies reveal that on unrestricted rural highway sections the majority of vehicle operators apparently do not consider the rural highway congested if they are able to maintain this average operating speed

## THE DETAILED PROCEDURE INVOLVED IN CALCULATING THE CONGESTION INDEX

The procedure for calculating the index, which was finally evolved and found most workable, is as follows:

*Step 1.* Determine basic section lengths for the study mileage

It was found most convenient to establish the basic section length for each numbered route involved in the study All or a part of 14 trunk routes were involved in the total study mileage and basic lengths were established for each route using the criteria previously outlined.

*Step 2.* Determine the design speed for each basic section

For many years in Minnesota it has been the policy to design rural highway sections for an overall speed of 50 or 60 mph. In calculating the design speed for the basic study section, it is necessary to determine whether the overall design speed of the section is either 50 or 60 mph. The design speed of each section is based on Figures 1 and 2[1] In some cases determination of the design speed of the section requires some degree of personal judgment. Where conditions of topography and alignment indicate a change in design speed, the study section is broken.

*Step. 3* Measure the length of roadway in each section having less than 1500-ft. continuous sight distance.

Traffic behavior studies reveal that passing

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[1] Abstracted from publications "Transition Curves for Highways" and "A Policy on Sight Distance"—AASHO

maneuvers are generally not attempted when the passing sight distance is less than 1500 ft. The mileage falling in this category was measured for each study section from the continuous sight distance profile so that the percent of restriction could be computed. To more clearly illustrate this step, a segment of continuous sight distance profile is shown on Figure 3.

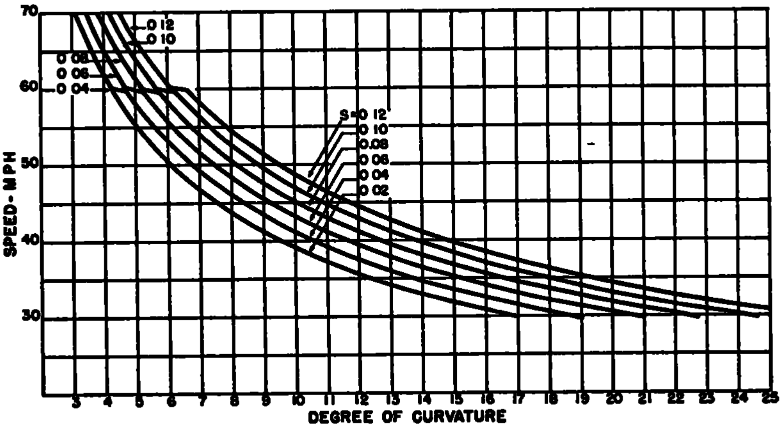


**Figure 1. Design Speeds for Curves**

$$V = \frac{(F + S)}{0.067} R$$

$F$ = 0.16 30–60 MPH
$F$ = 0.14 70–70 MPH
$V$ = Speed, MPH
$R$ = Radius of Curve
$S$ = Superelevation, Ft. per Ft.

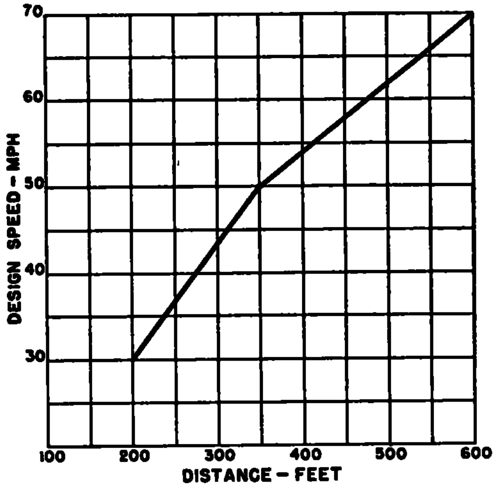


**Figure 2. Minimum Non-passing Sight Distances**

*Step 4.* First calculation of the practical operating capacity of each basic section based on sight restrictions and design speed.

The curves illustrated on Figure 4 indicate the relationship of traffic capacity to passing sight distance restrictions for the majority of main highways, based on an average operating speed of 45 mph For example, on a section having a design speed of 60 mph with a 40 percent sight restriction, practical capacity is reduced to 546 vehicles per hr.

*Step 5.* Final determination of the practical operating capacity for the study sections based on the effect of lateral clearance and roadway width

Final determination of the practical operating capacity for each study section was made from tables contained in the "Highway Capacity Manual," which provide a definite measure of the effect of restricted lateral clearances and lane widths Table 1 indicates the effect of restricted lateral clearances It reveals that a 20-ft. roadway with a 4-ft lateral clearance

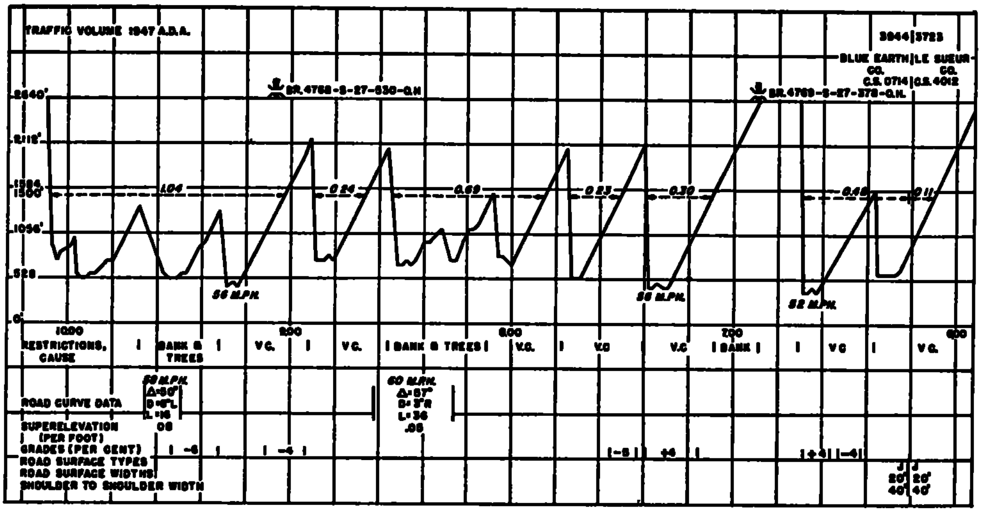


**Figure 3. Sample Sight Distance Profile—TH 169 between N. Junction TH 14 and N. Blue Earth County Line**

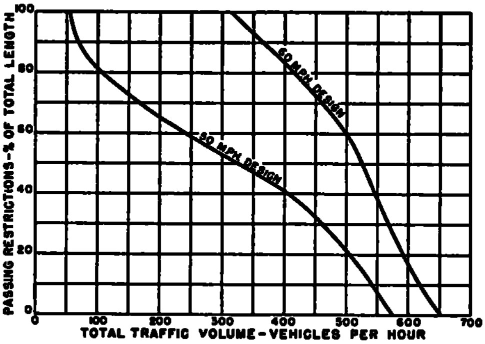


**Figure 4. Relation of Traffic Capacity to Passing Sight Distance Restrictions for the Majority of Existing Main Highways Assuming a Desirable Average Operating Speed of 45 MPH**

TABLE 1

| Clearance from Pavement | Effective Width of Two 12-Ft. Traffic Lanes |
|---|---|
| *Feet* | *Feet* |
| 6 | 24 |
| 4 | 23 |
| 2 | 21 |
| 0 | 18 |

is reduced to an effective roadway width of 19 ft.

The next step consisted of determining the effect of roadway width on practical capacity. That determination is made from Table 2.

TABLE 2

| Lane Width | Practical Capacity Percent of 12-Ft Lane Capacity |
|---|---|
| *Feet* | % |
| 12 | 100 |
| 11 | 86 |
| 10 | 77 |
| 9 | 70 |

From this table it is readily determined that an effective width of 19 ft has but 73.5 percent the capacity of the 24-ft roadway. This percentage is then applied to the practical capacity of 546 vehicles per hr., which results in a final practical capacity for the sample section of 401 vehicles per hr.

The study section used for illustrative purposes carried an annual daily traffic volume of 2,571 vehicles. Automatic traffic recorders located on this section indicate that the 30th highest hour is 12.7 percent of the annual daily average or 326 vehicles The congestion index is quite simply calculated by dividing the design hour traffic volume by the calculated practical hourly capacity. In the case of the illustrative section, the congestion index was determined to be 81, i e $\frac{326}{401}$

### LISTING AND SUMMARIZATION OF INDEX DATA

Indices similar to the above were computed for the several sections on the 1,265 mi. of highway covered by the study and listed together with other supplementary data, such as, control section number, year of construction and number of accidents. These sections were then combined into composite sections for each of which a weighted index was computed. The composite section represented lengths which appeared logical from the standpoint of driver behavior and reaction and generally extended between cities or important highway intersections.

### CORRELATION WITH ACCIDENT DATA

The relationship between highway accidents and highway congestion has been the subject of considerable discussion for many years. Consequently, an attempt was made to relate the index, which is a measure of congestion, to accident rate in an effort to determine whether there existed any reasonable correlation.

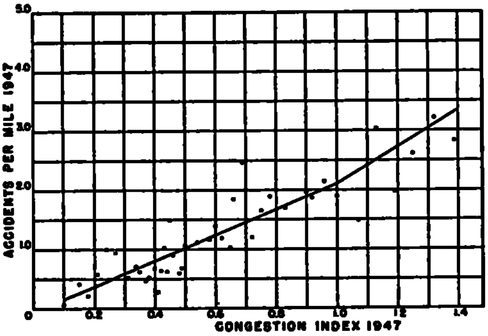


**Figure 5. Relation between Congestion Index and Accident Rate**

The indices for all study sections were listed in descending order, together with the mileage and the number of accidents. The listed mileage was then divided into 25-mi. increments and the average index computed for each increment. The number of accidents per mile for each increment was next computed. The results appear on Figure 5. The trend line on this chart indicates a straight line relationship between the congestion index and accidents up to about 1.0, at which point the rate of slope increased uniformly to about 1.4 At this point the slope leveled off and remained fairly constant. Not a great many congestion indices above 1.4 were found so the data above this point are questionable.

On the basis of the rather limited data the chart indicates that the accident ratio accelerates above 1.0. Thus it appears that a congestion index of 1.0, in addition to indicating the point of near intolerable congestion, also indicates the point at which the accident rate may be expected to rise.

An attempt was also made to relate the congestion index to maintenance costs by the several maintenance items and in total, but no correlation was found.

### APPLICATION OF THE CONGESTION INDEX TO PROGRAMMING AND DESIGN

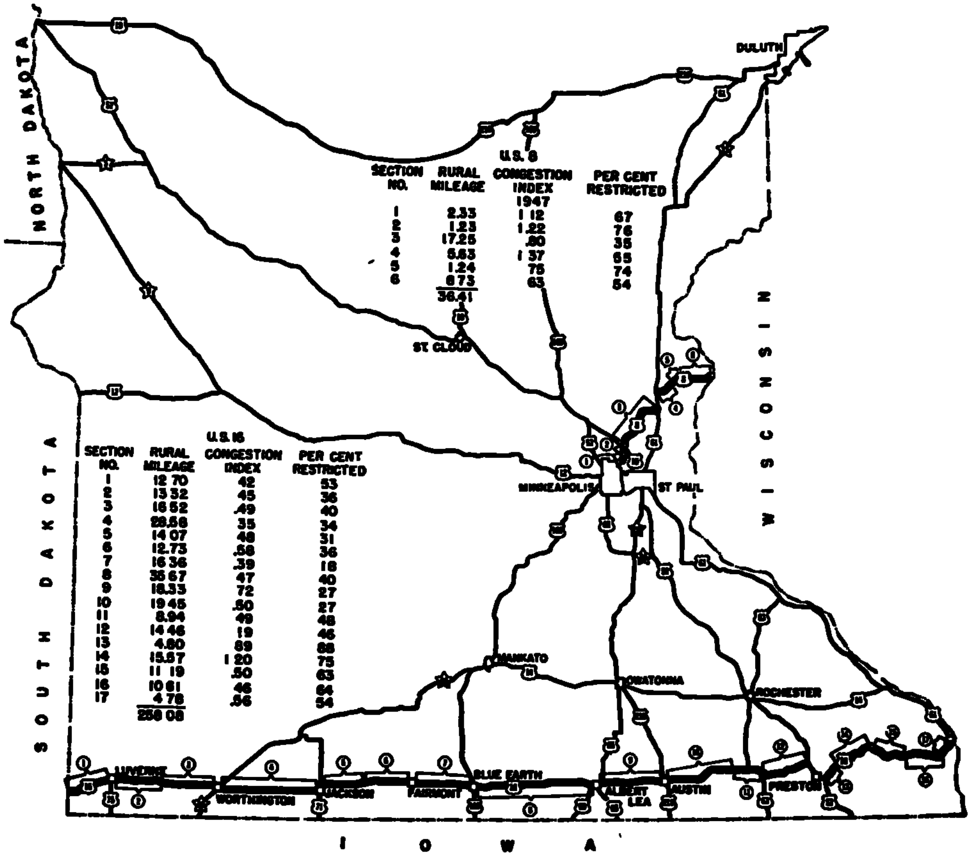
*The Congestion Index and Programming of Projects*—In considering the application of the congestion index to programming, several observations with respect to the perplexing problem which confronts every highway administrator are necessary. It is folly to assume that the calculation of a congestion index is in itself a complete and adequate reflection of projects qualifying for program inclusion. There are many factors which should be considered in programming highway projects for improvement, which have little relationship to the traffic capacity of the various sections of the rural highway system Physical obsolescence of a highway so severe that it has a definite effect on the economic life of a community or an area, even though involving routes of low traffic volume, must be considered. Need for construction improvements aimed at a reduction in extremely high maintenance costs is another factor which must be given consideration.

It does appear, however, that reference to the congestion index for any highway section will serve to provide an additional guide in both the determination of those projects which should be programmed and in establishing their priority for improvement.

A study of the congestion indices for each basic section listed by route should be of value in directing attention to isolated sections having an extremely high congestion index A detailed study of the characteristics of these isolated sections may reveal that fairly simple corrective measures can materially increase the traffic capacity of the entire composite highway section

To more graphically illustrate the use of congestion indices in this general way, Figure 6 presents two trunk routes in Minnesota The first is US 16 which crosses the state in a general east-west direction near the south state line This route has been divided into composite sections and congestion indices calculated for each section. The sections are identified on Figure 6 and information for each section setting forth section length, congestion index and percent restricted sight appears on a tabulation inserted in the figure. It is pointed out that only two sections on this entire route had a congestion index which approaches the critical point Section 13, 4.8 miles in length, lying in the easterly sector of the route, shows a congestion index of .89. The next contiguous section (No 14), 15.57 mi. in length, shows a congestion index of 1.2. US 16 is generally 20-ft. concrete pavement except for a portion of the route near the easterly end which is approximately 24-ft. bituminous surface

The two sections showing relatively high congestion indices follow a river valley. There are a considerable number of horizontal curves and some vertical curvature. The table insert in Figure 6 reveals that section 13 has an 88 percent sight restriction, whereas section 14 has a 75 percent sight restriction. It appears that US 16 is adequate as a traffic carrying facility over its entire length with the exception of these two sections. The congestion index thus reveals that if corrective measures are taken with respect to sections 13 and 14, the entire route will provide suitable and adequate traffic service for a considerable time to come.



U.S. 8

| SECTION NO. | RURAL MILEAGE | CONGESTION INDEX 1947 | PER CENT RESTRICTED |
|---|---|---|---|
| 1 | 2.33 | 1 12 | 67 |
| 2 | 1.23 | 1.22 | 76 |
| 3 | 17.25 | .80 | 35 |
| 4 | 5.63 | 1 37 | 65 |
| 5 | 1.24 | 75 | 74 |
| 6 | 8 73 | 63 | 54 |
|  | 36.41 |  |  |

U.S. 16

| SECTION NO. | RURAL MILEAGE | CONGESTION INDEX | PER CENT RESTRICTED |
|---|---|---|---|
| 1 | 12 70 | 42 | 53 |
| 2 | 13 32 | 45 | 36 |
| 3 | 16 52 | .49 | 40 |
| 4 | 28.58 | 35 | 34 |
| 5 | 14 07 | 48 | 31 |
| 6 | 12.73 | .58 | 36 |
| 7 | 16 36 | .39 | 18 |
| 8 | 35 67 | 47 | 40 |
| 9 | 18.33 | 72 | 27 |
| 10 | 19 45 | .50 | 27 |
| 11 | 8.94 | 49 | 48 |
| 12 | 14 46 | 19 | 46 |
| 13 | 4.80 | 89 | 88 |
| 14 | 15.57 | 1 20 | 75 |
| 15 | 11 19 | .50 | 63 |
| 16 | 10 61 | 46 | 64 |
| 17 | 4 78 | .56 | 54 |
|  | 258 08 |  |  |

Figure 6. Illustration of Congestion Index Application

The second route illustrated on Figure 6 is US 8 which extends from the city of Minneapolis in a general northeasterly direction to the Minnesota-Wisconsin interstate line. The first four sections reveal high congestion indices. Sections 5 and 6 do not appear to present any particular problem from a traffic service standpoint Sections 1, 2 and 3 are of three lane concrete pavement, 27 ft. in width. Section 4 is an 18-ft concrete pavement as are sections 5 and 6 It is obvious from a scrutiny of the congestion indices for this route that three of the first four sections have reached a point of intolerable traffic congestion and will require corrective measures within a reasonably short time. Sections 5 and 6, while not indicating severe congestion, must be rebuilt within a reasonable period of time due to physical obsolescence

*Application of Congestion Index to Design*—It appears reasonable to conclude that a highway section which does not presently or will not, through normal traffic increase, reach a congestion index of 1.0 is adequate to serve present and future traffic from a design standpoint. If improvement is indicated it is dictated rather by conditions of physical obsolescence or high maintenance costs. The existing geometric design with respect to general roadway alignment and width appears adequate to serve traffic The significance of the low congestion index lies in the fact that it may be of material value in assisting to prevent over-design.

In those instances where highway sections show a present congestion index of 1.0 or will reach that point within a reasonable time, given normal traffic increase, reference to the congestion index should serve as a guide to a design section in determining whether a planned improvement is adequate to serve present and probable future traffic needs.

## CONCLUSION

This discussion of preliminary conclusions has been necessarily rather broad. The congestion index should not yet be accepted at its face value. It is our opinion that a great deal more work should be done. There may be weaknesses in the methods set forth here which further study will reveal so that the general idea, which prompted the development of the congestion index, will eventually result in a useful tool for the highway administrator in meeting his ever present problem of highway improvements.

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# A SEGMENTED ELECTRICAL ELEMENT FOR DETECTING VEHICULAR TRAFFIC

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## SYNOPSIS

Most vehicle detecting mechanisms or systems in use today have a serious limitation in that they cannot accurately determine the transverse location of a vehicle. This deficiency is serious inasmuch as many important traffic problems cannot be properly studied or satisfactorily solved to the exclusion of data on lane traffic patterns and transverse placement. To facilitate the study of such problems, the Institute of Transportation and Traffic Engineering of the University of California initiated a research program to develop a more universally applicable detecting unit In addition to sensitivity to transverse placement, other important design criteria included inexpensive manufacture, inexpensive installation and maintenance, portability, rugged construction for field use, reliability of operation, concealment from the driver, and weather resistant qualities. The detecting unit which was designed is believed to embody the various qualities specified.

The detector is of the so-called metallic contact type in which two metallic elements, normally held open by some form of a spacer, are closed by a wheel passing over them In this design, the bottom contact extends throughout the entire length of the unit and serves as a common contact for all the circuits The top contact is made up of one-foot metal segments which, together with the common bottom contact, constitute the elements for the individual circuits Lead wires are attached to each segment so that, with appropriate jumper connections,