Urban Congestion Index Principles

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What is "congestion"?

Webster says: "overcrowded state; as congestion of traffic."

Webster also gives, as an obsolete meaning, "a gathering or accumulation; a heap."

It would appear that this so-called obsolete definition: "a gathering or accumulation; a heap", may not be so obsolete as the dictionary would lead us to believe, for it certainly is an apt description of many of today's traffic conditions and serves as well, or better, than the definition given as preferred.

The motoring public is extremely sensitive to congestion, but it does not have a real recognition of the causes and intensity of this congestion. Indeed, as judges of the degree of congestion and its consequences, motorists generally seriously overestimate its evils, which are bad enough in reality without exaggeration. Many drivers have said, for instance, of some particular experience with congestion: "Why, I had to wait 20 minutes" (this seems to be a popular standard), "I had to wait 20 minutes to go through a traffic light," when actual measurements proved them wrong. There are many illustrations available to show this proneness of the vehicle user to exaggerate his sufferings from congestion. Subjective evaluations are thus shown to be deficient in value. What is needed is a few objective measurements.

Highway engineers know, in a general way, what traffic congestion is, especially in its aggravated or extreme cases, and are principally concerned about some method of measuring congestion objectively so they may prescribe a cure for its evils; they are handicapped, however, because there is no generally accepted method of measurement and evaluation.

USES OF A CONGESTION INDEX

Such a measurement, if it were expressed as an index figure, would be valuable for many purposes: (1) It would provide a means of comparing the congestion existing in one place with the congestion existing in another place, whether a spot, a section of highway, or an area. (2) It would provide a measurement of trends in congestion for any subject of study, whether one facility or an area. (3) It would provide a useful tool for forecasting induced traffic, which is dependent upon population density as related to street adequacy. A congestion index of an area may provide a guide for measuring the traffic potential. One will readily assent that induced traffic will be greater in an urban area where streets may carry design capacity during the whole working day, than in rural areas where a highway reaches or exceeds design capacity for only 30 hours out of the year. (4) It would aid in setting up priorities for remedial expenditures. Thus it would do for urban highways what the so-called sufficiency ratings are supposed to do for rural highways. The currently used methods of establishing sufficiency ratings have not been found readily adaptable for urban streets, hence the practical importance to engineers of a congestion index as a companion of the sufficiency rating.

SOME CHARACTERISTICS OF CONGESTION

If we start with a premise that traffic congestion is an absence of complete freedom of movement of the vehicles of which the traffic stream is composed, along the prescribed or permissible paths of movement, then we may adopt as a corollary the statement that congestion actually begins whenever there is any impedance to such free movement, however slight. It must be recognized that congestion is not something which occurs suddenly to its fullest extent. It begins whenever there is any restriction of the freedom of drivers to choose their own speeds, spacing, and direction of movement. It is a gradual and compounding process, increasing (probably geometrically) in extent and severity as traffic volumes increase beyond the practical capacities of the facility. Congestion is not found to exist in the same degree at all times or places. During the 24 hours of the day it may occur only during a single hour, or for a few hours, as during the peak hours of traffic density. Or it may occur in greater or less degree at different times of the day.

Congestion may range in degree of severity over a wide variation between the limits of the minimum — which is the smallest distinguishable slowdown of traffic — and a maximum — which is a complete stoppage of all movement. Complete stoppage may not occur frequently or in many cases, except possibly at intersections that are governed by traffic signals or other such controls. It probably will not hold for extended periods, but it should be accounted for in any analysis and be included proportionally as a part of the average of maxima and minima of any given period in which it occurs.

Another characteristic of congestion is that it does not actually occur in the same degree at all points along any given section of a facility. Although the effects of congestion may be seen at various points along a so-called congested section, evidenced by stalled or slow-moving traffic, the impedance causing this congestion may be at another point some distance away. If the impedance could be removed it might be found that the effect of congestion over the section or the entire route would disappear, or diminish to a lesser degree, so that an entirely new evaluation would be necessary to determine the index for the changed situation.

SOME FUNDAMENTALS

In the search for a method of appraising congestion and determining its degree or intensity, undoubtedly some expression of the two elementary functions of the traffic capacity of the facility — time and space — should enter into the basis of measurement as they are reflected in densities of traffic, volumes of traffic, traveling times, or other characteristics of traffic movement.

A measurement of these characteristics and what influences them on any congested facility and a comparison of one or all of them with the theoretical optimum of each as it would be under conditions of the practical capacity of the facility — somewhere in this area probably will be found an index of the congestion.

Definitions of some of the terms as they are used here should be introduced at this point for the sake of clarity.

Density. The number of vehicles per mile on the traveled roadway at a given instant.

Volume. The number of vehicles passing a given point during a specified period of time.

Possible capacity. The maximum number of vehicles that can pass a given point on a lane of roadway during one hour under the prevailing roadway and traffic conditions.

Practical capacity. The maximum number of vehicles that can pass a given point on a lane of roadway during one hour under the prevailing roadway and traffic conditions, without unreasonable delay or restriction to the driver's freedom to maneuver.

Design capacity. The practical capacity or lesser value determined for use in designing the highway to accommodate the design volume.

OPERATIONAL-CHARACTERISTICS CONCEPT

One approach to the development of an index may be called the Operational-characteristics concept. This would entail the measurements of speeds, delays, and overall traveling times. Speed is a function of distance, which is fixed for any one facility; and time, which is influenced by volumes, geometrics, controls, and regulations; and possibly other factors.

That there is a relation between traffic volumes and travel time has been discovered in many time-delay studies. For an example, reference is made to Figures 1 and 2, which are charts of the results of a study made in Charleston sometime ago, of which a graph of the hourly traffic volumes, expressed as a percentage of the 24-hour total, is practically paralleled by a graph of the average time of travel over the course expressed in minutes.

The values for the two lines are not measured by the same basic units, one being in time and the other in percentages, but the similarity between the lines is striking, indicating that the possibilities of using this method for developing an index should be studied further on new series of tests, in which the time of travel, as well

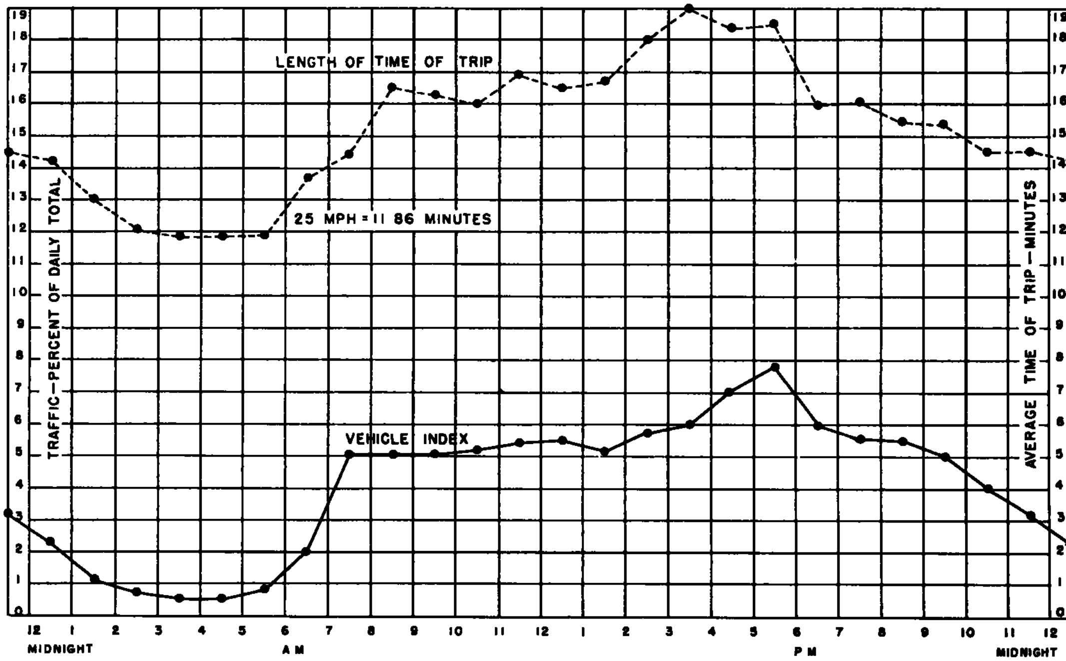

Figure 1. Time of average trip in minutes compared to traffic density on Washington Street from Patrick Street Bridge to Kanawha City Bridge, Charleston, West Virginia, 1944.

as volumes, is converted into a percentage base.

LIMITATIONS ON THE OPERATIONAL-CHARACTERISTICS CONCEPT

There is a fault in this approach lying in the probability that in running a time-delay study over the length of a course considered as a single unit, delays may be found only in some sections of it, or at some points in variable degree, such as at intersections; so that other sections, which may of themselves actually be free of any impedances (except for a backlog of stalled traffic) are charged, as it were, with the congestion caused by impedances in other sections or at other points. This is a characteristic which was previously mentioned.

To avoid this occurrence it is probable the course should be divided by frequent check points into shorter sections. As the intersections are generally recognized as the principal points of maximum impedance, it would appear logical to consider each block between intersections as an independent unit or subunit for analysis of delays.

The compounding characteristic of congestion may still persist, even in these smaller units, from the accumulation of an overflow between units as found in delays still being recorded in or for one block, or unit of section, actually being caused by slow traffic or other consequences of an impedance occurring ahead at some point in another unit. Under such circumstances to ascribe the congestion to an impedance in the subsection where the delay is recorded would still give a false index.

Probably one way of eliminating this error would be to try to record the delays, or slowdowns from the desired speed, by observed causes. An attempt at this method was used in a series of time-delay studies made at Clarksburg, West Virginia, where the potential causes of slowdowns or stops were listed and given a code number designation which was recorded, along with the duration of slowdowns where they occurred, as follows:

The locations were coded to show locations either at: (1) intersections, (2) between intersections, or (3) general slowdowns.

The causes were coded to show delays caused by: (1) traffic signals, (2) single slow passenger car ahead, (3) single slow truck ahead, (4) slow bus ahead, (5) vehicle making left turn, (6) double parked vehicle, (7) traffic encroaching from opposite lane, (8) pedestrians, or (9) general slow traffic.

A laborious tabulation of the whole 24-hour period was made to show the average delays for hourly periods by ascribed causes, and charted as shown in Figures 3 and 4.

The figures in these charts reveal some interesting phenomena, which need further analysis. One of the principal ones was that nearly half of all delays were caused by the traffic signals, which were set for simultaneous operation. They were operated only between 6 a. m. and midnight. It will be noticed that during the hours of signal operation the loss of time per trip due to the signals was fairly constant in amount during all hours of signal operation at about 3 or 3½ minutes per trip, regardless of the differences in total traffic volumes. It will be also noticed that the delays from other listed causes do not follow the total traffic pattern as much as it does the pattern of the commercial vehicle traffic.

Some other things needing further examination are the influence of traffic signals upon other causes of delay and the influence of commercial vehicles as a percentage of the total traffic rather than by actual commercial vehicle count. The charts would seem to indicate that these and other relationships might be found to be important factors in the computation of a definitive index of congestion.

One distinguishing feature of these particular studies is the fact that about 21 percent of the lost time has been ascribed to the geometric condition of the roadway. This was caused by the roughness of surface and similar features responsible for a delay over the calculated travel time, even at the legal speed limit (25 mph. in this case) which still would have occurred if the test vehicle had been the only one on the road.

The fallacy of drawing conclusions from a compilation of delays as they occurred over the entire route as compared to a compilation by subsections is shown in Figure 5, in which the delays are charged to individual sections.

This chart indicates a wide variation in the time of delays and in causes, by sections. While the chart is not platted on a per-unit-of-length basis, and there are variations in the length of units, it can readily be seen that there still would be a considerable difference even if the basis had been on a per-unit-of-length basis. Another feature revealed by this chart is that the delay caused by traffic signals

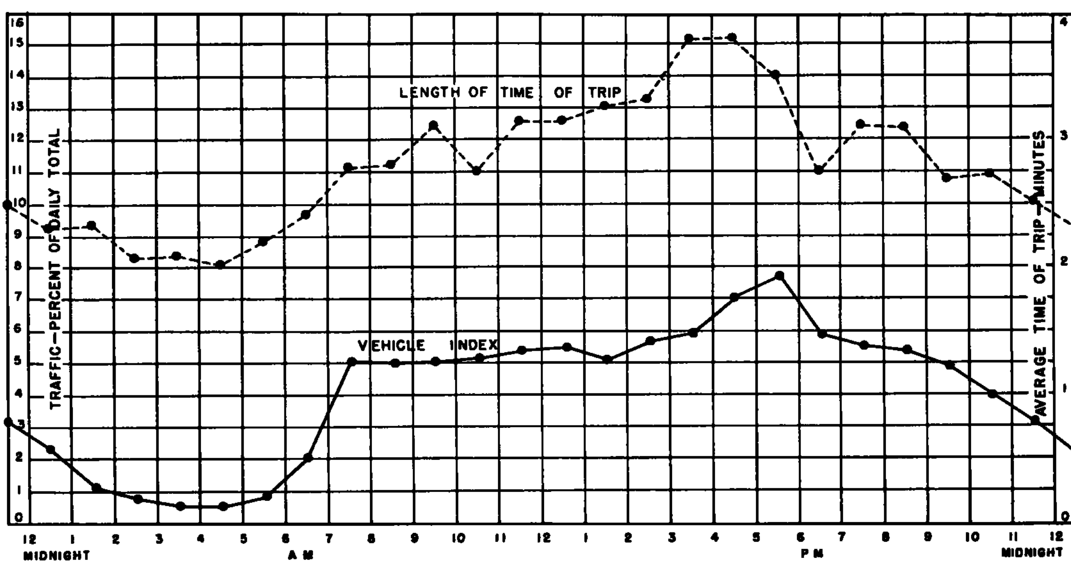

Figure 2. Time of average trip in minutes compared to traffic density on Summers Street from Kanawha Boulevard to Dryden Street, Charleston, West Virginia, 1944.

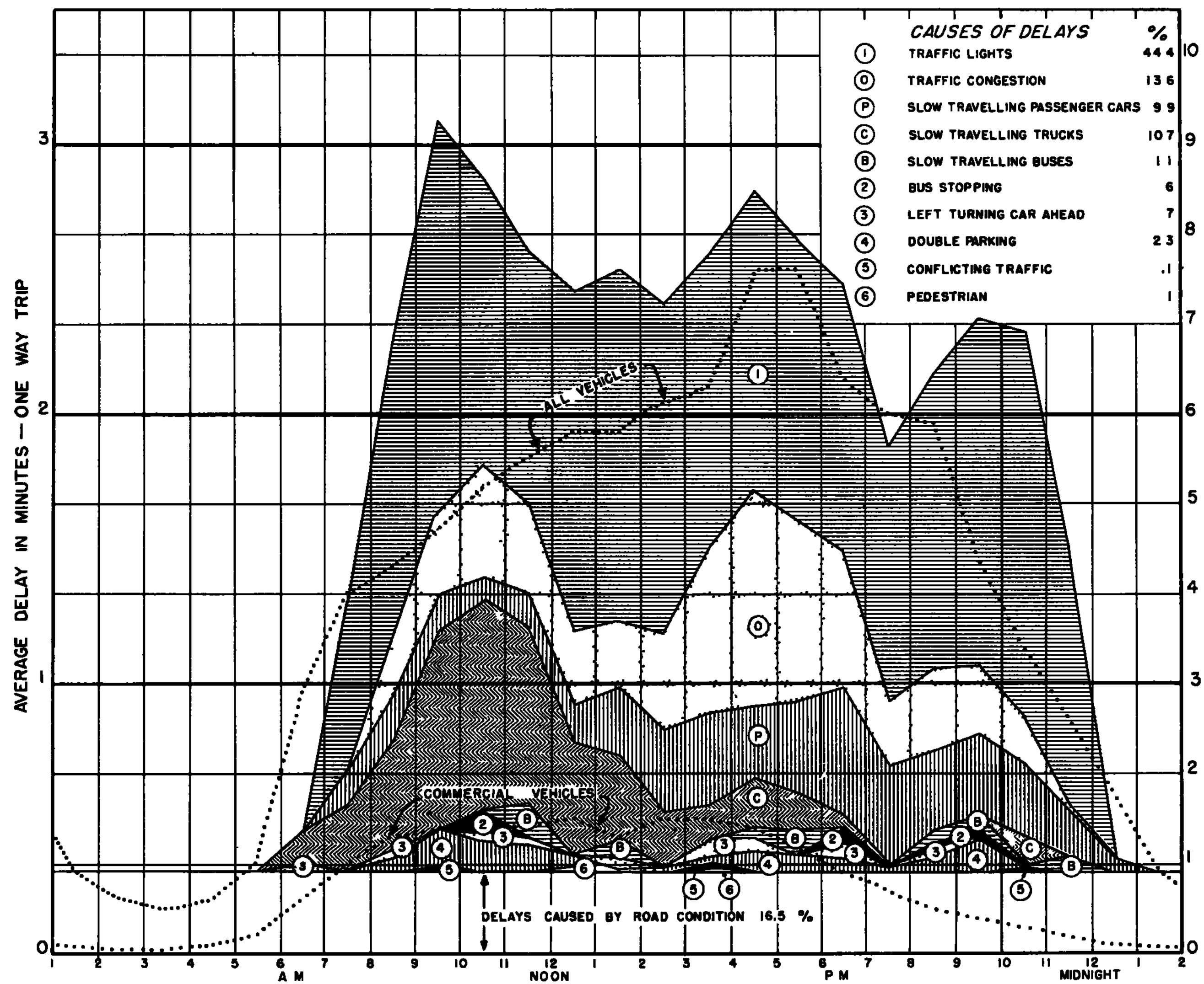

Figure 3. Time-delay study on US 19 and US 50 showing average hourly amounts and causes of delays to west-bound traffic compared with hourly traffic densities, Clarksburg, West Virginia, 1944.

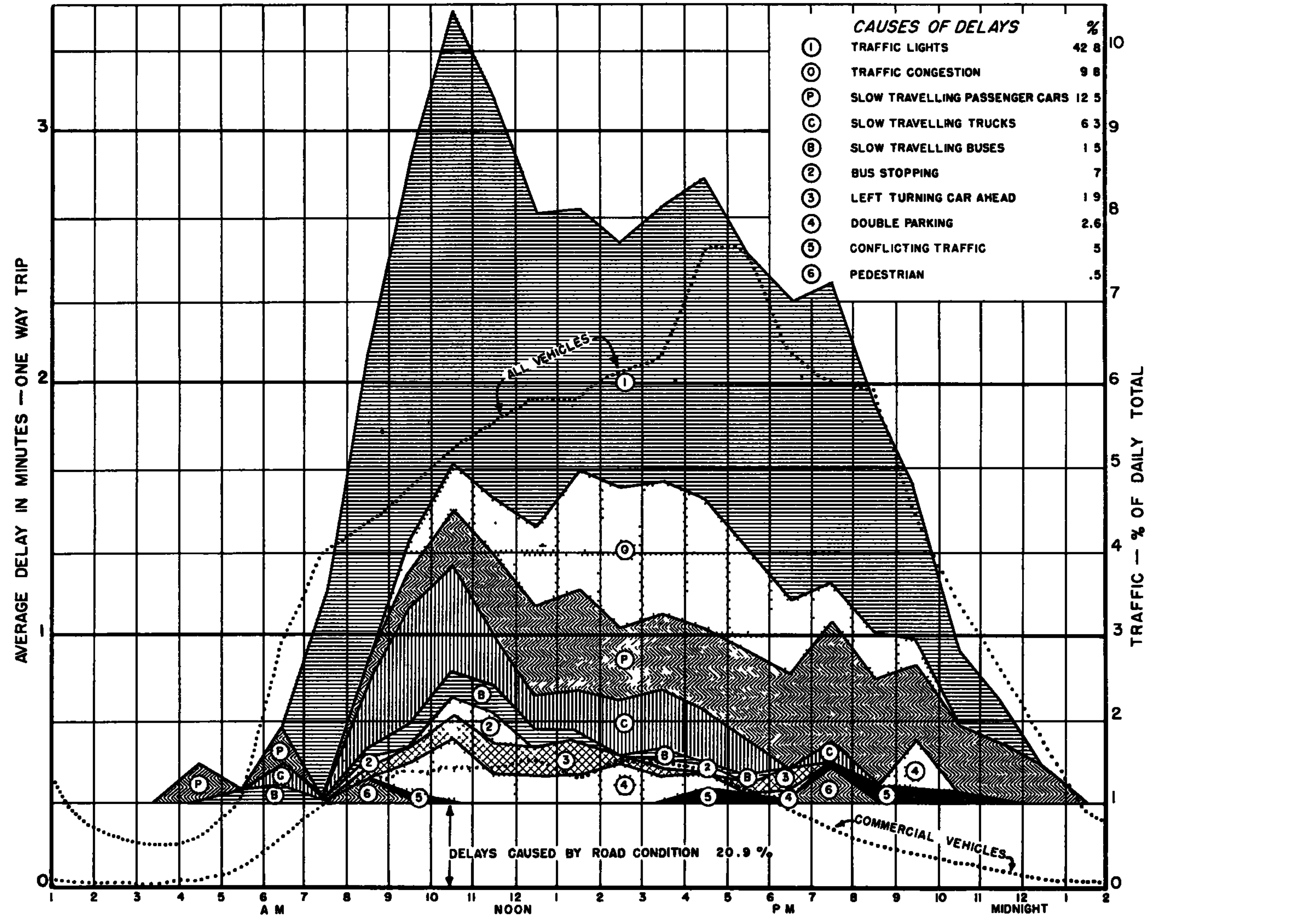

Figure 4. Time-delay study on US 19 and US 50 showing average hourly amounts and causes of delays to east-bound traffic compared with hourly traffic densities, Clarksburg, West Virginia, 1944.

assumes an entirely different scale of importance in comparison with the other causes of delays than it did in the previously shown charts.

The Clarksburg studies, and others made in West Virginia with similar results, had not been made for the purpose of discovering an index of congestion. At that time the Capacity Manual had not been published, and we were endeavoring, in a rather pioneering sort of way, to indicate the causes and the necessity for some sort of remedy to the congestion in the individual cases at hand. Because of shortcomings in the methods by which the studies had been made and recorded, and in the light of the knowledge now available in the Capacity Manual, it is not probable that much more of value beyond that already mentioned could have been extracted with bearing upon the present subject, a congestion index.

Mention of the basic restrictions due to below standard geometrics of the roadway brings up another problem, that of the effect of speed limits upon congestion. In Clarksburg the speed limit of 25 mph., as an average, was not attainable. Inasmuch as speed limits may control in some cases, then speed and delay do not actually reflect the density of traffic. Speed is set, not only by legal limits, but also by controls, such as signals and other regulations. For this reason obtainable speed may not reflect obtainable traffic density. Thus, traffic congestion may not be reflected in operational characteristics, although congestion is usually reflected in speeds.

One suggestion has been made that an index of congestion might be determined by a relation between the volumes of traffic and total lost time, that is: one factor to be the sum of the average required extra time of travel to all vehicles during a given period on a section beyond a standard time picked as the optimum, the other factor to be the average volumes of traffic traversing the section during the same period.

FREEDOM-OF-MOVEMENT CONCEPT

There is a second concept which needs examination as a basis for congestion measurements which may be called the freedom-of-movement concept. This method would require measurements of traffic densities to determine whether the movements of vehicles are restricted and to determine the changing percentages, magnitudes and durations of restrictions. Density may be measured in terms of vehicle occupancy per unit width and length of roadway, or perhaps an occupancy figure by time periods would suffice. An index might be developed, for instance, to show the duration of time that a given percentage of the vehicles are restricted from moving or from free movement. No studies revealing data of this kind are available for analysis, as far as is known, but the concept certainly warrants further investigation.

VOLUME-TO-CAPACITY CONCEPT

It should be evident that congestion is caused by a lack of capacity in the roadway to handle the demands of traffic. This leads to consideration of a third concept, that of a capacity-to-volume comparison, with a proposition that some index may be found in a relation between the practical capacity of the facility and the demand for additional capacity which causes the congestion.

In this method the ratio of actual traffic volumes to the so-called design volumes, otherwise known as the practical capacity, probably would constitute the unit of measurement.

A practical partial application of this concept was made recently in a city in West Virginia as a side issue to a traffic study made at a series of intersections for the primary purpose of determining traffic signal warrants and the best methods of signal operation. Turning-movement and traffic-classification counts were made at eight intersections, comprising the congested business area, for the peak eight hours of the day. Each intersection was analyzed by application of the methods in the Capacity Manual to determine its practical capacity, as compared to the possible capacity the actual number of vehicles entering during the peak hour.

The practical capacity in these cases was taken to be: "The maximum volume of traffic that can enter an intersection from one approach street during one hour with most of the drivers being able to clear the intersection without waiting for more than one complete signal cycle."

By this criteria it was found for one intersection for which the calculated practical capacity was 700 vehicles per hour in the direction of maximum volume, the actual

ZONE NO	LENGTH IN MILES	LOCATION
I	255	US 19–FROM WEST CITY LIMITS TO JUNCTION US 50 (WEST PIKE STREET)
II	285	US 50 (WEST PIKE STREET) FROM JUNCTION US 19 TO JUNCTION OF 24 Th STREET
III	361	US 50 (WEST PIKE STREET) FROM JUNCTION 24 Th STREET TO ADAMSTON BRIDGE
IV	315	US 50 (WEST PIKE STREET) FROM ADAMSTON BRIDGE TO COLEMAN STREET
V	.350	US 50 (WEST PIKE STREET) FROM COLEMAN STREET TO JUNCTION US 19 (MILFORD STREET)
VI	.158	US 50 (WEST PIKE STREET) FROM JUNCTION US 19 TO JUNCTION OF US 50 E (MAIN STREET)
VII E	.597	US 50 E B (MAIN STREET) FROM JUNCTION OF PIKE STREET TO JUNCTION OF 2Nd STREET
VII W	.563	US 50 W B (PIKE STREET) FROM JUNCTION OF 2 Nd STREET TO MAIN STREET
VIII E	192	US 50 E B (MAIN STREET) FROM JUNCTION OF 2 Nd STREET TO JUNCTION OF MONTICELLO St
VIII W	186	US 50 W B (PIKE STREET) FROM JUNCTION OF MONTICELLO STREET TO JUNCTION OF 2Nd St
IX E	409	US 50 E B (MAIN AND OAK STREETS) FROM JUNCTION MONTICELLO St TO JCT OF PIKE St
IX W	259	US 50 WB (EAST PIKE STREET) FROM JUNCTION OF OAK St TO JUNCTION OF MONTICELLO STREET
X	440	US 50 (EAST PIKE STREET) FROM JUNCTION OF OAK STREET TO JCT OF JOYCE STREET
XI	.145	US 50 (EAST PIKE STREET) FROM JUNCTION OF JOYCE STREET TO CITY LIMITS EAST

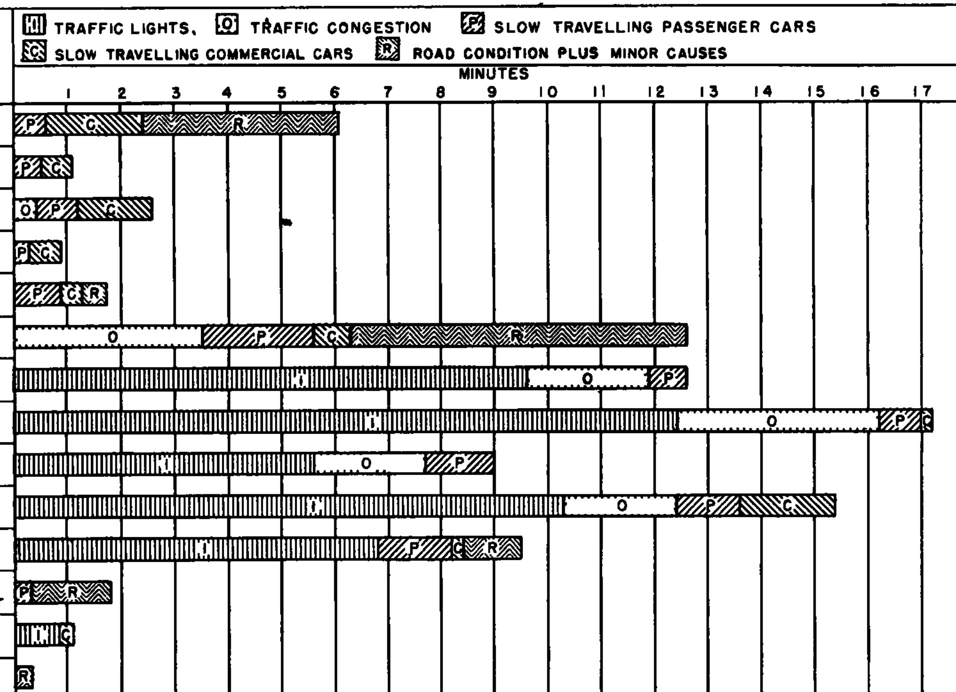

Figure 5. Daily amount of loss and its composition by principal causes to all traffic in each zone, expressed as the rate per mile for each zone, Clarksburg Traffic Survey, 1944.

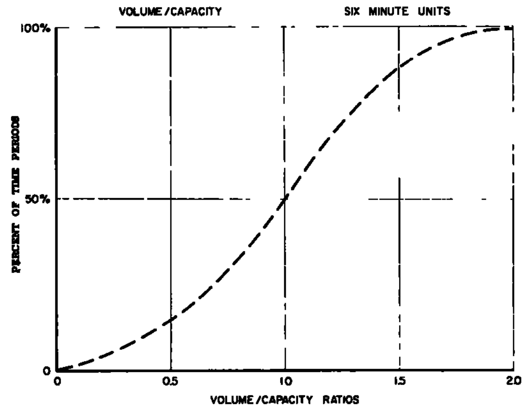

Figure 6. Frequency distribution of the ratio of volume to capacity in terms of 100 six-minute units.

number of vehicles entering during the peak hour was 870. Another intersection for which the practical capacity was calculated as 460 vehicles per hour was found to be actually carrying 640 vehicles during the peak hour; and the investigation revealed likewise for other intersections actual volumes beyond the calculated capacity. Would a ratio between these volumes constitute the basis of a congestion index?

It was observed incidentally during the counts that at times traffic was stalled into a backlog for short periods, projecting back through an adjacent intersection. No records of the amount of these backlogs were made at the time, but if they had been, analysis might have revealed a factor by which to qualify the capacity-to-volume ratio.

The counts were made only for hourly units, because that is the basic time used in the Capacity Manual computation. Possibly some smaller or larger unit of time, or a combination of a number of time units, should be used in the determination of a congestion index.

One suggestion has been made that the ratios may be determined for a combination of certain specified time periods, possibly a schedule which would include 6-minute periods for 10 hours (8 a.m. to 6 p.m.), thus providing 100 units of time. A frequency-distribution curve of the ratios would be made, somewhat as shown in Figure 6, and an index formulated from the frequency curve, either by picking some percentile value or deriving an equation of the curve.

SUMMARY

Application of the three above-mentioned concepts to the problem of determining a congestion index should be by some basis of measurement predetermined as acceptable to all researchers. A fundamental agreement should be to make the modulus as simple as is possible.

Agreements should be had as to the place of measurement, as well as the purpose for which the measurement is intended. For instance, should an index be used to determine the relative degree of congestion at bottlenecks, by block units, by a whole project, or of an entire central business district? If by the method of smaller sections or bottlenecks, could the indices for the several smaller units be combined or summarized to obtain a composite index?

It may be that the three variant methods of measurement under the different concepts mentioned above could be correlated. If this were found possible, then the simplest method of measurement can be used and all concepts be satisfied in use of the simplest method.

There is no doubt that future studies of traffic characteristics, for whatever original purpose, can furnish considerable data capable of analysis aimed at the determination of a congestion index if some agreement could be reached on standards so that studies by one researcher could be compared with studies by another.

What is needed is a project statement consisting of an outline of the aims, standardization of methods of observation and tabulation, definitions, and other criteria.

The subject seems worthy of correlated study by a group. There should be little doubt that a method of comparative evaluation of congestion by an index would be of great use as a working tool for highway engineers.

Discussion

THEODORE F. MORF, Assistant Engineer of Research and Planning, Illinois Division of Highways — I am glad to be asked to comment on Rothrock's excellent paper. Urban congestion is one of the most—important problems facing highway engineers, and an objective measurement of it is badly needed.

The author mentioned that one of the uses of an urban congestion index would be in connection with the sufficiency rating of city streets and I will confine my comments to that particular aspect of his discussion. I might add that I believe that a working formula is needed much worse today, than a final and definitive formula is needed 5 or 10 years from now.

Illinois is one of the few states which has established a method of sufficiency rating intended for application on urban streets. Of a possible point score of 1,000, 300 are devoted to a rating of capacity which is essentially a measure of congestion. Of these 300 points, 150 are allocated in accordance with what Rothrock has described as the operational-characteristics concept. More specifically, it is based on the ratio of driving done during periods of peak traffic and during periods of normal traffic. The remaining 150 points are assigned to what we call an "intersection-congestion rating," where the functioning of intersections during the peak period is compared by direct observation with their possible capacity.

We recognize, of course, that this formula might be immensely improved in the light of knowledge stemming from discussions such as this. With its imperfections, however, it has furnished us some basis of comparison as among the traffic capacity of urban streets, which is all that a sufficiency rating system is expected to do.

One other point raised in Rothrock's paper concerns the length of rating sections. The author comes to the conclusion that ratings should be made block by block. The question of the length of a rating section should be given much more attention than it has been given in discussions of sufficiency rating. In Illinois we regard the question as of the utmost importance. While we can agree that objective measurement might best be served by the automatic fractioning of the street under study into block by block segments, these units are not always practical for other purposes. In Illinois we are concerned with a homogeneous portion of highway, taking into consideration all traffic conditions and adjacent land use. Thus, for instance, a route through a city might be divided into at least three sections (1) residential areas approaching the downtown area, (2) the downtown area, and (3) the residential area as the route leaves the city. These could be added to if, for instance, an industrial area were also to be traversed and for important changes in traffic movements served by that route.

DONALD S. BERRY, Assistant Director, Institute of Transportation and Traffic Engineering, University of California— As Rothrock points out, traffic congestion actually begins whenever there is any impedence to free movement. Thus, congestion begins in some degree whenever the average driver takes a longer time to make a trip than he would under conditions of no delay.

Ideally, therefore, one congestion index could be defined as the ratio between the actual average travel time for the conditions under study to the average running time under no-delay conditions. The congestion index for peak-hour traffic on a downtown street then could be determined by making travel-time studies during the peak hour, and comparing results with running times obtained under no-delay conditions.

From a practical standpoint, the travel-time studies for the no-delay conditions are the major problem. Test-car runs need some traffic to provide a guide as to average speed under no-delay conditions. Thus, it may be desirable to run such tests under free-operation traffic-volume conditions which exist in the midmorning or early afternoon, when traffic volume may be less than half of the practical capacity of the key intersections. Also, on streets with unusually rough surfaces or bad alignment, adjustments would be necessary in selecting an optimum travel time for no-delay conditions.

Recording equipment now is available which permits one-man operation of test cars in speed and delay runs. The University of California has equipment which is actuated by push buttons. This equipment prints time to the nearest hundredths of a minute on a tape along with one of twelve code numbers to indicate intersections or other check points in the test course and stopped-time delays.

R. M. BROWN, Assistant Engineer of Road Design in Charge of Metropolitan Surveys, Indiana State Highway Department— The development of a congestion index presents an entirely new concept in the field of traffic engineering. The facts as presented in Rothrock's paper indicate clearly that its translation into a tangible value involves complex factors, which are most difficult of assigning or determining realistic values with present yard sticks.

The three concepts of operational characteristics, freedom of movement, and volume-to-capacity ratio present logical means of initial research by the evaluation of the three and their subsequent combination to a final index as against the possibility of discovering that the volume capacity concept with some amplification would produce the same factor.

Steps in the immediate development of an index could take the form of analyzing pertinent data, recorded at a group of congested points in a selected list of urban areas, to provide comparable empirical indexes, to be subsequently evolved by true mathematical processes if sufficient consiliency resulted.

The presentation is a challenge to comprehensive research that should lead to another sorely needed tool by the traffic engineers.

FRANK J. MURRAY, Engineer of Planning Survey, Division of Planning and Programming, Ohio Department of Highways— Rothrock's paper is certainly stimulating and thought provoking. The possibility of devising a unit of measure for evaluating the relative degree of congestion on urban arterials will be of extreme interest to all traffic and planning engineers. Just as sufficiency-rating procedures are being developed to provide a factual means of measuring the relative adequacy of each section of rural highway to carry traffic safely, rapidly, and economically, a congestion index would evaluate the impedance to the free flow of traffic on urban streets. The relative extent of this impedance could thus be used as a guide in indicating the need for the adoption of remedial measures.

In devising an acceptable method of determining the relative degree of congestion on urban facilities, it is essential that only those elements be used which can be precisely defined and accurately measured. Furthermore, it is desirable that the method provide simplicity and economy of application; however, these qualities can be sacrificed if the system which is devised will adequately serve the purpose.

The three concepts suggested by Rothrock as possible approaches to the development of a congestion index are interrelated. Since the traffic volume on a roadway is the product of traffic density and speed, it may be seen that all the factors involved in a study of any one of these concepts will also influence the other concepts. The operational-characteristics concept involves the element of speed which is influenced by the volume and density of traffic. The freedom-of-movement concept requires measurement of traffic densities which vary with the volume and speed of traffic. Similarly, the capacity-volume concept is related to the density and speed of traffic. Thus, it would appear that the combined effects of the three elements — volume, speed, and density — must be considered as a whole in a study of congestion.

Of these three elements, traffic density (or the spacing of vehicles) is perhaps the most difficult to measure, although it is one of the most-significant indications of traffic congestion. Complete congestion will occur when the density is maximum and, therefore, the volume is zero. Conversely, a minimum of congestion will exist under conditions which permit basic capacity.

To the average motorist, the most-apparent index of traffic congestion is revealed by the operational characteristics of the street as they are reflected in the operating speed which can be maintained while one is endeavoring to travel at the highest legal speed. The reduction in this operating speed is the result of the extent to which the intersectional, marginal, and medial frictions may impede the free flow of traffic. Speed and volume provide elements which are capable of measurement.

Since the capacity of a street is related to the speed of traffic on that street, the same factors which influence the capacity will also affect the traffic speed. These factors may include the composition of traffic, physical characteristics of the street (including lateral impediments such as access drives), intersections, presence of parking, turning movements, grades, weather, etc. Each of these factors will have a distinct and different influence upon the speed at which traffic will operate on a street. Thus, if the extent to which each of these factors influenced the speed of traffic were determined and properly weighted, the combined effect of the presence of several of these impediments on a street would indicate the average overall speed at which traffic would operate.

This might conceivably be accomplished by selecting streets upon which only one of these speed reducing factors existed to the exclusion of all others and recording the observed speeds by means of a speed meter for each separate condition. Since the vehicular speed varies with the proximity to the impediment, it may be necessary to make observations at intervals of, perhaps, 100 feet along the street in advance of an intersection.

The average of all observations recorded for each type of restrictive influence when related to the normal or unimpeded speed, which might be considered the legal speed limit, would provide a factor indicative of the extent to which traffic flow was influenced by that particular condition. The combination of these factors for a given set of conditions and location on a street would provide the existing average overall speed.

The average density at a particular location on a street may then be determined from the ratio of the existing traffic volume to the existing average overall speed.

The ratio of the normal or unimpeded flow of traffic, which might be considered the basic capacity of the street, to the normal or unimpeded speed of traffic would provide the normal or unimpeded density on the street. The Highway Capacity Manual reports that "the highest volumes per lane occur on roads where vehicles travel between 30 and 40 miles per hour . . ." which would indicate a normal or unimpeded speed of 35 mph.

An index of congestion could thus be obtained from the ratio of the existing density to the normal or unimpeded density.

It is realized that the existing average overall speed on a street could be obtained from speed and delay studies, but this would entail considerable labor and expense to perform these studies at innumerable locations where it was necessary to obtain an index of congestion. The thought behind this suggested approach to the development of a congestion index is to point out the possibility of obtaining adjustment factors for speed similar to the adjustment factors used in the determination of street capacity and, from these factors, of deriving an index of congestion.

O. K. NORMANN, Chief, Traffic Operations Section, Highway Transport Research Branch, Bureau of Public Roads — In his paper, Rothrock raises several questions which serve to provoke a great deal of thought regarding a suitable method of arriving at a useful congestion index for urban streets.

It is apparent, as the author suggests in his summary, that a suitable index must embody a combination of the three different concepts which he has outlined. The operational characteristics concept, for example, in itself is not adequate, because it only relates travel time to the traffic volume. Although delays are classified as to cause, such as traffic signals and left turns, the portion of the total delay for each of these categories which is chargeable to overloading the facility or to improper operation of the signals and other control methods or devices cannot be separated. Likewise, the volume-to-capacity concept in itself is not adequate, because two identical streets carrying equal hourly volumes would have identical volume-capacity indexes even though the travel time on one of the streets with a progressive signal system might be only half as long as on the other street with signals being operated independently. This is so because a progressive signal system does not necessarily greatly increase the capacity of a street, but it can cause a marked reduction in the travel time over a given distance. The one street would be providing a much higher type of service than the other street.

The third concept which involves the

percentage of vehicles restricted from moving or from free movement is, in itself, obviously inadequate for urban conditions. On urban facilities practically 100 percent of the vehicles are restricted from a movement which can be considered entirely free, even at relatively low traffic volumes. For this concept to be applicable to urban conditions, the duration of time and degree of restriction must be included, in which case the freedom-of-movement concept would approach the operational concept.

Furthermore, when one considers the several different types of streets in an urban area and the difference in the functions they perform, as related to the abutting property and the overall transportation problem, it becomes evident that the same index of congestion cannot be used for all the facilities within an urban area. A different standard of performance or index of congestion, for example, must be expected and applied to a street carrying through or arterial traffic than to a street serving principally as an access to the adjacent property.

C. A. ROTHROCK, Closure — Regarding Morf's comment, I believe Illinois has made a forward step in introducing its conception of an index of congestion as a factor of its sufficiency rating formula for urban streets. The selection of a criteria of 9 seconds headway would seem to need some justification, since the tables and charts of which the Illinois charts have been extracted have been taken from the section of the Highway Capacity Manual dealing with rural traffic conditions rather than urban. This brings up again the question of just what is congestion. For instance, is it not probable that drivers will queue up without exhibiting impatience if they can keep moving at what might be called a reasonable speed, considering safety, etc., under urban conditions, at a rate considerably less than would be tolerated in rural areas? In such cases the headway may be considerably less than 9 seconds.

With regard to the point of studying small sections instead of larger, I would like to see a comparison of a block-by-block analysis added up to represent the whole, with an analysis of the whole section. I am inclined to think that instrumentation and ways of analysis might be found by which observations of the whole section might then be cut up into individual representations of the lesser sections.

As to the classification of conditions as residential, downtown, industrial, etc., I believe that the kind of index of which my paper dealt should measure the absolute amount of congestion regardless of areas, or even causes. Analysis as to the contribution of these latter factors to the result measured would come later.

On the whole I believe that there is not such a wide area of difference between the opinions of Morf and those of mine in the paper that it cannot be readily narrowed by such discussions, and I wish to thank him for his comment as an addition to our general knowledge.

Don Berry's comment brings up no points of disagreement. He properly calls attention to the difficulty of obtaining a true average travel time by use of a test car, especially during so-called no-delay conditions. In many cases, however, speed is controlled by legal limits, and if these are observed by the general public, then the legal speed limit may be used in calculating the optimum travel time. This was the method used in some past studies in West Virginia where, incidentally, in several cases it was not possible during tests on some streets to even reach this limit. I believe a new definition of the optimum condition of travel may be needed so that proper standards may be used in all cases.

The matter of instrumentation necessary for accurate observations is one which needs more attention. The one described by Berry is certainly an improvement over the manual methods used in past investigations.

R. M. Brown's discussion does not raise any questions requiring comment further than that contained in the original paper. It shows the trend of general thought on the subject, and indicates that there is a need for research aimed at the problem.

Murray's excellent discussion has gone to the heart of the problem in citing the difficulties in making field observations by simple and inexpensive methods. It is probable that a few completely detailed studies on short sections may develop some stable relations that can be applied on the basis of data less costly to obtain.

He properly recognizes that the three concepts discussed in my paper are not so independent as the discussion may indicate.

Actually, their supposedly different factors are only another way of expressing one or the other of the basic elements: time and space.

While some of the illustrations of my paper dwell upon the causes of congestion as well as the effects, I had intended to imply a primary interest in an absolute measurement of the effect — congestion — disregarding the causes for the present. Having fixed the extent of the disease, investigation of the causes is another problem, although interrelated, of course.

Murray's remarks show a keen appreciation of the problem and are most helpful.

Normann has correctly pointed out the weak spots in the three concepts, considered separately, principal of which is the question of effects of signalization on capacity and time of travel. He also brings up the question of the need for a standard of performance, differing for different types of services rendered by the streets.

Both points certainly need clarification, which, at the present stages of thinking, I am unable to give. I believe that one of the principal jobs of analysis is the determination of such optimum standards of performance. Such an optimum may be discovered in an array of the performance data on a given section under variable traffic volumes. The principal questions are: What is congestion? When does it begin?

Some research is now planned which may indicate at least a path to answers to the vital questions Normann poses.

All of the discussions have proved stimulating and no doubt will do much toward clearer thinking on this subject. Certainly further research is needed, and one of the principal points needing clarification is that of an understanding common to all of us: What is Congestion? A definition is needed, so that all researchers may be discussing the same conception. I hope such a definition may be forthcoming soon.

In going over the comments together I find a considerable degree of centering of opinion, tending toward a general agreement on at least the principal points of the problem. Some more research and analysis may result in the answers.