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Urban Traffic Congestion

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Contents

Economic Costs of Traffic Congestion

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● IF the current rebirth of public interest in the highway problem is to generate constructive action on an adequate scale, a much-greater effort will have to be made to acquaint the average citizen with his pocketbook stake in traffic relief.

The economic-benefit factor and the humanitarian factor of saving lives are the two most-compelling incentives for support of essential road programs. Until recently, however, the economics of highway transportation has been deemed a subject of concern only to experts. It has remained largely the private domain of the economist, the engineer, and the traffic manager. As a tool for public enlightenment, it has never got much beyond the sphere of technical reports.

The time has come to let the general public in on some of the economic facts of life about roads and their use.

Certainly nothing could be more persuasive in demonstrating the value of better facilities than the dollars-and-cents advantages to the ordinary user. Road needs, no matter how well documented, have only a superficial meaning for the taxpayer unless the proposed improvements are translated in terms of dividends to himself, his family, and his community. The most tangible of these are the savings that would accrue to every citizen with a reduction of the huge annual waste of traffic congestion and accidents.

Over the years there has been plenty of discussion of the penalties of the traffic jam. Alarm has been expressed repeatedly about its destructive effect on downtown business, property values, municipal tax structures — on the economic health of communities generally. It has long been recognized that clogged traffic is not only a source of great public inconvenience and hazard, but that it adds heavily to the cost of transportation and the price of goods and services to all consumers.

That the traffic jam constitutes a tremendous drain on the economy is not open to serious doubt. But what do we really know about the monetary losses? How much of presently circulated information is fact — how much conjecture? What reliable data are there to support the broad generalizations? What aspects of the subject has research already explored, and what gaps in our knowledge remain to be filled?

Answers to these questions are needed to give substance and impact to the education campaign. In an attempt to provide some of them, the publications division of the Automotive Safety Foundation has reviewed much of the available data and literature in this field. While by no means exhaustive, the findings serve to give some idea of the scope, principles, and methods of past research on the economics of congestion. They furnish at least a clue for separating the wheat of fact from the chaff of speculation. They highlight some of the more significant work that has been done and suggest phases which require further scientific study.

CONGESTION BUILDING UP FOR DECADES

The fact that even as far back as the mid-1920's cities were trying to evaluate losses due to traffic snarls is evidence that congestion is no new problem. It is only bigger and vastly more complex. Motor-vehicle travel since than has increased several fold. Without substantial enlargement of capacity in the last 30 years, urban streets (which represent only a tenth of the nation's road plant) must now accommodate 50 percent of the total traffic. Result is that almost all major arterials in metropolitan areas have become chronic bottlenecks. Similarly, many rural routes are perennially swamped.

It is revealing to note that one of the pioneer books on commercial motor transportation, published in 1923, comments on the need for better "methods by which the traffic of the future is to be handled in congested districts which already are causing much concern" in the same context with a prediction that "mechanical means will eventually displace the horse in retail delivery."

Evidence of that concern was a U. S. Department of Commerce survey, undertaken in 1925-26, to appraise the influence of congestion on retail business throughout the country. The report indicated that bad traffic conditions were hurting trade in the case of 61 percent of the stores in cities of more than 200,000 population; 53 percent of those in the 50,000-to-200,000-population group; 46.5 percent of those in the 10,000-to-50,000 group; and 22.3 percent of those in the 2,500-to-10,000 group.

"Where congestion occurs," the report stated, "volume of business has been brought down from 1 to 20 percent below that which would have been transacted with the automobile as a 'business-bringer' minus the factor of congestion."

At about the same period, the Committee on Metropolitan Facilities of the National Conference on Street and Highway Safety was reporting to Secretary of Commerce Herbert Hoover:

> Two billion dollars — $20 for each man, woman and child in the United States — is the price the country pays in accidents, loss of time through congestion, depreciated real estate values, and in many other ways for the lack of properly developed traffic facilities and their control . . . .
>
> Data gathered in a large number of cities indicate very clearly that congestion and other factors can be calculated with more or less accuracy. For example, detailed traffic tallies in Worcester, Massachusetts, indicated that congestion was costing the city $35,000 a day. The price paid by Cincinnati for similar conditions was estimated at $100,000 a day. St. Louis congestion losses were set at $125,000 a day, including time loss and accidents. In the Loop District of Chicago it is estimated that parking of cars (at the curb) costs the city $200,000 a day, while the loss from congestion in the region including New York City is fixed at approximately $1,000,000 a day.

Supporting testimony on the size of the congestion bill came from Boston, for instance, which computed a yearly loss of $24,750,000; and Pittsburgh, where downtown delays were said to add up to an annual equivalent of 21 years of 8-hour working days—with monetary losses to the trucking interests alone reaching $4,140,000 a year.

Regardless of the accuracy of those early estimates, it is apparent that as far back as a quarter of a century ago, the traffic crush was definitely on. And the figurative "mud tax", which to the first generation of motorists signified excessive wear and tear on the cars due to poor roads, was evolving into a burdensome congestion tax on everybody and everything.

ECONOMICS BY RULE-OF-THUMB

Of the congestion-cost investigations made during that period, the best that can be said is that they were rough and ready. While some of the figures publicized may even have been conservative, probably few of the studies that produced them would stand critical analysis today. Since this was more-or-less virgin territory, the tendency was to expand narrow facts with broad assumptions. Authentic cost data on vehicle operation were scarce, particularly with respect to differing traffic conditions. Methods of measuring delays were primitive, and criteria for assigning time loss to the various classes of users varied widely. Dollar value of time wasted in traffic, in some aspects difficult to assess even now, was almost purely a matter of opinion.

As an illustration, some cities based their calculations on the premise that a flat 10 percent of the total operating time of all vehicles on downtown streets could be charged to traffic delays. Then assigning known or estimated unit values for the lost time of commercial vehicles, and arbitrary values in the case of private cars, they arrived at an overall monetary loss to the community on a daily or annual basis. Sometimes 1 cent per minute was used as the average value of time for all vehicles.

Rough-hewn though they were, these early investigations at least showed recognition of one of the most vital problems emerging in the automotive revolution. Thinking men began to suspect that traffic congestion did not end with the mere inconvenience of people but instead, with the economic and physical decay of communities.

It was becoming clear that existing street patterns were not in harmony with the use of the automobile as a major form of transportation; that congestion, accidents and related traffic evils were symptoms of inefficient facilities; and that the urban traffic jam was not a simple question of street widths, but a whole complex of

Figure 1. Traffic congestion is no new problem.

Figure 2. Many millions of dollars are wasted everyday due to traffic congestion.

physical and operational deficiencies, including lack of off-street-parking space—together with numerous other factors such as haphazard land use, unsound building codes and zoning regulations, and ineffectual traffic laws and weak enforcement.

However, few researchers ventured to penetrate deeper than those surface aspects of congestion; losses ascribed to cities, for instance, failed generally to weigh the economic attrition which loss of access brings in its wake. Business enterprise, property ownership, municipal budgets are all affected.

Obviously it is hard to segregate, dollar-wise, the part that congestion plays in abnormal decentralization, decline of downtown business, shrinkage of realty values, and blight of residential areas due to influx of heavy volumes of commercial traffic. But patently the traffic jam is a significant factor, and accountable in some degree for the enormous losses involved. By the same token, no picture of the economic waste of congestion can be reasonably complete if such elements, as well as accident costs, are ignored.

Some of the congestion loss figures resulting from the pioneer surveys continued to be quoted, without revision, for decades afterwards, even though traffic volumes doubled and quadrupled. Types, speeds, and uses of motor vehicles changed; living standards and prices changed; traffic regulations and control techniques changed; the very face of our cities changed. But the same old estimates were hauled forth again and again to dramatize the costliness of traffic paralysis.

The million-dollar-a-day estimate for the New York area, mentioned earlier, was first published by the Regional Plan Association of New York in 1924. It was frankly based on extrapolation of figures developed by Worcester, Cincinnati, and Chicago. It continued to have wide and unchallenged currency until 1953 when a reappraisal by the Citizens Traffic Safety Board set the amount at a billion dollars annually, about three times the 30-year-old figure.

COST OF DELAYS

The point has been made that vehicle-operating losses do not tell the whole congestion-cost story, and hence cannot be equated with the total economic penalties paid by the community. Many of the figures publicized by cities, therefore, have really represented only one aspect of the problem.

Even within these limitations, the estimates have often been perfunctory. Vehicle operating losses were sometimes computed for a so-called composite vehicle by combining rough estimates of extra gasoline consumed while idling, increased wear and tear caused by decelerating and accelerating, plus an assigned value for lost time. The loss for the composite vehicle was then applied to the total estimated traffic.

In more-recent years, the losses to motorists have been based, as a rule, on operating-cost data. Certain of the costs are classed as mileage elements, including fuel, oil, tires, maintenance, and that part of depreciation due to the distance traveled. Insurance, license, and other fees; interest; garage rent; and that part of depreciation due to elapsed time are grouped as time elements, or fixed charges. The value of the driver's time is sometimes included as a fixed cost, sometimes added as a separate item.

One of the methods used in calculating unit operating losses is to add the mileage and time elements and divide by the number of miles traveled. Some authorities hold, however, that the fixed cost alone is the appropriate measure of the value of lost time. In the method based on this thinking, the fixed cost per mile is multiplied by the average speed of the vehicle. To this is added the cost of fuel and the value of the driver's time. In both cases, the unit value for loss of time for each class of vehicle is applied according to their proportionate numbers in the traffic stream.

Tests conducted by the Oregon State Highway Department in 1938-39 disclosed that for the average passenger car, fuel losses represented approximately 41 percent of the increased mileage-element costs in congested traffic. For trucks and buses, the percentage varied with the gross weight, from 31 percent for a light truck to 25 percent for a heavy one.

In a follow-up study (1944) by the highway department and Oregon State College, designed to correlate fuel consumption with such factors as congestion, alignment and surface type, the annual cost of traffic delays in the Portland metropolitan area was estimated to range between $75,000 and $100,000 per mile. These figures included arbitrary values for lost time, a passenger-car-hour being rated at 60 cents.

Excess Gasoline Consumption

In a research project at Boston in 1939, A. J. Bone, of the Massachusetts Institute of Technology, found that 50 percent more fuel was burned up on crowded downtown streets than on runs of the same length on unimpeded streets in other parts of the city.

The tests indicated that under ordinary conditions it took 7 minutes to drive 1 mile in the downtown area, with 2½ minutes spent for traffic stops, 1½ minutes in first or second gear, and 3 minutes in high gear. About ½ minute was required for each of the four to five intersections per mile of route. Gasoline consumption averaged 12. 2 miles a gallon, as against 18. 2 miles to the gallon on runs not subject to stop-and-go and other interference.

Assuming that all vehicles experienced the same proportional waste of gasoline, he estimated that the additional fuel cost (at 16 cents per gallon) caused by delays in the central business district amounted to approximately $18,000 per mile per year.

Earlier, in 1935, T. T. Wiley (at that time with the Illinois State Highway Department) had conducted extensive tests to determine the excess fuel required for automobile stops. Using vehicles of different weights, he made stop-runs at varying speeds. The findings of the Illinois tests are tabulated in comparison with those of Oregon in Table 1.

TABLE 1

Excess Fuel Required Per Stop

Speed	Illinois Tests*	Oregon Tests
mph.	gal.	gal.
10	0. 0017	. . . .
20	. 0032	0. 0030
30	. 0049	. 0051
40	. 0066	. 0075
50	. 0091	. 0097
60	. 0105	. 0110

*Average of all vehicles tested

Taking into account extra oil and wear on tires, brakes and clutch, as well as fuel, Wiley found that the increased cost per stop amounts to 0. 056 cent at 10 mph., 0. 16 cent at 30 mph. and 0. 3 cent at 60 mph. (In his calculations, he assumed the oil cost to be a sixth that of fuel, and figured tire costs as if the additional gasoline had been used for travel at constant speed.)

The effects of stop and slowdown cycles were probed further in a 1940 study undertaken by an automobile manufacturer at the request of the Yale Bureau of Highway Traffic. It revealed that at a cruising speed of 30 mph., with three normal stops per mile, the average car consumed as much gasoline as at a constant speed of 55 mph. It was also demonstrated that with sudden, or "hard," stop cycles the fuel consumption rate rose more than 300 percent above that of uninterrupted travel at the same speed.

Speed and fuel consumption studies made in 1947 by the Automobile Club of Southern California established that gasoline mileage on congested downtown arteries of Los Angeles averaged only 8. 7 miles per gallon, compared with 23. 86 miles per gallon at a sustained speed of 25 mph. on the Arroyo Seco Freeway. Of course, average speed on the freeway is nearer 45 than 25, and gasoline consumption at the higher speeds is proportionately greater. Table 2 shows the variables resulting from different speeds for both the continuous and the stop-and-go travel.

TABLE 2

Gasoline Consumption and Fuel Costs* Per Mile

Speed	Miles Per Gal. (No Stops)	Fuel Cost Per Mile (No Stops)	Miles Per Gal. (5 Stops Per Mile)	Fuel Cost Per Mile (5 Stops)
mph.		cents		cents
25	23. 86	1. 17	15. 75	1. 78
30	22. 75	1. 23	13. 60	2. 06
45	20. 00	1. 40	9. 68	2. 89

*At 28 cents per gallon

A further index of fuel wastage in snarled traffic appears in a 1949 study by Thomas J. Fratar, engineer-economist associated at that time with the Yale Bureau. Fratar confined his analysis to a heavily traveled area of 2. 4 sq. mi. in Manhattan, employing flow charts and speed data prepared by the New York City Police Department.

He found that during several hours of the day the average vehicle was forced to halt about 1¼ times a minute; that the average speed was about 9 mph.; and that approximately half the total traffic time was spent motionless. Average weekday travel represented 90,000 vehicle-hours, of which 45,000 were spent idling, with a consequent fuel waste of 18,000 gallons a day. Extra fuel required for stops (at 0.0024 gallon per stop) accounted for an additional 16,000 gallons a day. Total excess fuel burned up per weekday in the limited study area was therefore 34,000 gallons, which meant a daily loss of $8,500 to motorists.

The wide variance in fuel mileage under roadway conditions ranging from the free flow on expressways to the dense crowding found on many downtown thoroughfares is highlighted in Table 3. It was developed by Lawrence Lawton of the New York City Traffic Engineering Department, on the basis of the gasoline consumption studies of the Automobile Club of Southern California, and on other data derived from the New York State Highway Planning Survey and the California Board of Equalization.

findings a dozen years previously indicated an average of 12.2 miles per gallon on the downtown streets. The later investigations showed a range from 9 to 13 miles per gallon, with a low of 5 miles per gallon on some runs.

Extra Wear on Tires and Equipment

In 1944-45 the Iowa Engineering Experiment Station (Iowa State College) conducted a series of studies on tire wear on various types of road surface. The project, under the direction of Ralph A. Moyer and Glen L. Tesdall, included tire-wear measurements made on selected sections of highway during more than 2 million miles of travel in Iowa, Kansas, Missouri, and Wyoming.

One phase of the work was stop-and-go tests simulating city traffic conditions. They revealed, for instance, that a single stop at 35 mph. wears away as much rubber as a mile of travel. They also indicated that the average rate of wear of tires used

TABLE 3

Roadway Condition	Passenger Vehicle	Light Truck	Heavy Truck	Tractor Trailer
	Miles per Gallon			
Expressway	22.3	12.3	7.5	4.5
Arterial street with coordinated traffic signals	18.4	10.1	6.2	3.7
Ordinary city street	14.9	8.2	5.0	3.0
Heavily congested business area street	8.7	4.8	2.9	1.8

The Citizens Traffic Safety Board of New York asserts that fuel consumption per vehicle in the city is 30 percent higher than need be, due to the traffic jam. Test runs made as part of the board's broad-gauge survey of congestion costs showed that passenger car mileage per gallon on Manhattan streets between 11 a.m. and 6 p.m. averaged only 9.77 miles. The dollar loss for New York's automobiles and trucks was set at $75 million a year. Twenty million dollars of this amount is ascribed to the estimated 80 million gallons of gasoline used up in cruising about in search of a place to park or load and unload.

In Boston, further research (1952) in this vein by Bone attested to the impact of worsening traffic conditions on fuel consumption. It will be recalled that his

regularly on city streets at customary speeds was between two and three times that of tires used on rural highways at 45 mph. Tire costs in stop-and-go driving on concrete pavements averaged 0.61 cent per mile, which was more than three times the corresponding cost in traveling the open road.

In a technical paper last year, Moyer stated that fuel, tire, and brake costs total, on the average, 1¼ cents more per vehicle-mile on congested surface arteries than on free-flowing expressways.

Investigators attribute virtually all the maintenance cost of brakes and clutch to traffic stops. Information gathered from service stations in the Los Angeles area, in connection with a recent study, "The Economy of Freeways", brought out that the brake lining and adjusting required by the average car per 25,000 miles comes to a minimum of $25; and that the clutch requires at least $35 of work per 35,000 miles. Cost of both these items totals 0.2 cent per vehicle mile of which sum, the report holds, 90 percent is chargeable to stops. Extra wear on all moving parts (including brakes and clutch) was estimated at 0.24 cents per vehicle mile.

As a concrete example of accelerated wear and tear on vehicles in New York's daily traffic crush, the citizens board study cites the experience of a major oil company with operations extending throughout the state. In intracity service, the firm's trucks require a new clutch every 18,000 miles; on out-of-town routes, every 40,000 to 50,000 miles. Rate of repair per delivery truck operating in the city is 6 cents per mile; upstate it is 4 cents. Truck motors require overhaul after 80,000 miles of city use; in upstate service, after 100,000 to 120,000 miles.

Altogether, New York's dollar loss from vehicle repairs necessitated by congestion (no accident involvement) is estimated by the safety board at $70 million a year.

Time Losses

The time loss factor looms large in all appraisals of the economic side of the traffic jam. However, though lost time is measurable with some degree of accuracy, its evaluation in terms of dollars and cents has been debated for years.

TABLE 4

Type of Road	Speed		
	High	Low	Mean
	mph.	mph.	mph.
4-lane divided parkway	62.4	48	55.1
4-lane U.S. 1	50.9	39.3	45.4
2-lane state highway	48	36.3	43.1
County road	39	30.2	33.6
City street	31	23.2	26.8

Source: "Study of Vehicle, Roadway and Traffic Relationships by Means of Statistical Instruments", Thomas J. Carmichael and Charles E. Haley, 1950 Highway Research Board Proceedings.

Worth noting as background in discussing this phase of research are Tables 4 and 5 on recent overall speeds, the first group recorded in Connecticut and the second in California. They give an idea of relative efficiency of present highways and suggest some of the sources of time waste.

Table 5

Signalized urban streets	Mean speed mph.
2-lane, uncongested	21.1
2-lane, congested	17.6
Multilane, uncongested	16.8
Multilane, congested	13.2
Rural sections	
2-lane, 1130 vehicles per hour	42.0
2-lane, 1440 " " "	31.9
4-lane, uncongested	49.4

Source: "Evaluation of Techniques for Determining Over-all Travel Time", Donald S. Berry, 1952 HRB Proceedings.

As the practical, or working, capacity of a surface street is reached, any further increase in volume results in mounting loss of both fuel economy and time. Intersections are the limiting factor in street capacity, and frequency of intersections is the chief cause of delays in urban travel.

Even with efficient signal control, and with only moderately heavy traffic, time losses at street crossings add up to substantial daily totals. This is demonstrated as far back as the early 1930's in studies made in Washington, D. C., by the Bureau of Public Roads. For instance, at one such intersection it was found (assuming a normal driving speed of 22 mph.) that delays during the two rush hours averaged 50 seconds per vehicle, and 30 seconds during hours of lighter travel. For a 10-hour day, including 8 hours with normal volumes averaging 380 vehicles and two peak hours with volumes averaging 1,750 vehicles, the estimated time loss was 6,500 car-minutes at the single stop, despite excellent signal control.

Similar tests at Los Angeles in 1949 by Donald S. Berry and Forest H. Green, of the Institute of Transportation and Traffic Engineering, University of California, indicated an average loss of 1.05 minutes per vehicle at peak hours at a typical major intersection. Observations made in connection with the studies of the Automobile Club of Southern California revealed that at rush hours, vehicles were sometimes held up at arterial crossings for as many as ten signal-change cycles.

Fixing a precise money value for time lost in traffic is a complex problem compounded by numerous variables and intangibles. In reporting the intersection delay tests just cited, E. H. Holmes called attention to the pitfalls of trying to establish a formula applicable to general conditions. He did, however, suggest what the cost of the delays at the signal stop investigated might be with theoretical values (see Table 6). The figures, of course, represent price levels of two decades ago.

TABLE 6

Assumed cost per car-minute	Delay per day	Per day	Per year (300 days)
cents	car-minutes	$	$
½	6,500	32.50	9,750
1	6,500	65.00	19,500
1½	6,500	97.50	29,250
2	6,500	130.00	39,000

Beginning around 1928, when T. R. Agg and H. S. Carter, of Iowa State College, published their report, "Operating Cost Statistics of Automobiles and Trucks," a great deal of work has been done in compiling cost data, which are the basis for estimating congestion losses. Ralph Moyer and Robley Winfrey, then of the same institution, not only collected and tabulated cost figures, but through mathematical analysis determined the operating cost of typical vehicles. Many commercial fleets and trucking associations have likewise assembled reliable data in this area. The Metropolitan Life Insurance Company has published a series of studies on the operating costs of various classes of commercial vehicles as a service to group-insured companies.

It is in the commercial vehicle field that unit-time value can be established with most accuracy. The biggest question mark in computing vehicle operating losses has been the amount that may properly be assigned for driver's time. Wide divergence of opinion has prevailed as to the money value of time in the case of drivers of private automobiles. On the other hand, no one questions that the lost time of personnel paid to drive trucks, busses and business cars should be equated with their wages.

The common view with respect to the commercial vehicle costs is expressed in "A Policy on Road User Benefit Analyses for Highway Improvements," a report issued in April of 1953 by the Committee on Planning and Design Policies of the American Association of State Highway Officials: "There is general acceptance of the premise that the saving of time for trucks and busses has a value in direct ratio to those costs of operation related to time ... such as the hire of drivers and the hourly rental of equipment. It has value also for fixed daily or monthly costs, such as overhead and possibly insurance, because saving in travel time results in greater usage for a given period of time."

We have at least an index of the huge annual surcharge that the traffic jam imposes on commercial vehicle operators in two fairly recent studies.

A 1948 survey in Providence, Rhode Island, revealed that trucks operating in the downtown section lost between one and a half to two hours daily. With truck time valued at from $3 to $4.50 per hour, according to vehicle type, the annual loss to the city's trucking interests was estimated at approximately $15 million.

A similar investigation by the New York Truck Association found that, in 1950, the average truck in midtown Manhattan was losing four hours of earning time daily. It is estimated that the average loss for each of the 30,000 trucks serving the area was $16.80 per day (at the rate of 7 cents per minute). Total annual cost of these delays was set at $150 million.

The Wall Street Journal, recently probing into economic aspects of New York's traffic problem, has cited some striking loss statistics for individual companies. The Railway Express Agency, with 1,200 vehicles in use in the city, reported that extra costs due to congestion now run $500,000 more per year than a decade ago. For the National Biscuit Company's vehicles delivering to New York stores, the annual extra costs were figured to be $50,000 higher last year than in 1947. The United Parcel Service, operating 250 trucks on Manhattan routes, estimated that due to traffic delays its labor costs alone were $100,000 greater in 1952 than five years ago.

Investigations of the Citizens' Traffic Safety Board of New York indicate that increased meter charges and tips for taxicab travel in the city come to something like $57 million per year.

Recognizing that congestion was exacting a progressively heavier toll from commercial carriers, the California Public Utilities Commission in 1948 conducted a series of truck-travel-time studies as a basis for an upward revision of rates. It was found that delays and other hindrances imposed higher operating costs equivalent to mileage additions of from 12 to 18.2 percent over the actual distance of the routes tested.

A startling statistic (if such information were available, and it isn't) would be the aggregate extra costs due to congestion for the vehicle fleet of the U. S. Post Office Department. The department uses nearly 85,000 government-owned-and-operated or contract vehicles, the world's largest automotive delivery operation. A few months ago it was reported that the department is striving to decentralize the handling of mails in congested areas. One plan to be tried is the establishment of distributing centers several miles outside of large cities, with revision of mail routes to bypass the traffic jam as much as possible.

School bus transportation is another large-scale public activity affected by congestion. More than 7,200,000 public school children are conveyed in busses daily in the United States. A Baltimore County official reports that while a few years ago, one of their busses could make three short trips each morning and each afternoon, only two such trips morning and afternoon are possible now because of dense traffic. This naturally necessitates the use of more vehicles. Multiply this case by countless others all over the nation, and the added cost is unquestionably substantial.

Commercial carriers which transport perishable goods are subject to still another penalty of the traffic jam — spoilage. Though no data have ever been assembled as to the amount of such waste, the annual cost may be very considerable.

The influence of the growing traffic jam on travel time is clearly evidenced in Table 7, based on passenger-car test runs made 10 years apart. This study was made by the Traffic Engineering Bureau of the City of Los Angeles.

As to the question whether it is justifiable to set a money value on the time of private car drivers, there have been pros and cons aplenty. Since some 55 million American drivers fall into this category, it makes a vast difference in congestion loss computations whether or not such value is assigned.

Some economists maintain that a distinction must be made between productive time and leisure time. Leisure time is accorded no economic significance. Only time which is used to create goods and services, or which can be exchanged therefor, is deemed capable of measurement in terms of dollars. This rules out monetary value for time lost in traffic by all motorists except commercial drivers and those who use vehicles strictly for business.

Other authorities hold that anything people are willing to pay for has economic value. It has been amply demonstrated that the public, including so-called pleasure drivers, is willing to pay substantial cash premiums to save time and avoid traffic interruptions. Even the regular

TABLE 7

	Distance	Speed		Time		Increase In Time
		1937	1947	1937	1947	
	(Miles)	(mph.)		(Minutes)		%
Pico Blvd. from Western to LaBrea	1.5	27.3	14.5	3.3	6.2	88
Hollywood Blvd. from Cahuenga to Western	1.2	18.9	15.1	3.9	5.05	30
Alameda from 1st to 6th	0.75	27.9	15.4	1.72	3.1	80
Third St. from Vermont to Western	1.0	24.0	18.4	2.5	3.3	32

taxes paid for the development of toll-free facilities are, in the final analysis, a reflection of this fundamental desire. For time-saving is the dynamic incentive behind all transportation progress, and both society and the individual have always attached high value to it.

Another fact adduced is that leisure time, far from having no economic value, often commands higher rates than regular work hours in business and industry — as witness time-and-a-half and double-time payments for overtime.

It is pointed out also that the bulk of private car driving today is for essential purposes. Ninety-two percent of all cars are used regularly for getting to work, shopping or both. According to the latter authorities, it is illogical to assume that the lost time of the countless people involved has no dollars and cents value, especially since these activities are closely tied in with the nation's economy. The mere difficulty of establishing a value that is universally acceptable certainly does not warrant complete elimination of this factor.

$0. 75 per person per hour results in a vehicle total of $1. 35 per hour."

The report uses this value in suggested formulas for calculating road user costs for continuous and interrupted operation. It is included, for instance, in a computation of extra cost per passenger car stop (above that for constant speed of operation) as shown in Table 8.

What is particularly significant about the dollar value for passenger car time proposed in the AASHO report is the fact that it takes into account not only the driver's time but that of other occupants. This is a relatively new departure. It opens up the question whether, in any comprehensive estimate of congestion cost, the time losses of other elements of traffic ought not to be considered.

For instance, there are 40 million daily transit riders. They are subject to the same traffic delays as passenger-car users. The vast majority of their trips, too, are for essential purposes, such as getting to work and shopping. If, as some experts assert, the increasing traffic delays tend to nullify the gains from shorter

TABLE 8

Standing Delay Period	Extra Cost per Vehicle Stop for An Approach Speed of					
	10 mph.	20 mph.	30 mph.	40 mph.	50 mph.	60 mph.
sec.	¢	¢	¢	¢	¢	¢
0	0. 1	0. 4	0. 7	1. 1	1. 8	2. 6
20	1. 0	1. 2	1. 5	2. 0	2. 6	3. 5
40	1. 9	2. 1	2. 4	2. 9	3. 5	4. 3
60	2. 8	3. 0	3. 3	3. 7	4. 4	5. 2

The latter view has gained ground in recent years, and virtually all recent studies on the economic feasibility of highway projects include money values for potential time saving for all segments of traffic.

This trend of thinking is reflected in the newly published AASHO report, "A Policy on Road User Benefit Analyses for Highway Improvement," mentioned earlier. In discussing unit operating costs for passenger cars, the report states: "The dollar value of time saving may vary considerably and no precise method of evaluation has been determined. A value of $1. 35 per hour or 2. 25 cents per mile is used herein as representative of current opinion for a logical and practical value. The typical passenger car has 1. 8 persons in it, and a time value of

working hours of recent years, great numbers of transit riders obviously are likewise affected.

In this connection, it is noteworthy that the Citizens' Traffic Safety Board study in New York includes an estimate of wages covering time lost in traffic. The figure (involving mainly industrial wage loss) is set at $350 million a year. In addition, the report calculates the time losses of top-salaried business executives at $18,750,000 annually.

Numerous origin-and-destination studies and public-opinion polls seem to indicate that the motorist considers time the most important factor in his choice of routes. Two illustrations will suffice:

Investigation in a certain section of Pittsburgh, established that drivers preferred a route that was 5. 7 miles long to

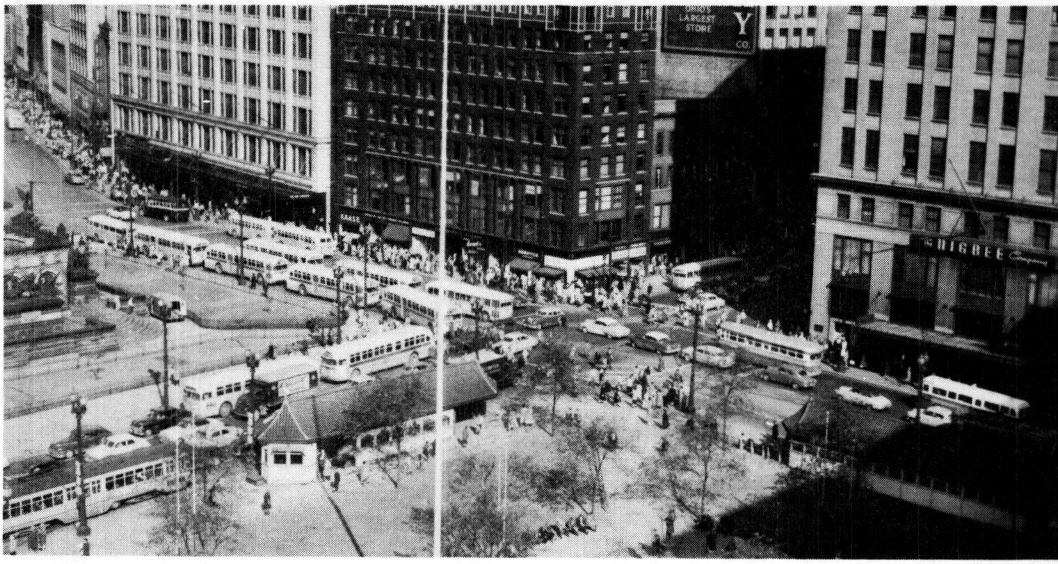

Figure 3. Some 40 million people ride mass transit daily in the United States.

another that was only 4 miles. Average time for the longer trip was 9.5 minutes. The shorter and more-congested route took 13.5 minutes. Thus motorists were willing to travel 1.7 miles farther in order to save 4 minutes.

More recently, the Bureau of Public Roads made a study of the use of the Shirley Highway (a freeway in Arlington and Fairfax Counties, Virginia) in comparison with use of parallel surface roads. It was revealed that of all freeway trips examined, only 38 percent saved distance, while 81 percent saved time.

Vehicle time, in short, is not only the most-accurate measure of highway efficiency but a basic index of savings or loss to users. It has long been a primary yardstick in establishing the economic justification for new facilities. Actually, much of what we know about congestion costs has been derived, in rather roundabout fashion, from studies of anticipated benefits from improvements. Many of the techniques for determining losses have evolved from early research on economic feasibility.

A classic example is the economic survey in the mid-1920's which preceded the development of the New Jersey High-Level Viaduct (now known as the Pulaski Skyway), completing the express highway

Figure 4. Part of the Shirley Freeway, in northern Virginia near Washington, D.C.

from Elizabeth to the Holland Tunnel. The survey was directed by Sigvald Johannesson, at that time design engineer with the New Jersey State Highway Department. The main object of the proposed improvement was to eliminate acute traffic bottlenecks caused by two low-clearance drawbridges (10 feet above mean high water) over the Hackensack and Passaic Rivers.

Figure 5. Pulaski Skyway, an example of a high-level viaduct.

It was first proposed to carry the highway across on a new pair of bridges with an under-clearance of 40 feet, to be constructed a short distance above the existing ones. Johannesson's calculations showed that this solution was uneconomical, since even with increased clearances the delays due to openings and closings would total 32,470,000 vehicle-minutes annually, which he evaluated in the sum of $714,355 a year. In addition, he figured that the carrying capacity of the highway itself would be reduced by 6.33 percent, representing $1,392,000 of its estimated $22 million cost. As a result, the alternative viaduct plan was adopted.

The formulas for evaluating time loss which Johannesson developed are significant because they later served as a basis for congestion cost estimates of a number of cities in other parts of the country. Detroit, for instance, used them to arrive at $10 million-a-year figure in 1936, and by extrapolation, at $18 million-a-year figure in 1941.

The New Jersey study was one of the earliest to assign value to the time of private car, as well as commercial drivers. Modern toll roads had not yet come into being, so he drew his justification from other forms of transport. He noted that railroads charged extra fare on trains making the run between Chicago and New York in less than normal time. The premium paid was $1.20 an hour, or 2 cents per minute saved. Again, he pointed out that on the New York-to-Cherbourg steamships with comparable accommodations and service, the rates varied in accordance with whether the trip took 6, 7, or 8 days. The extra charge per day saved was $30, or about 2 cents per minute also. In view of this, he thought it was reasonable to assess the driving time of the private motorist conservatively at 0.75 cent per minute.

As a matter of historical interest, the per-minute time values he developed for the various types of vehicles are given in Table 9.

TABLE 9

	Cents
Trucks	
vehicle operation	0.34
driver's time	1.15
	1.49
Commercial passenger cars	
vehicle operation	0.15
driver's time	1.23
	1.38
Private passenger cars	
vehicle operation	0.03
driver's time	.75
	0.78

Following completion of the high-level viaduct, a before-and-after study of travel times was made jointly by the New Jersey Highway Department and the Bureau of Public Roads. The findings were described in the February 1934 issue of Public Roads magazine by Lawrence S. Tuttle. In substance, they showed that on the old route, peak travel (over 1,300 vehicles per hour) had occurred during two hours of each weekday, 5 hours on Saturday and 13 hours on Sundays and holidays. Average passenger car time for these hours was 13.2, 14.6, and 17.9 minutes, respectively. On the viaduct the average trip time for the same hours was 5.8, 6.0, and 6.3 minutes, respectively.

It was estimated that, at a minimum, the time saved annually by all vehicles using the viaduct was 49,130,000 minutes. In addition, the reduced congestion on the old ground-level route resulted in an annual saving of 5,542,000 minutes for a grand total of 54,672,000 vehicle-minutes. At an assumed average value of 2 cents per minute, the time saving brought about by the new facility amounted to $1,093,440 per year.

The ultimate test of the validity of assigning monetary value for the time of the nonprofessional driver is, of course, whether he is willing to pay extra to save it. Growing public acceptance of toll roads suggests the answer, since the motorist's cost on a toll facility is about four times as great as on a free road, and the chief benefits are time-saving and freedom from congestion.

As an illustration, the Maine Turnpike and the parallel US 1 route are approximately equal in length. The higher speeds on the turnpike consume more fuel than those on US 1, and this factor largely offsets the extra costs caused by traffic stops on the free road. However, the driving time on the 44-mile turnpike section between Portland and Kittery is less than an hour, whereas on US 1 it ranges between 1½ and 2 hours. On the basis of tolls charged, it is estimated that the value of the time saved is a little over 50 cents per hour for passenger cars, and between $1 and $2 per hour for trucks.

In the case of the Pennsylvania Turnpike,

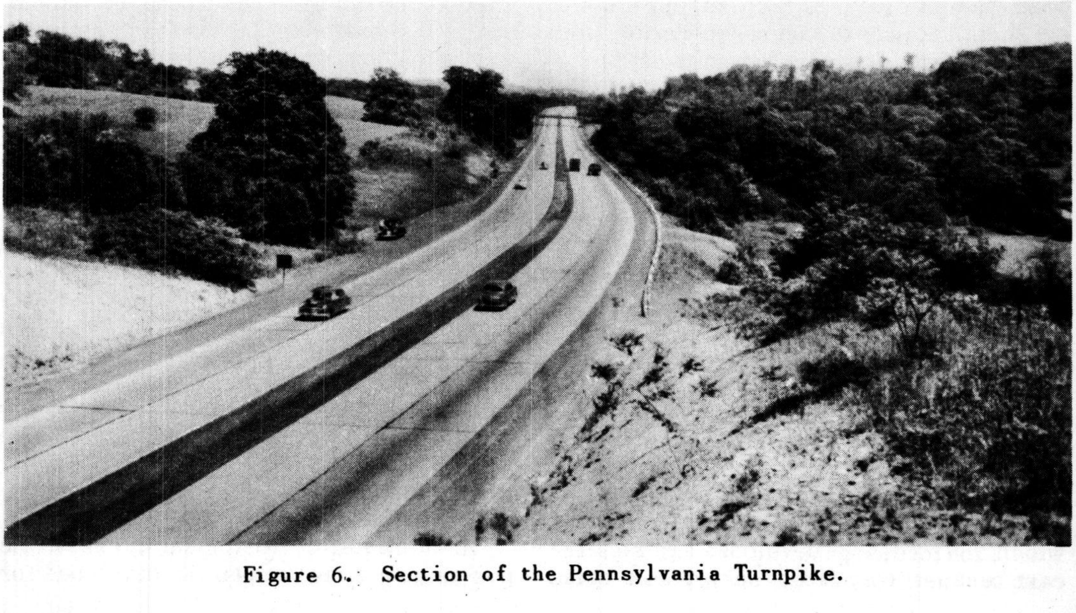

Figure 6. Section of the Pennsylvania Turnpike.

the distance differential between the 160-mile original section and the alternative free route (combined US 30 and US 110) is also negligible. However, grades on the turnpike are substantially less than on the other route, 3 percent and under compared with 6 to 8 percent. In 1948 a series of test truck runs were made on a 149-mile portion of the turnpike and on a similar length of the alternative route. Results were reported in the Highway Research Board report "Time and Gasoline Consumption in Motor Truck Operation." They showed that time savings on the turnpike ranged from 1¼ hours for very light trucks to 4½ hours for the heaviest units.

Because of the easier grades, substantial savings in fuel cost are also realized on the turnpike, especially by commercial traffic. For a combination truck of 62,000 lb. gross weight, it was demonstrated that there was a 23-gallon saving in gasoline as well as a 3-hour reduction in time. Taking into account drivers' wages, rental value of the truck, fuel, depreciation and other operating costs, total savings on the turnpike probably amount to more than $20, at conservative estimate, or twice the $10 toll charge for a truck of this weight.

The tests in question did not include passenger cars, but other sources indicate that as against the $1.50 toll for the 160-mile trip on the turnpike, the average automobile saves about 1½ hours of time and 3 gallons of fuel. Since the alternative route has an unusually large number of stops, wear-and-tear savings are also appreciable.

Some notion of the aggregate traffic time loss in urban areas is given in "Highway Needs for the National Defense," a 1949 study of the Interstate System by the Bureau of Public Roads. Annual travel on the sections of the system in cities of 5,000 population or more was computed as 17,180 million vehicle miles. Total travel time for this movement was reckoned at 47,589 million vehicle minutes (average speed about 22.5 mph.).

It was estimated that if the streets were adequately improved so as to permit an average speed of 35 mph., a saving of 20,919 million vehicle minutes would be possible, taking into account the increased traffic the better facilities would induce. The study brought out that at a cent a minute, this time saving would be worth more than $209 million annually, a sum approximately four fifths of the annual cost of the required modernization.

As a footnote to the costliness of delays in American cities, it is interesting to note that the British Road Federation recently estimated that if the speed of London's transit busses and coaches could be increased by 1 mile per hour, that saving alone would amount to £2 million ($5,600,000) a year.

In emphasizing the economic significance of time loss, both in terms of vehicle operating costs and man-minutes, the related factors of inconvenience and discomfort should not be overlooked. The strain and fatigue caused by bad traffic conditions may have important implications for the nation's health and can hardly be ignored as contributory to the high accident rate.

Because traffic inconvenience and discomfort are relative terms, with different meanings for different people, they are equally hard to measure and evaluate. In the past they have been viewed more or less as indeterminate aspects of time loss or, as it were, its physical symptoms. Traffic interference and irritations being inescapably bound up with delays, the cost of the latter was assumed to be inclusive of the former.

A change in viewpoint seems to be in the making. For instance, the recent AASHO report "A Policy on Road User Benefit Analyses for Highway Improvements" assigns a definite value for comfort and convenience as one of the operating cost factors, along with time, fuel, vehicle depreciation and others. The 1 cent per vehicle-mile assigned this factor for "restricted operation" on paved highways might conceivably become an additional unit of measurement of congestion cost.

ACCIDENT LOSSES

The relationship between congestion and accidents remains one of the unexplored frontiers of research. No scientific evidence is yet available to indicate what proportion of accidents is directly due to the congestion factor. We do know, however, that the elements of design and operation which impede free movement also contribute materially to mishaps. Further, the evidence clearly shows that when modern design provides adequate capacity in heavy-volume highways, those roads become much safer.

The nation's losses from traffic accidents reached $3¾ billion in 1952, according to the National Safety Council. It might be pointed out, in this connection, that with formulas developed by the council, states and cities can determine what motor vehicle accidents are costing them annually in terms of wage loss, hospital and medical expenses, overhead cost of insurance, and property damage.

Relatively little progress has been made on the question of relating road conditions and design to accidents. A major stumbling block has been the lack of adequate information about accidents. Reporting is nonuniform and spotty; available data frequently do not lend themselves to correlation with elements of highway design and operation. Moreover, precise identification and measurement of these relationships by the engineer present many difficulties.

One notable attempt to relate physical characteristics of roadways to accident experience was a study conducted in 1941-45 by C. F. McCormack and David M. Baldwin, under the joint sponsorship of the National Safety Council and the Bureau of Public Roads. More than 16,000 accidents on approximately 5,000 miles of highway in 15 states were analyzed. Procedures were worked out to correlate design features, the character of traffic, and roadside development on different sections of highway as closely as possible with the accident rates on those sections. The findings were later amplified and the techniques appraised in a report by Morton S. Raff, entitled "The Interstate Highway Accident Study," published in the June 1953 issue of Public Roads Magazine.

These investigations revealed such important facts as the following:

At high traffic volumes, the lowest accident rates occur on divided roads with controlled access, while the highest rates are found on three-lane roads.

On most types of highways the accident rate mounts with increasing traffic volume, except for a slight reversal at extremely high volumes, presumably because extreme congestion limits the driver in making passing maneuvers.

The average number of accidents per intersection carrying between 10,000 and 14,000 vehicles per day is ten times greater than the ratio for intersections handling between 4,000 and 5,000 vehicles per day.

The total accident rate per million vehicle miles is higher for curves than for tangents on all classes of highways.

Table 10 summarizes some of the study's basic findings with respect to the relation of roadway type and volume to accident rate. The rates indicated are per million miles of travel.

This phase of research merits further study. While the surface has barely been scratched thus far, such evidence as has been unearthed seems to support the statement made in 1952 report of the Engineering Committee of the President's Highway Safety Conference: "Lack of capacity lies at the root of much of the traffic-accident problem."

Earlier, in 1948, former Public Roads Commissioner Thomas H. MacDonald had declared in his Beecroft Memorial Award Lecture:

> The outstanding hazard of our streets and highways is undercapacity for the traffic load. Nearly half of the rural highways carrying 1,000 vehicles a day and over are less than 20 feet wide. On each mile of such highway, over 60 times per hour — or once each minute — a vehicle is encroaching upon the left lane when meeting an oncoming vehicle. Expanding these figures to the many miles of rural highways in this country, the accident potential reaches unrealized dimensions.
>
> The accident rate on two-lane rural highways carrying less than 1,000 vehicles per day is approximately half that on similar highways where the volume is in the 8,000 vehicles or over per day range. That is, on overloaded highways or underdesigned highways, the accident rate increases with the traffic volume. On such highways, we would logically think drivers would become more careful. Paradoxically, driver behavior becomes worse as the road becomes more inadequate to carry safely the traffic volume. Contrariwise, evidence supports the conclusion that as the standard of design is raised, driver performance becomes more responsible.

The 1949 report, "Highway Needs for the National Defense," pointed out that of some 32,000 miles comprising the rural portion of the National System of Interstate Highways, only 1,900 miles were adequate for current traffic. The fatality rate on the adequate sections averaged only 5.65 deaths per 100 million vehicle miles. The report estimated that if the rate could be brought to the same low level on the total rural mileage, more than 1,400 lives a year could be saved on the rural sections of the 38,000-mile system alone.

But it is in the larger cities that the

TABLE 10

Average Daily Traffic Volume, Vehicles	2-lane	3-lane	4-lane Undivided	4-lane Divided	4-lane Controlled Access
Under 5,000	3.5	3.8	2.3	---*	3.4**
5,000 to 9,000	4.5	4.1	4.0	3.2	---
9,000 and Over	2.6	11.1	3.8	4.1***	1.5
All Volumes	3.7	5.0	3.7	3.8	2.3

* Sample considered too small for reliability.
** Very high speed roadway.
*** Includes a considerable portion with median strip delineated by paint only.

heaviest concentrations of traffic are found and the effect of overloading on the accident rate most striking. Studies in California and other states have shown that the accident rate on major city streets is double the national average for all streets and highways. Moreover, research on the West Coast has indicated that the rate on the average major street is five times that of the average urban freeway.

"The Economy of Freeways," a study of high-type motorways in comparison with major surface thoroughfares in the Los Angeles area, reported: "A freeway on an equal number of traffic lanes handles three times as many vehicles at twice the average speed and at an accident rate five times as favorable as a comparable surface artery."

Table 11 gives comparative rates (or other accident indices) on various expressways and ordinary surface arteries carrying similar traffic volumes.

These representative examples amply demonstrate the safety value of such expressway features as the physical separation of opposing streams of traffic, control of access and elimination of crossings at grade, as well as multilane design, ample pavement and shoulder widths, easy curves and adequate sight distances.

Moyer estimates that the accident cost on urban freeways averages about ¼ cent per vehicle mile, compared with 1½ cents on major surface streets. The cost differential, which he lists as one of the benefits of freeway design, is – conversely – also an index of the part of the accident cost which is eliminated where congestion is eliminated.

The following excerpt from the New York Citizens' Traffic Safety Board report deals with the annual accident bill of a city the size of New York:

> Studies show accidents rise in proportion to the amount of traffic congestion rather than in the actual number of vehicles using a certain thoroughfare. Insurance company executives figure if traffic flow in New York were "normal" the accident rate would drop about 25 percent – a saving to the companies of $18,250,000 in accident insurance settlements this year. We can add to that the $26.5 million for wage loss, medical expense and repairs to property – plus the tragic cost in grief and misery.
>
> A reduction in congestion – and the accompanying drop in accident rate – would reduce premiums by about $30 million annually for private passenger cars, commercial vehicles and taxicabs. In the decade between 1940 and 1950, the number of passenger cars carrying bodily injury insurance rose almost four times. But, since total losses multiplied about seven times, the insurance companies had to increase premiums almost five times.

ECONOMIC BENEFITS OF EXPRESSWAYS

The economic penalty that the public pays for inadequate highways is like an iceberg in that the major part of it is submerged and invisible. It is the job of the engineer and economist to identify, define and evaluate the components of the total cost and make them intelligible to the average citizen. This is the purpose of the growing number of economic feasibility studies being made for proposed projects. The recent AASHO report setting forth practical procedures for analysis of highway improvements in terms of benefits to road users was prepared to the same end.

Since expressways are built specifically to relieve congestion, it is pertinent to examine one or two comprehensive estimates of resulting monetary benefits, as developed in recent surveys.

In "The Economy of Freeways," the Los Angeles Department of Public Works reports results of a study of sections of different freeways, totaling approximately 16½ miles in length, in comparison with major surface arteries. Minimum benefits per vehicle mile on the freeways are evaluated in Table 12.

TABLE 11

State	Highway	Period	Fatality Rate per 100 Million Vehicle-Miles
Maine	U S. Route 1*	1948	22.3
	Turnpike	1948-50	2 8
Connecticut	Boston Post Road*	1940-48	10.7
	Merritt Parkway	1940-48	3.4
New York	Metropolitan New York Parkway System	1938-48	2.5
New Jersey	3 and 4 Lane Undivided Highways*	1935-48	14
	Same Highways when Rebuilt as Divided Highways	1935-48	4.5
	Route 4, Divided Highway with Grade Separation	1935-48	4.0
	New Jersey Turnpike	1952	5.8
Pennsylvania	Pennsylvania Turnpike	1941-50	10.0
	" "	1952	7.3
Virginia	Pentagon Network	1942-48	1.5
	Shirley Highway	1952	4.4
	U. S 1*	1952	17.9
Illinois	Chicago Outer Drive	1946	2.9
Texas	Gulf Freeway	1949	1.9
California	Rural State Highways*	1947-51	9.0
	Arroyo-Seco Parkway	1941-51	1 5
	Hollywood (Cahuenga) Freeway	1948-51	2.5
	San Francisco Bayshore Freeway	1948-51	2 2
Oregon	S. W. Harbor Drive	1949	0

State	Highway	Period	Fatal and Injury Accidents per 100 Million Vehicle-Miles
Michigan	U.S. 112*	1946	625.3
	Detroit Industrial Expressway	1946	91.1
California	Figueroa Street*	1947	407
	Wilshire Boulevard*	1947	267
	Riverside Drive	1947	114

State	Highway	Period	Fatal, Injury & Property Damage Accidents per Unit of Traffic Volume (Depressed Section = 100)
Michigan	Davison Expressway, Detroit		
	Surface Drive (Local traffic)*	1945-48	1667
	Depressed Section (through traffic)	1945-48	100

Sources: U. S. Bureau of Public Roads, Engineering Committee Report, 1949 President's Highway Safety Conference.
*Not modern highways.

Over a 3-year period, the total travel on the freeway sections studied was 76 millioh vehicle-miles. At a 2 cents a mile savings, the monetary benefits amounted to $15 million. If the savings at this rate were applied to the payment for the facilities, their original cost of $42 million would be amortized in less than 10 years.

In a similar, but more general, study of unit costs, Moyer arrived at a per-mile saving of 4 cents to users of freeways, as itemized in Table 13.

TABLE 12

	¢
Gasoline savings	0.33
Maintenance cost savings due to elimination of stop-and-go travel	.24
Time savings (commercial vehicles only)	.56
Accident savings	.87
Total	2.00

Moyer stated that his estimate was in line with fees charged on various toll facilities. He pointed out that the toll for passenger cars on the Pennsylvania Turnpike is 1 cent per mile, 2 cents on the Maine Turnpike and 3 cents on certain sections of the New Jersey Turnpike. Truck tolls are from two to six times the passenger car tolls, depending upon the weight of the vehicle. He added:

"The average combined toll for cars and trucks on the sections of the New Jersey Turnpike near New York City are not less than 4 cents per vehicle mile. This is an indication that the promoters of this project are collecting a toll equal to the monetary savings of 4 cents per vehicle mile, which my analysis shows may normally be expected when driving on freeways."

TABLE 13

	¢
Operating cost savings	1.25
Time savings (commercial and business vehicles only)	1.50
Accident savings	1.25
Total	4.00

Some recent feasibility studies have used a novel approach to present benefits in meaningful perspective. One example is the economic survey for proposed expressways in the Richmond-Petersburg district, made in 1946 for the Virginia Department of Highways. In the report, the itemized costs of the recommended facilities are set side by side with the itemized, dollar-evaluated benefits, in a single package, as it were.

It is interesting to note that in this study, as in the AASHO policy report on road-user benefit analyses, a specific money value is assigned for "comfort and convenience." In addition, fixed values are set for such intangibles as insulation from traffic nuisances and assistance to zoning, and to increased accessibility. The latter advantage, for instance, is rated at $5,000 per mile per year.

minutes a year. Evaluating the time at 2 cents per vehicle-minute for cars and 5 cents for trucks, they calculate the annual savings to users at more than $2,888,000 annually.

The Hollywood Freeway is 10 miles long and is used daily by 120,000 motorists. The California State Highway Commission estimates that the motorist saves a minimum of 1 cent per mile in vehicle operating costs, exclusive of the value of time conserved. These savings total $4,380,000

Figure 7. Airphoto of the Gulf Freeway, Houston.

Here are a few more examples of transportation economies resulting from expressways:

The Edens Expressway in Cook County, Illinois, was completed in October, 1951. The motorist covers its 14 miles, comfortably and without a stop, in 17 minutes. On the old route in the same vicinity, the trip required 30 minutes under the most favorable conditions. In terms of time, tire and gasoline savings, it is estimated that benefits total $3 million a year. Thus the cost of the facility ($22 million plus) will be recovered in less than 8 years.

Authorities at Houston estimate that the 8-mile original section of the Gulf Freeway is conserving over 100 million vehicle-

a year — which capitalized at 4 percent, demonstrates that the real worth of the facility is nearer $109,250,000 than the $55 million it took to build.

"If the value of time is considered," the commission declared, "the annual saving would be double the amount ($4,380,000). It would result in a valuation in excess of $200 million, and pay back its cost in a little over 6 years."

Numerous other illustrations to the same effect could be cited. From the savings that have been realized on the relatively small mileage of expressways completed in the United States to date, it is apparent that with congestion still as widespread as it is, the economic losses to the public are tremendous.

Recent research by the Automobile Manufacturers Association sets at $3 billion the yearly loss due to congested and unsafe highways. This figure is broken down roughly as follows: $1¼ billion for accidents, $750 million in wasted gasoline and needless wear on tires and brakes, and $1 billion in increased trucking costs.

URBAN BLIGHT AND RELATED LOSSES

Over and above the congestion losses already discussed — those to which all road users are subject more or less directly as individuals — are others, somewhat more difficult to measure, which affect whole neighborhoods in urban areas.

Municipal officials have long been concerned about the destructive effect of the traffic jam on the economic vitality of downtown business centers. They have viewed with growing apprehension the steady decline of residential sections, where the swelling flood of commercial and through traffic spilled over and invaded local streets.

Abnormal decentralization, flight of trade, blighted areas and slump of property values are some of the costly results which are commonly associated with bad traffic conditions. All tend to choke off municipal tax revenues, which in turn means a narrowing of essential public services. In the background, inevitably influenced by these trends, fester crime, juvenile delinquency, disease and other social hazards.

As regards our major cities, however, no effort has been made in recent years to segregate and gauge the actual effect of congestion on retail business and the other elements in the economy of downtown centers. A limited amount of information has been developed for smaller communities. Perhaps the most revealing of this is embodied in the series of bypass studies conducted in 1949-50 by California.

These investigations showed unmistakably that relief of congestion in a small city, even when obtained by an expressway bypass, tends to benefit the majority of retail establishments. In the communities studied, decrease in traffic volumes due to bypass ranged from 10 to 44 percent. Despite this, the overall volume of business rose from 17 to 48.5 percent. These gains far outstripped comparative increases in the respective counties and the state as a whole. The only exceptions to the marked business improvement were types of enterprise catering chiefly to through traffic, such as bars, cafes, and service stations. To some extent, these establishments were affected adversely, though in some instances these too experienced gains.

These findings seem to bear out what many authorities have long held, without much empirical proof: Congested traffic is not an asset but a liability to main shopping districts. In this view, the traffic jam is progressively destroying the chief requisite of the central business core — accessibility — upon which, in the final analysis, the prosperity of our metropolitan areas depends.

With reference specifically to urban blight, it is a moot question how much of the losses involved are attributable to traffic troubles. Many other factors are involved, including growth and shifts of population, fluctuation of economic conditions, changes in employment patterns, the quickening trend of suburban development, and neighborhood layouts and individual buildings which are functionally and structurally outmoded for today's needs.

In 1950, Walter J. Mattison, then chairman of the American Bar Association's Committee on Urban Redevelopment and City Planning, Section of Municipal Law, described the dimensions of the blight problem in these terms: "It has been estimated that serious blight has already overtaken approximately one fifth of the commercial and residential areas of larger urban cities . . . and that it is destroying realty values to the extent of more than $4 billion a year."

A survey by the National Association of Real Estate Boards revealed that 173 sq. mi. of developed areas in 117 large cities are so deteriorated as to require complete rebuilding; and that in addition, 54,000 blocks in 93 cities of over 100,000 population are in an advanced state of blight and obsolescence.

Shrinkage of property values in the downtown business districts proceeded at an alarming rate in the 1930-46 period, as shown in a few representative statistics from a 1946 American Automobile Association compilation covering some 35 cities (see Table 14). The deflationary effect of the depression years accounted for much of the decline, obviously, though few municipal officials discount the importance of such contributory factors as congestion, parking shortage, decentralization and blight.

culprit in the drastic ebb of the property tax yield.

For instance, the late Mayor Jeffries of Detroit, in a statement in 1944 before the Committee on Roads of the U. S. House of Representatives asserted that the $200-million-plus shrinkage in assessed valuation of downtown property since 1930 was largely due to reduced accessibility arising out of deficiencies in the street system.

TABLE 14

City	Valuation	Year	Valuation	Year	Decline $	Decline %
Philadelphia	$511,893,706	1935	$363,734,500	1946	$148,159,206	28.9
Columbus	445,000,000	1930	287,000,000	1940	158,000,000	35.5
Louisville	105,347,445	1930	74,569,225	1945	30,778,230	29.2
Portland (Ore.)	38,765,720	1935	23,490,350	1945	15,275,370	39.4
New Bedford	133,255,000	1930	91,600,000	1938	42,225,000	31.6
Yonkers (N. Y.)	13,820,268	1936	10,228,550	1945	3,591,718	26.0

Between 1930 and 1946, the wealth of the City of Milwaukee, as reflected in its tax rolls, decreased by 25 percent. Realty values during the period dropped nearly $90 million, "the greater part of the loss occasioned by the inroads of blight in the very heart of the city."

A significant study in St. Louis showed that the city's rundown sections were receiving public services costing 2¼ times the amount paid by them in taxes.

As has been emphasized, not all — and maybe not even a major part — of this urban decay stems from congestion and related traffic ills. But it is inconceivable that the transportation elements do not exert a substantial impact. No one can dispute that the vehicle-choked streets, the noise, the fumes, the delays and exasperations, all tend to make the city a less-desirable place in which to live and do business. Nor is there reason to doubt that these factors materially retard and repress normal urban development and redevelopment.

Measurement of the congestion influence poses an intricate problem. It is full of variables and unknown quantities, and probably cannot be resolved with a high degree of accuracy. The difficulties, however, do not justify the almost-complete absence of research in this field. A subject of such scope and importance surely deserves at least an attempt at scientific exploration — particularly since many municipal authorities feel that the traffic jam is the chief

In Boston, the mayor's 1941 report to the city council cited a $456-million drop in property values during the preceding decade, nearly half of the city-wide decline being accounted for by losses in the downtown district. He sized up the situation in these words: "Unless we can, as a start, relieve traffic congestion which exists within our city and unless we can provide facilities for business terminals and parking of motor vehicles, we shall make no progress in the rehabilitation of Boston."

There is evidence that, since the end of World War II, downtown-property values, at least in certain sections of the country, have been making substantial recovery. For instance, investigations in connection with the current Highway Research Board study on parking economics (see Special Report 11) revealed that the market value of some parcels of property in the business districts of San Francisco and Oakland is now on the peak level reached in 1929. A trend of stabilization or improvement in downtown property values has also been reported in other cities.

Another sign of a strengthening in the downtown economic situation is the recent spurt in office-building construction noted in many leading cities, including New York, Philadelphia, Pittsburgh, Dallas, Atlanta, Chicago, and Denver. <u>Business Week</u>

magazine reported a few weeks ago that "hardly a city in the nation has an office-occupancy rate of less than 95 percent. Office-building owners are normally pleased with a 90 percent rate."

If these straws in the wind do actually represent a national trend, it would seem to indicate that congestion exerts a lesser effect on property values than generally believed — considering the unprecedented increase in traffic postwar. On the other hand, the postwar years have been marked by heavy gains in population, employment, and national income. The fact that these upward forces have served to lift the level of property values downtown does not eliminate the possibility that the gains would have been even more impressive with the alleviation of traffic ills.

Nothing in our limited knowledge about congestion costs refutes the dramatic statement made a few years ago by the Urban Redevelopment Division of the National Housing Agency: "Investments in real property of all kinds — homes, stores, apartment houses — are at the mercy of the traffic stream. Properly channeled and controlled, this stream will stabilize and enhance property values. Uncontrolled, it can undermine the value of homes and entire neighborhoods in a city."

The potentials for boosting property values through provision of safe and congestion-free facilities are clearly evident from expressway developments in many parts of the country. The Westchester County Parkway Commission reported in 1933 that the value of land adjoining the Bronx River Parkway, completed in the early 1920's, soared more than 700 percent. Property adjacent to the San Joachin Valley Freeway (California) increased from two to six times the appraised value at the time right-of-way was acquired. Market price of land abutting the Gulf Freeway, in the 5 years after the Houston section was in place, rose 70 percent above that of land beyond the zone of influence of the facility.

A report just issued by Robert Moses, "The Influence of Public Improvements on Property Values, New York City", contains a number of equally striking examples. To cite just a couple:

Between 1939 and 1953, the assessed

Figure 8. West Congress Street Expressway looking east towards the Federal Building, Chicago.

valuation of property alongside the Shore Parkway in Brooklyn went up 76 percent, as against an increase of only 14 percent for the borough as a whole. In the Borough of Queens, property within the area of influence of the Grand Central Parkway increased in value by 937 percent between 1935 and 1953. The ward in which the parkway is located recorded a rise of 158 percent during the same period, and the entire borough only 76 percent.

principal streets are clogged, as they often are, almost to the point of immobility.

STATUS OF RESEARCH AND NEEDS

Congestion, which has reached a critical stage not only on metropolitan arteries but on many rural trunklines as well, is making huge inroads on the economic substance of the nation. Many believe it poses a direct threat to the solvency and physical stability of most of our larger cities.

Figure 9. Hollywood Freeway in Los Angeles.

Rounding out the congestion-cost picture, mention also should be made of the extra expenditure required for conducting normal municipal services. This is another of the economic penalties of the traffic jam, though often overlooked. New York, for instance, estimates that traffic confusion hampers the efficiency of these municipal activities to the extent of $10 million a year.

Our cities have a huge investment in the trained personnel, facilities, equipment, and vehicles associated with police work, firefighting, public utilities, and health services. Their stand-by value for emergencies is a prime consideration in the establishment of these services; yet this value is regularly impaired by congestion. Beyond the immediate losses lurks the danger of far more appalling costs — not only in dollars but in life — if a major fire or similar disaster should strike when

While congestion has been recognized as an increasingly serious problem for over a quarter of a century, its economic impact and ramifications are still but superficially understood today.

Road-user losses, the traditional yardstick for evaluating the economic penalties of the traffic jam do not reflect the total cost.

Research on the economics of congestion is still in its infancy, despite the fact that the subject has deep and long-recognized implications for the general welfare. Intensive study of all its complex phases is urgently needed to bring the congestion-cost picture into clearer focus and to define more accurately the burden imposed upon the individual citizen, the community, and the nation.

Areas which call for further technical study include:

Vehicle-Operating Costs

At present there is no uniformity either in the types of expense included in estimates of operating losses, or in the weighting given certain variables and intangibles. This underscores the need to develop more facts so as to limit the number of assumptions and arbitrarily assigned values, or at least to cut down the probability of error. Research might succeed in narrowing the margin of current differences in evaluation, to the end that acceptable norms could ultimately be established.

Causes of Accidents

More facts are needed on the effect of highway deficiencies, particularly lack of capacity, on the accident rate. Up till now there has been little scientific inquiry into the relationship between accidents and highway design, traffic operations, vehicle design, and driver characteristics.

Investigation of motor-vehicle accidents should be brought to the same high level of thoroughness and competency as that prevailing with respect to industrial, railroad, and airline accidents. The President's Highway Safety Conference has repeatedly emphasized that study should be undertaken to develop sound investigative techniques, as the basis for improvement of accident records in the states and cities.

Congestion Impact on Municipal Economy

The backward status of research on the economic side of the traffic jam is especially marked as to facts about the detrimental effect on downtown business activity, property values, blight, etc. It is commonly held that congestion has a disintegrating influence on cities; that it tends to strangle the economic life of communities. To what extent these things are true, and how precisely these adverse results can be appraised dollarwise, no one knows. Quantitative measurement is admittedly not easy. Even the most exhaustive research might produce only partial answers. But the challenge to find some kind of answers is inescapable.

Development of Comparable Statistics

Uniform procedures should be developed for estimating total congestion losses (1) as a more reliable measure of the cost nation-wide and (2) as a means of determining economic justification of road and street improvements.

A well-planned program of research, bringing to bear all the pertinent sciences and the integrated experience of business men, public officials and other leaders, would go far towards removing these subjects from the realm of pure speculation. The many-sided Highway Research Board study of the effect of parking on business, which recently has been carried forward at four major universities with funds provided by the automotive and petroleum industries, is an example of what can be done along this line.

In the future, more than ever before, road financing and design policy will be controlled by the economics of highway transportation as determined by facts. It is all too clear that currently we lack much vital information about the vast segment of highway economics represented by congestion costs.

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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

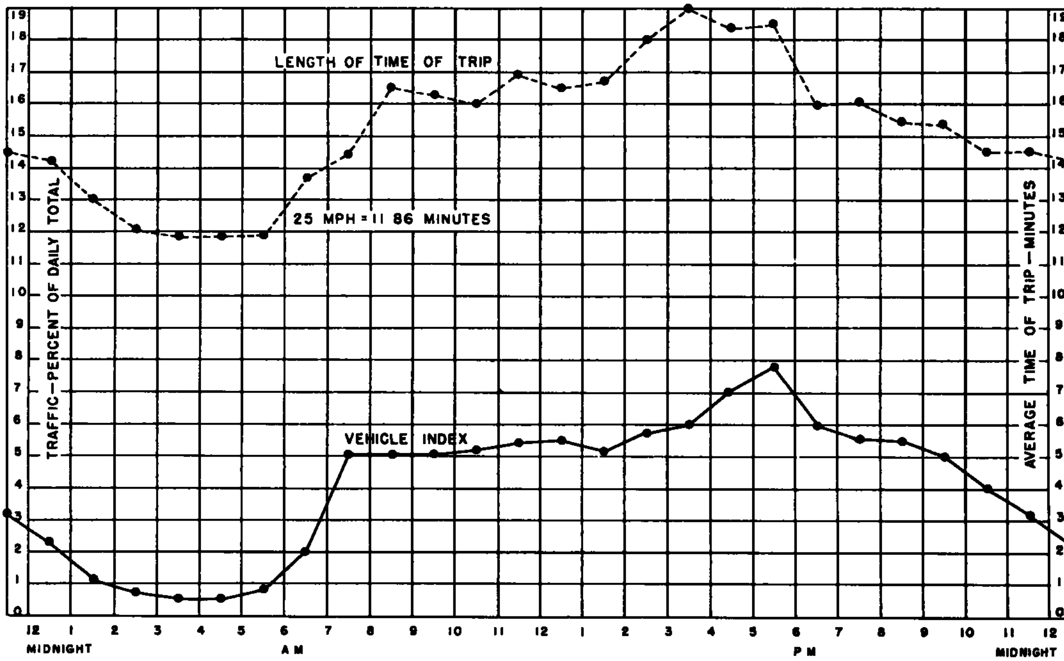

Figure 1. Time of average trip in minutes compared to traffic density on Washington Street from Patrick Street Bridge to Kanawha City Bridge, Charleston, West Virginia, 1944.

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

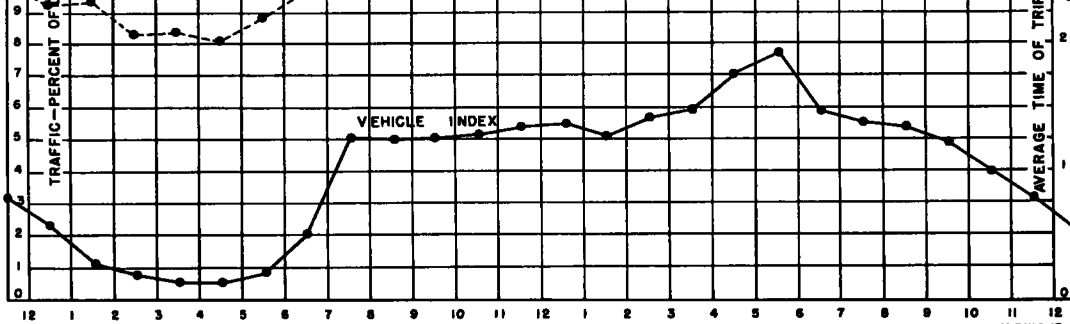

Figure 2. Time of average trip in minutes compared to traffic density on Summers Street from Kanawha Boulevard to Dryden Street, Charleston, West Virginia, 1944.

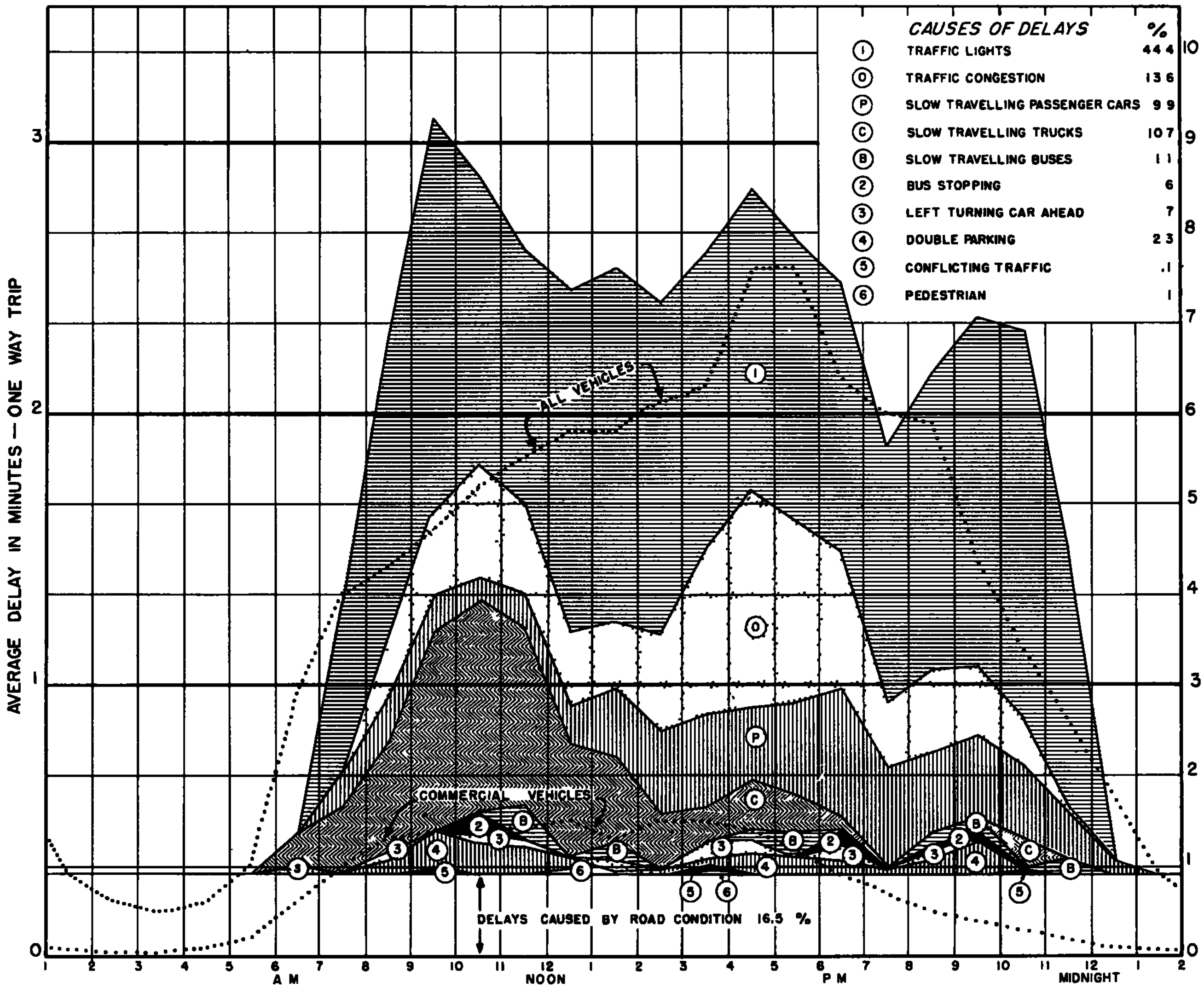

Figure 3. Time-delay study on US 19 and US 50 showing average hourly amounts and causes of delays to west-bound traffic compared with hourly traffic densities, Clarksburg, West Virginia, 1944.

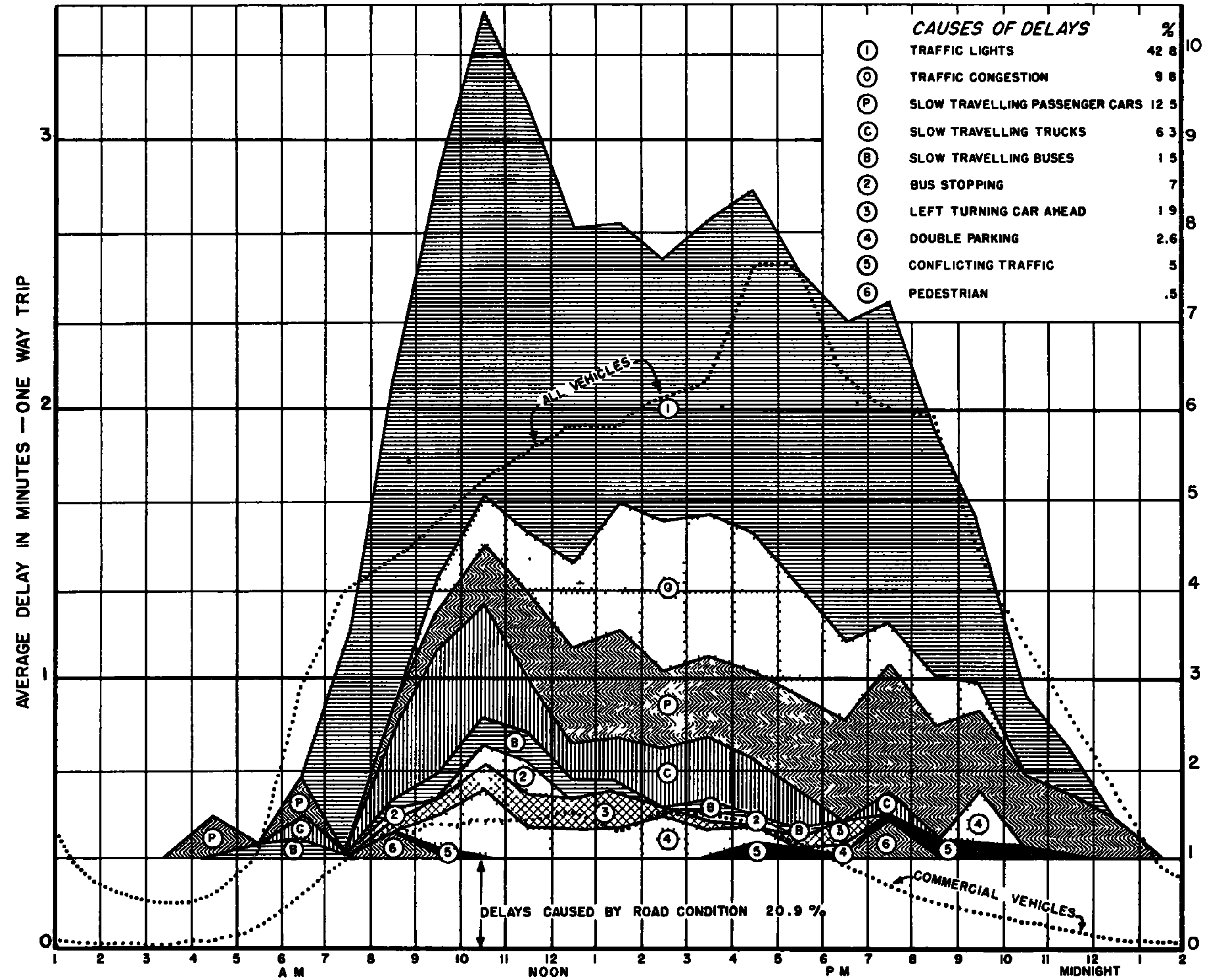

Figure 4. Time-delay study on US 19 and US 50 showing average hourly amounts and causes of delays to east-bound traffic compared with hourly traffic densities, Clarksburg, West Virginia, 1944.

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 24Th 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

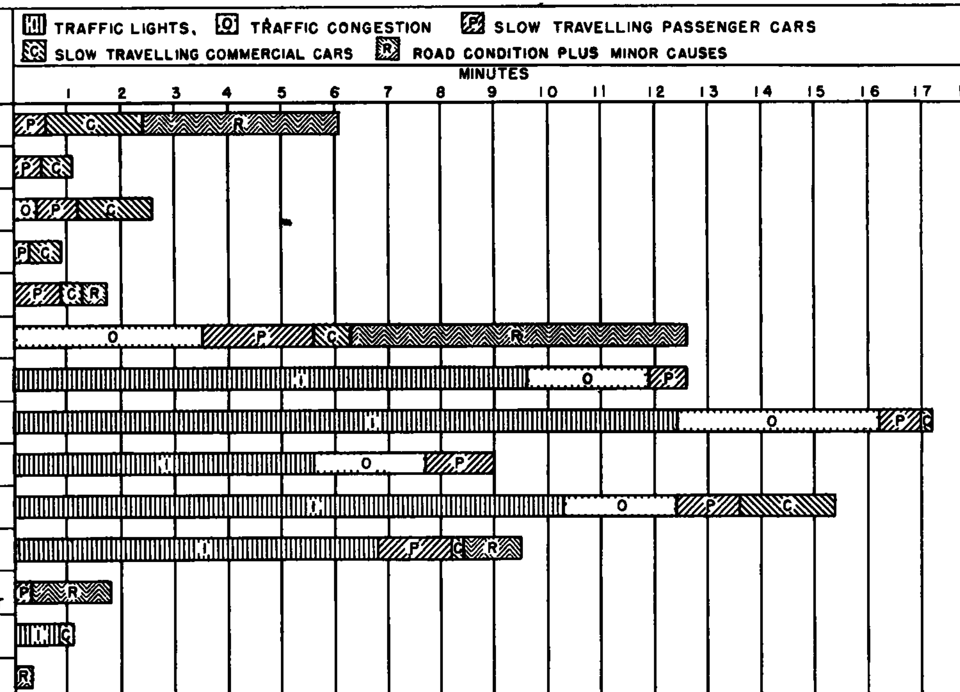

Figure 5. Daily amount of loss and its composition by principal causes to all traffic in each zone, expressed as the rate per mile for each zone, Clarksburg Traffic Survey, 1944.

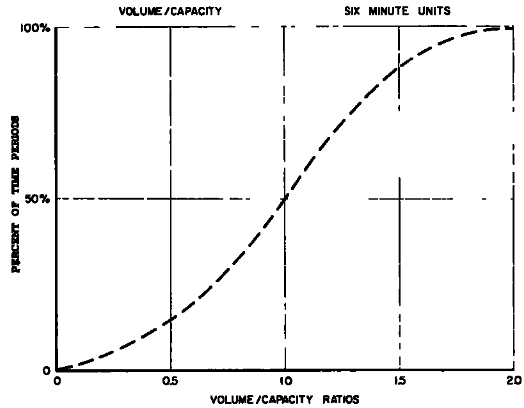

Figure 6. Frequency distribution of the ratio of volume to capacity in terms of 100 six-minute units.

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.

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